Hand preference and spatial ability: a study of performance in spatially demanding occupations

Wood, Charles J.

HAND PREFERENCE AND SPATIAL ABILITY: A STUDY OF PERFORMANCE IN SPATIALLY DEMANDING OCCUPATIONS

CHARLES J. WOOD

1989

Thesis submitted for the degree of Master of Arts at the University of Durham, Department of Psychology.

I declare that the work contained in this thesis has not been previously submitted for any other degree.

ACKNOWLEDGEMENTS

I am very grateful to my supervisor, Dr. John Aggleton, for kindling my interest and for his subsequent patience and advice. I would also like to thank the academic and technical staff and post-graduate students of the Department of Psychology for their help and their cheerful friendship.

I owe a great deal to the large number of people, psychologists, sports administrators and players, who replied patiently to my letters or filled in time consuming questionnaires.

Finally, I am indebted to my parents for their financial assistance and encouragement.

ABSTRACT

Widely cited studies report an excess of left-handers among top athletes (tennis players, cricketers, and fencers) and architects. These findings are seen as being consistent with the influential theories of Annett (1985) and Geschwind and Galaburda (1985a, 1985b, 1985c) which predict that left-handers are over-represented in activities making heavy demands on spatial abilities. This present research reexamined the proportion of left-handers in both sport and architecture.

The analyses of sport only found evidence for an excess of left-handers among cricket bowlers and tennis players and among this latter group the effect was highly capricious. In both sports the rarer left-handers enjoys tactical advantages; there is no need to invoke neurological explanations. Among the other groups of top athletes examined: soccer goalkeepers, cricket batsmen, ten-pin bowlers, snooker and darts players, and golfers, no evidence was found of an excess of left-handers. Similarly, an analysis of a large group of practicing architects failed to reveal an abnormal proportion of left-handers.

As handedness data was obtained from the architects and the soccer goalkeepers using a mail survey an additional study was undertaken to determine whether a mail survey is a valid method of collecting handedness data. This survey failed to find any systematic bias between those who do and do not reply. Thus the findings for goalkeepers and architects are strengthened.

Although this present research cannot rule out the possibility that some left-handed linked advantage in spatial advantages may exist, it nevertheless raises doubts whether these earlier studies substantiate its existence.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 ATTITUDES TOWARDS LEFT-HANDEDNESS

> "Cack-handed, bang-headed, wacky-handed, gammy, keggy, scrammy, skiffly, skivvery, watty, coochy, schoochy, scroochy, quiffy, bawky, cowey, cowley, hawky, garpawed, kay-pawed, and cow-patted" (Harris, 1980).

At a casual glance it would seem that humans beings are bilaterally symmetrical down the vertical axis. Our eyes, ears, and limbs appear to be symmetrically placed on either side of the midline. Yet, under closer scrutiny various asymmetries become apparent. Portrait painters often notice facial asymmetries. One ear is higher than the other; perhaps one eye is larger than the other. Other parts of the body also show asymmetries. Among others, differences in limb length, testicle size and position, hand and foot size, and breast size have been reported.

More striking than structural asymmetries are functional ones. Despite no obvious morphological differences between the hands most people prefer to use their right-hand and are more adept with it. Similar functional asymmetries exist between the feet, eyes, and ears; again despite structural similarity.

Handedness has exerted a powerful influence on human mythology, folklore, and value systems. Corballis (1983) believes that part of the reason for this is that it seems such a baffling phenomenon. Why should most humans prefer to use a particular hand when it appears to be the mirror image of the other? A second reason handedness has exerted such an influence may be that it seems to be a uniquely human characteristic (Corballis, 1983). Other species do not show this bias. If preferences exist they are evenly distributed between the left and right limbs. Corballis (1983) suggests that human right-handedness serves to reassure us that we are different from other animals and may even suggest that we are superior.

Like many minorities, left-handers have inspired enmity, suspicion, and the reputation for lacking many human virtues and skills (Harris, 1980). One only has to consider the mean-spirited slang names listed at the top of this chapter that have been used to describe left-handers or the derivations of various words such as 'sinister' (from the Latin word meaning left) or 'gauche' (from the French word meaning left) to realise how entrenched prejudice against the left-hander has been in European culture. Even in biblical times negative qualities were ascribed to the left-hand. Wile (1934) points out that there are over 80 references to the right-hand in the Bible ascribing to it honours, virtues, and powers. In contrast, "there is not one honorable reference to the left hand" (Wile, 1934). Barsley (1979) has gone as far as to suggest that the Vision of Judgement (Matthew 25:31-34, 41, 46), listed below, is responsible, more than anything else, for implanting the prejudice against left-handers through the ages.

> "When the son of man shall come in his glory, and all the holy angels with him, then shall he sit upon the throne of his glory: And before him shall be gathered all nations: and he shall separate them one from another, as a shepherd divideth his sheep from the goats: And he shall set the sheep on his right hand, but the goats on the left: Then shall the King say unto them on his right hand, Come, ye blessed of my father, inherit the kingdom prepared for you from the foundation of the world....

> Then shall he say also unto them on the left hand, Depart from me, ye cursed, into everlasting fire, prepared for the devil and his angels....
> And these shall go away into everlasting punishment: but the righteous into life eternal".

It is interesting to note that in our time serial killer Edmund Emil Kemper III described the cutting off of one of his victims left hand as being, "Symbolic, I suppose... I think it is like the left-hand-of-God thing" (Leyton, 1986).

Harris (1980) stresses the importance of studying these former associations of left-handedness as he believes many of the old ideas and myths have influenced contemporary conceptualizations of left-handedness.

In this century left-handedness has been linked with, among other things, stuttering (Nice, 1915), birth defects (Bakan, 1971), emotional instability (Blau, 1946), homosexuality (Stekel, 1911), and criminal behaviour (Lombroso, 1903). Reviewing the large body of literature linking left-handedness with deficit Hardyck and Petrinovich (1977) report that,

> "this relationship is rather striking in its persistence ... there is usually just enough of a relationship to suggest a possible link but never enough of one to suggest a firm correlation.... It appears that the data indicating left-handedness is associated with deficits of various kinds is far from compelling".

There have also been attempts in the popular press to link left-handedness with deficits. The San Francisco Chronicle and Examiner, for example, linked Gerald Ford's infamous clumsiness (e.g. falling down stairs and bumping into security guards) to the fact that he was left-handed (Bell, 1974).

Recently, however, it has been recognised that not all left-handers have impaired abilities. Numerous examples are cited of really outstanding left-handed people in various fields of human endeavour such as art (Michelangelo, Leonardo Da Vinci, Picasso), political leadership (Charlemagne, Adolf Hitler), entertainment (Charlie Chaplin, Woody Allen), music (Jimmy Hendrix, Janis Joplin), and sport (Babe Ruth, Mark Spitz, John McEnroe). Indeed, it is now claimed that left-handers have a distinct advantage in certain activities, particularly sport and other tasks requiring spatial abilities. It is the purpose of this thesis to investigate such claims.

1.2 WHAT IS HANDEDNESS?

According to Beaton (1985), "although it is clear that most people are right-handed, the question of how handedness is to be measured is not easily answered". Similarly, Annett (1985) points out the problems in trying to pin down "a rather elusive characteristic". Generally when someone is said to be 'left-handed' we mean either that he or she prefers to use his or her left-hand in unimanual tasks or that he or she is more proficient (i.e. more skillful or stronger) when using his or her left-hand.

Although there is a correlation between measures of hand preference and proficiency, especially for those who display strong handedness (Corballis, 1983), they are not always concordant (Satz, Achenbach, & Fennel, 1967; Provins, & Cunliffe, 1972). Even when simply considering measures of skill, differences between the hands depend on a number of factors including degree of practice (Provins, 1967), type of movement (Flowers, 1975), and task complexity (Steingruber, 1975).

The lack of concordance between proficiency scores and preference scores which has been obtained in certain cases is illustrated when populations of both type of score are considered. Populations of proficiency scores reveal a normal shaped distribution with the mean shifted towards the right (Fig. 1.1), i.e. the majority of people are more skillful with their right-hand. However, populations of scores on preference measures of handedness reveal a J-shaped distribution (Fig. 1.1) with a principal peak indicating a strong right-handed preference and a smaller secondary peak indicating a strong left-handed preference, i.e. the majority of the population prefer to use their right-hand for unimanual activities, a small minority prefer to use their left-hand with the rest somewhere between the two. While both graphs show a majority of right-handers they clearly differ in certain respects, for example the proficiency measure reveals a far greater proportion of 'ambidextrous' people than the preference measure (Porac & Coren, 1981).

Two recent studies have attempted to determine the nature of the superiority of one hand over the other (Annett, Annett, Hudson, & Turner, 1979; Peters, 1980). Both concluded that it is not due a better capacity to process feedback but rather due to the more efficient control of motor output to the preferred hand. As each hand is controlled by the

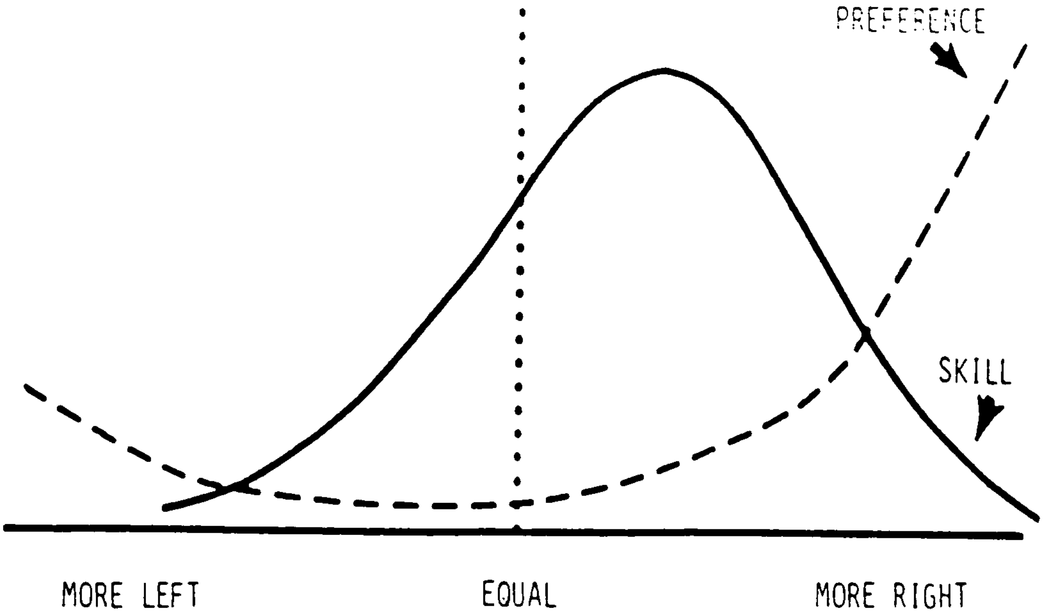

Figure 1.1 The typical J-shaped distribution found in preference measures of handedness (dotted line) compared to the typical right biased normal distribution for skill or proficiency measures of handedness (solid line) (after Porac & Coren, 1981).

opposite hemisphere this means that the reason most people are right-handed is that their left-hemisphere motor cortex has some sort of advantage over that in the right-hemisphere. Annett (1985) suggests that this advantage may be an incidental consequence of the fact that language functions are generally located in the left-hemisphere (v. Section 1.5.1). She points to the close proximity of mouth and hand areas in the sensorimotor cortical strip and argues that any advantage to the left-hemisphere mouth area would also be likely to give the left-hemisphere hand area, and hence the right hand, an advantage. It should, however, be noted that Kimura (1979) has suggested the opposite; namely that lateralization for speech developed as a consequence of an advantage for the right hand, and hence left hemisphere, in gestural communication.

1.3 MEASUREMENT OF HANDEDNESS

1.3.1 Performance and preference measures

Probably the first ever formal measurement of handedness was carried out by Sir Francis Galton at a health exhibition in 1884 (Porac & Coren, 1981). The measure Galton used was a test of strength in which subjects pressed a dynamometer with each hand in turn. Galton's data was subsequently analyzed by Woo and Pearson (1927) to arrive at an estimate of the incidence of left-handedness in the population. In this case a performance measure was used. More recently tests of handedness have generally employed preference measures, probably because of the ease with which they can be administered (Borod, Caron, & Koff, 1984).

Beaton (1985) discusses several different ways in which hand preference is generally measured: self report in which subjects simply state whether they are left or right-handed (or mixed-handed), writing hand (in which the hand used for writing is used to classify the preferred hand), observation of hand use in a number of unimanual activities, and use of a questionnaire. The first two methods are the least satisfactory since they treat handedness as a dichotomy (or a trichotomy) when measures of proficiency and, to a lesser extent, performance show handedness to be a continuous variable (Fig 1.1). In addition the criteria which people use to class themselves as being left-handed seem to be somewhat idiosyncratic, and the hand that people write with seems to be subject to considerable cultural pressure (v. Section 1.4.3). Actual observation of the hand used for a variety of unimanual tasks seems to be the best indicator of hand preference although it is not always clear what activities should be selected (Beaton, 1985). In practice, it is more convenient to use a questionnaire.

1.3.2 The Edinburgh Handedness Inventory

One of the most commonly used questionnaires is the Edinburgh Handedness Inventory (Oldfield, 1971) (Fig. 1.2). Oldfield's original version consisted of 22 items; from these 10 were selected as being the most appropriate: writing, drawing, throwing, using scissors, holding a toothbrush, holding a knife (without a fork), holding a spoon, holding a broom (upper hand), striking a match, and opening a box. Respondents indicate their preferences by putting '++' (if they would always use that hand) or '+' (if they would generally use that hand) in columns marked left and right. If subjects are really indifferent as to which hand they would use for a particular activity they are asked to put a '+' in both columns (Fig 1.2). A 'laterality quotient' can then be calculated by subtracting the number of '+'s in the left column from that in the right column, dividing this figure by the total number of '+'s and multiplying by 100. The laterality quotients obtained range from -100 indicating extreme left-handedness, through 0 indicating complete 'ambidextrality', to +100 indicating extreme right-handedness.

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

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

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

Figure 1.2 The Edinburgh Handedness Inventory (Oldfield, 1971).

1.3.2.1 Reliability of the Edinburgh Handedness Inventory

A number of studies have attempted to measure the reliability of common items on handedness questionnaires (Raczkowski, Kalat, & Nebes, 1974; Coren & Porac, 1978; Coren,Porac, & Duncan, 1979; McMeekan & Lishman, 1975). Table 1.1 shows the results of these studies for the items that are included in the Edinburgh Handedness Inventory plus the item 'holding a racket'. It can be seen that, with the exceptions of 'striking a match' and 'holding a broom', the items for which data is available have a good degree of reliability, even with a one year test-retest interval.

Table 1.1 Reliability of those items of the Edinburgh Handedness Inventory for which data is available.

	Raczkowski et al. (1974) % Agreement* (1 month) n = 41	Coren et al. (1979) % Agreement (1 year) n = 171	Coren & Porac (1978) % Agreement (1 year) n = 27
Writing	96	96	100
Drawing	96	100	100
Throwing	93	100	100
Scissors	95	-	-
Toothbrush	96	100	100
Broom	74	-	-
Match	89	-	-
Racket	96	-	-

* All cases were discarded in which a subject answered 'either' on one question but not on the other.

McMeekan and Lishman (1975) retested subjects (n = 73) between 8 and 26 weeks after they had initially filled in the Edinburgh Handedness Inventory. Of the total number of changes of response to items made at retest, only 20% involved switches between 'right' and 'left' responses. The majority (80%) of changes involved switches between 'left' and 'either' responses or 'right' and 'either' responses. It is also reported that 83% of subjects made at least one change in reporting the strength of their preference for an item, i.e. made a switch between '++' and '+'. It should be noted that the subjects in McMeekan and Lishman's (1975) study, and those in the study of Raczkowski et al. (1974), were chosen to include a majority of left-handers and this may have biased the results.

1.3.2.2 Validity of the Edinburgh Handedness Inventory

Studies have also investigated whether questionnaire items relate to observed hand usage (Raczkowski et al., 1974; Annett, 1985). As Table 1.2 shows, all the items on the Edinburgh Handedness Inventory for which data is available, with the exception of 'holding a broom', seem to have a high degree of validity.

Table 1.2 Validity of hand preference questionnaire items. Changes between questionnaire and objective tests. (S = Subjects).

	Raczkowski et al. (1974) % S making a change between R & L* (n = 47)	Annett (1985) % S making a change between R & L (n = 113)	Annett (1985) % S making any change between R, L & E (n = 113)
Writing	0	0	0
Drawing	0	-	-
Throwing	2	3.5	5.3
Scissors	6	1.8	6.2
Toothbrush	3	0.9	5.3
Broom	22	4.4	15.0
Match	6	0.9	7.1
Racket	5	0.9	1.8

* Subjects who responded 'either' for any item are not included in the analyses for that particular item.

1.3.2.3 Factor structure of the Edinburgh Handedness Inventory

Bryden (1977) administered the Edinburgh Handedness Inventory to a large number of undergraduates (males, n = 620; females, n = 487). Factor analysis of the responses of these subjects revealed two factors. The first of these was specific to handedness as described in terms of everyday activities. Items scoring highly on this factor were: 'writing', 'drawing', 'throwing a ball', 'holding a toothbrush', and 'holding scissors' ('holding a racket' also scores highly on this factor). Items scoring highly on the second factor were: 'holding a broom', 'opening a box', and 'striking a match'; rare activities that are difficult to visualise. Similar results were obtained by White and Ashton (1976). An association analysis performed by Annett (1970) showed that all the factors that load highly on Bryden's (1977) first factor, with the exception of 'holding scissors', clustered together. This 'handedness factor' has been shown to be stable across age and sex and over a 4 week test-retest interval although the factor loading of the item 'scissors' was unstable in test-retest comparisons (McFarland & Anderson, 1980).

Given these considerations of reliability, validity, and loading on this 'handedness factor' Bryden (1982) suggests that handedness questionnaires should be shortened to include the following five items: 'writing', 'drawing', 'throwing a ball', 'holding scissors', and 'holding a toothbrush'. Before such an inventory could be considered satisfactory, however, Bryden (1982) stresses the need for work to weigh these items according to their relative frequency.

1.4 THE INCIDENCE OF LEFT-HANDEDNESS

Most researchers now accept that handedness is a continuous rather than a dichotomous (or trichotomous) variable. This being the case, the choice of a cut-off point to assign people into different handedness groups such as 'left-handers' is entirely arbitrary.

1.4.1 Contemporary estimates

Oldfield (1971) suggests that the criteria for describing subjects as 'left-handed' should be their having a negative laterality quotient (v. Section 1.3.2). He reports that 10% of a sample of males (n = 400) and 5.9% of a sample of females (n = 709) he examined were left-handed according to this criteria. However, this formulation has not been widely adopted and only very recently has normal data using this criteria become available (Ellis, Ellis, & Marshall, 1988). When most researchers report the incidence of left-handedness in the population they generally refer to the percentage of subjects who use their left-hand for a unimanual activity, usually writing.

Using the writing hand as the criterion, estimates of the proportion of left-handedness in Western populations of 8-10% have generally been accepted (Levander & Schalling, 1988). Spiegler & Yeni-Komshian (1983), however, cite studies yielding higher estimates (11-16%) among young adults and suggest that the figure above should be raised.

1.4.2 Age differences

Almost every study that investigated the link between handedness and age has noted that there is an increase in right-handedness as age increases (Ashton, 1982; Tan, 1983; Lansky, Feinstein, & Peterson, 1988; Fleminger, Dalton, & Standage, 1977). Porac and Coren (1981) classified theories that have attempted to explain age related differences in handedness in to 4 groups:

a) Different mortality rates for different handedness groups.

b) Maturational processes which favour right-handedness.

c) An accumulation of pressures on individuals to switch towards right-handedness as they grow older.

d) Over the last century a decrease in the pressure on left-handed children to write with their right hand by parents and educators.

Support for the latter theory (d) comes from Levy (1974) and Brackenbridge (1981) who studied the proportion of individuals writing with their left-hand during the 20th century in the United States and Australasia respectively. Both report an increase in left-handedness from about 2% at the start of the century to 10-12% by the 1970's where the curves reach asymptotes (Fig. 1.3). Corballis (1983) suggests that the "natural" of left-handedness has now been reached.

Beukelar and Kroonenberg (1986) believe that shifts in cultural pressure are sufficient to account for all the change in handedness with age. Other investigators do not agree. Ashton (1982), for example, points out that the relationship between age and handedness has persisted for at least a century and so liberalization of attitudes cannot be the total explanation. For this issue to be resolved carefully controlled longitudinal studies are needed.

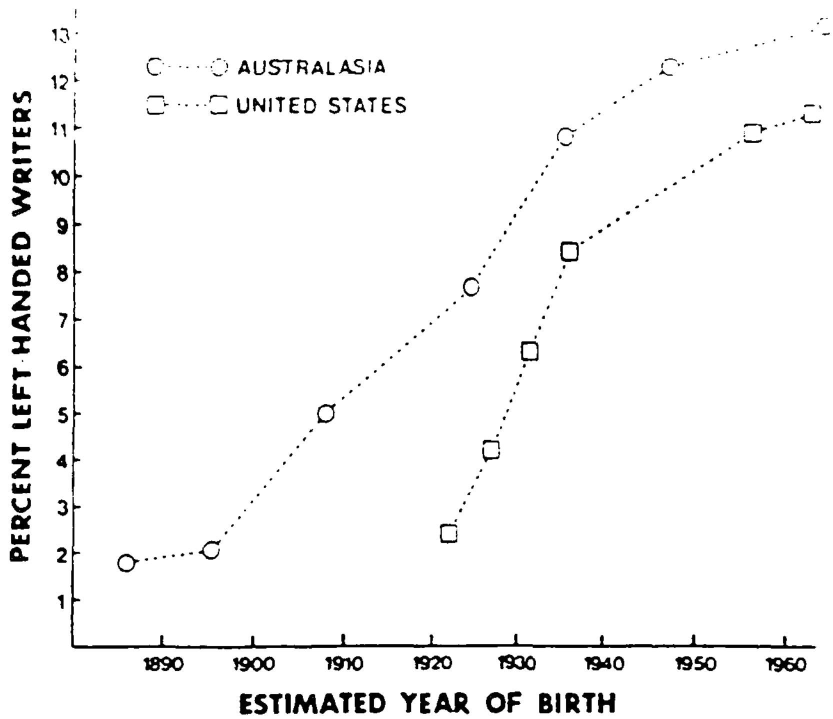

Figure 1.3 Percentage of left-handed writers plotted according to estimated year of birth among samples from Australasia and the United States (after Corballis, 1983).

1.4.3 Cross cultural differences

There are considerable cultural differences between attitudes towards left-handedness. In societies where there is still some sort of stigma attached towards being left-handed its incidence is relatively low. For example, Hatta and Nakatsuka (1975) found that only 4% of a sample of Japanese adults were left-handed while Verhaegen and Ntumba (1964) reported that only 0.5% of a sample of children in Zaire were left-handed.

It is interesting to note that the proportion of left-handed writers found at the start of the century in the United States and Australia, approximately 2% (Figure 1.3), corresponds to that found in modern day Taiwan, a country where there is still considerable cultural pressure to write with the right hand (Teng, Lee, Yang, & Chan, 1976). When Oriental children are raised in the United States this figure seems to rise considerably, presumably reflecting a reduction in cultural pressure (Hardyck, Goldman, & Petrinovich, 1975).

Porac and Coren (1981) review cross cultural studies of handedness and conclude that estimates of the incidence of left-handedness in English speaking countries that share common cultural and historical traditions such as Britain, Canada, and the United States are very similar.

In addition to cultural factors, Porac and Coren (1981) speculate that genetic factors may account some of the difference in the incidence of left-handedness between cultures. It is widely accepted that handedness is, at least partly genetically controlled (v. Section 1.6). In their review of cross cultural studies Porac and Coren (1981) find that the proportion of left-handers is generally higher in Caucasian than non-Caucasian groups.

1.4.4 Sex differences

The literature is divided between studies which have found a higher incidence of left-handedness amongst men (Oldfield, 1971, Annett, 1970; Heim & Watts, 1976) and those that have not (Bryden, 1977; Inglis & Lawson, 1984; Beaton & Moseley, 1984). Even in those studies reporting no significant sex differences the estimate for males is consistently higher for males than females (Spiegler & Yeni-

Komshian, 1983). Most reviewers conclude that there is a higher incidence of left-handedness amongst males (Geschwind & Galaburda, 1985a; Annett, 1985; Beaton, 1985), although this difference is probably small and may only reach significance when large samples are considered.

1.4.5 Educational differences

A number of researchers (Lansky et al., 1988; Annett, 1985) have reported that university students may be less biased to the right hand than other members of the population. One possible explanation for this may be that university students come from families that differ in socio-economic status and attitudes towards left-handedness to other families. It should, however, be noted that several recent studies have failed to find a link between socio-economic status and handedness (Leiber & Axelrod, 1981; Silverberg, Olber, & Gordon, 1979)

Unfortunately, as in many other areas of psychology, much of the research into handedness has concentrated on student subjects.

1.4.6 The historical record

Burt (1937) reports that the first quantitative account of handedness appears in the Bible,

> "And the children of Benjamin were numbered ... 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 left-handed; every one could sling stones at an hair breadth, and not miss" (Judges 20: 15-16).

Thus Coren and Porac (1977) calculate that 3% of this biblical population were left-handed. However, it has been pointed out that there is no evidence to suggest that all the other 2600 soldiers were right-handed (Hardyck & Petrinovich, 1977). As such written references to handedness are rare attempts have been made to assess the incidence of left-handedness in the past by more indirect means.

Hardyck and Petrinovich (1977) review anthropological and archeological literature and conclude that there is no reason to suggest that the incidence of handedness in early man was any different to that found today. Among the evidence cited is a report of the location of fractures on animals' heads which suggest the hand used by primitive man to hold implements to kill. Coren and Porac (1977) suggest that ancient drawings and paintings may mimic the distribution of hand use which the artist actually observed. They examined over 12,000 works of art from various cultures and eras, with samples dating from approximately 15,000 B.C. to 1950 A.D. The incidence of right-handedness ranged from 86-98% with no apparent significant changes or trends over time.

1.5 CEREBRAL ASYMMETRY

It is widely accepted that the left and right cerebral hemispheres perform different functions (Walker, 1980). In addition, in recent years the study of anatomical asymmetry has been revived and there have been suggestions that anatomical asymmetry is a correlate of the functional specialization of the hemispheres (Witelson, 1980).

This section is not intended to provide a comprehensive review of the literature on cerebral asymmetry but rather a brief account of the main findings of research. Various topics are not included such as hemispheric specialization for emotion. For a detailed review of functional asymmetry the interested reader is referred to Corballis (1983), Bryden (1982), and Nass and Gazzaniga (1987) whilst Witelson (1980) provides an extensive review of anatomical asymmetries.

1.5.1 The typical pattern of functional asymmetry

The left hemisphere is dominant for language in the vast majority of right-handers (Nass & Gazzaniga, 1987). This was first suggested as early as 1836 by Marc Dax who noted an association between left hemisphere pathology and language disturbances (Springer & Deutsch, 1981). More recently, modern scientific methods including intracarotid amytal testing, PET scanning assessing regional cerebral blood flow and metabolism, electrophysiological studies and cortical stimulation studies have confirmed and further clarified this theory of dominance (Nass & Gazzaniga, 1987). There is, however, some evidence to suggest that the right hemisphere may have some degree of linguistic capacity, particularly from studies of commissurotomy patients and studies of recovery of function after left hemisphere damage or hemispherectomy. The extent of this capacity is not fully known at present and is a matter of some controversy (Corballis, 1983).

There is a also a good deal of evidence that the left hemisphere is specialised for more than language. Corballis (1983) discusses studies illustrating left hemisphere control over fine movements of the tongue and other articulators. Indeed, the very phenomenon of right-handedness implies that the left-hemisphere has some sort of superiority in motor skills. In particular, the left hemisphere seems to have a particular role in the production and perception of sequences.

As early as 1876 special functions were attributed to the right hemisphere (Jackson, 1876). However, most of the early work on functional asymmetry concentrated on the language functions of the left ('dominant') hemisphere with little importance being attached to the right ('non-dominant') hemisphere. As late as the 1960's, Young (1962) suggested that the right hemisphere may merely be a "vestige" (although he prudently stated that he would rather keep his than lose it).

Nass and Gazzaniga (1987) review right hemisphere specialization and point out that it appears to consist of several separate but interrelated elements. These elements are best characterized, according to Nass and Gazzaniga, by a requirement for manipulation and that they are not amenable to any form of verbal interpretation or mediation. Thus the right hemisphere seems to be specialised for perceptuospatial skills in all sensory modalities although generally this specialization does not seem to be to the same extent as that in the left hemisphere for language. Sperry (1974) devised a simple schema which summarised his inferences about cerebral specialization based on studies of split brain patients. This schema is shown in Figure 1.4 and it provides a useful, if oversimplified, overview of the normal pattern of cerebral dominance.

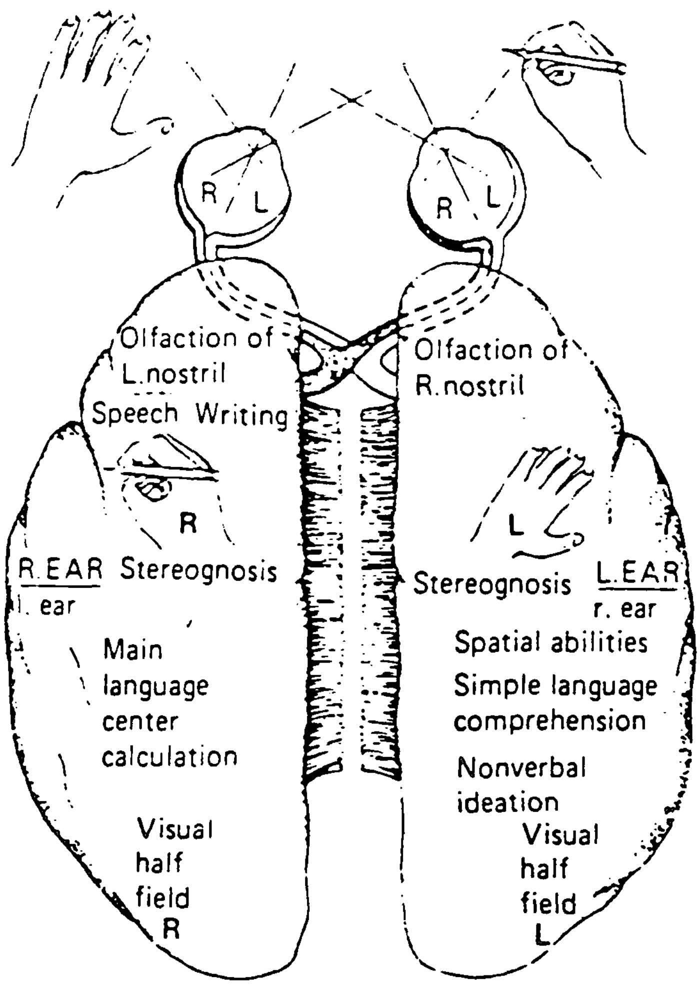

Figure 1.4 Sperry's 1974 schema summarising inferences about cerebral specialization.

1.5.2 Anomalous dominance

Section 1.5.1 examined the typical pattern of hemispheric asymmetry which occurs in the majority of right-handers. However certain groups, among them a small minority of right-handers, deviate from this standard pattern and show 'anomalous' dominance.

At the start of this century it was assumed that verbal and manual dominance were two aspects of the same function (Geschwind & Galaburda, 1985a). Thus, while right-handers had left cerebral dominance, left-handers were assumed to have right cerebral dominance. This view prevailed despite various reports of crossed aphasia in which left-handers developed language disorders after left hemisphere lesions and right handers developed language disorders after right hemisphere lesions. It was not until after the Second World War that doubt was cast on this 'contralateral' rule for language dominance and handedness. It now seems likely that both left-handers, as well as right-handers, show a tendency toward left hemisphere dominance for language although this is less marked than it is amongst right-handers.

Corballis (1983) reviews the various methods used to assess language dominance and concludes that the most reliable evidence comes from sodium amatyl (the Wada test) and ECT studies. Table 1.3 shows combined data from such tests (Corballis, 1983). Similar figures have been obtained by Segalowitz and Bryden (1983) using unilateral brain injury data. It is evident that the vast majority of right-handers have left-hemisphere speech while a very small minority have right-hemisphere speech. In contrast, left-handers show a more variable pattern; while most have left hemisphere speech a proportion seem to have right hemisphere speech and a proportion seem to have language represented bilaterally.

Table 1.3 Incidence of left, right, and bilateral representation of speech (after Bryden, 1982).

	Lateralization of speech		
	% Left	% Right	% Bilateral
Right-handers	97	0	3
Left and mixed-handers	68	12	19

There have been various attempts to predict which left-handers have right hemisphere speech. Variables examined as possible predictors have included history of family sinstrality, strength of hand preference, and hand posture during writing. However results of such studies have been inconsistent and no clear pattern has emerged (Bryden, 1982).

Relatively few studies have investigated the link between handedness and 'minor' hemisphere function. Part of the reason for this is that many authors have assumed that right-hemisphere specialization is secondary to left hemisphere specialization and thus the relationship between handedness and cerebral dominance would dictate the overall pattern of lateralization in the brain (Corballis, 1983).

Bryden (1982) estimates the incidence of left, right, and bilateral representation of spatial abilities using data from two studies examining the incidence of spatial disorders following unilateral brain injury (Table 1.4). It should be noted that Bryden points out that, at best, this data can only be regarded as a preliminary estimate of the distribution of hemispheric dominance for spatial dominance. It can be seen that left-handers are more likely to have left hemisphere or bilateral representation of spatial abilities than right-handers. A comparison of Table 1.3 and Table 1.4 shows that visuospatial functions do not seem to be as dependant on the right hemisphere as language functions are on the left hemisphere.

Table 1.4 Incidence of left, right and bilateral representation of spatial abilities (after Bryden, 1982).

	Lateralization of spatial abilities		
	% Left	% Bilateral	% Right
Right-handers	30.7	0.0	69.3
Left-handers	28.1	29.3	42.6

1.5.3 Neuroanatomical asymmetry

Anatomical asymmetries between the two hemispheres were first noticed at the start of the century but were thought to be insufficient to have any functional significance (von Bonin, 1962). Interest in anatomical asymmetries was revived following the observation by Geschwind and Levitsky (1968) that the left temporal planum was larger than that on the right in 65% of a sample of 100 adults. The planum was approximately equal in size in 24% of the sample and larger on the right in 11%. It has been claimed that the difference in some cases can be quite striking, for example Geschwind and Levitsky (1968) reported instances where the left planum is five times larger than the right while, Wada, Clarke, and Hamm (1975) have reported instances where the right temporal planum is absent altogether. Since the left temporal planum is known to be crucial for language functions, it has been suggested that this anatomical asymmetry is related in some way to left hemisphere specialization for language (Corballis, 1983).

Witelson (1980) reviews anatomical asymmetries and lists the following left-right differences that have been reported in addition to that described above:

a) A larger antero-parietal region on the left side.

b) A larger prefrontal region on the right side.

c) A larger postero-occipital region on the left side.

d) A longer occipital horn in the left lateral ventricle.

e) Larger motor pyramidal tracts on the right side.

f) Various right-left differences in cerebral vascularization.

As for functional asymmetries, there are differences between left and right-handers in anatomic asymmetries. Witelson (1980) reviews the literature concerning the relation between hand preference and anatomical asymmetries and concludes that in most cases right-handedness is associated with asymmetry in one direction, and left-handedness is associated with less anatomical asymmetry or asymmetry in the opposite direction. Witelson suggests that the experimental data she reviews supports the hypothesis that neuroanatomical asymmetry is associated with, and may actually be a substrate of functional asymmetry. However, this position has not gone entirely unchallenged. Beaton (1985), for example, points out that the proportion of brains showing temporal lobe asymmetries is less than the proportion showing left hemisphere dominance for language (v. Section

1.5.2). In addition, Beaton (1985) questions how a "quantitative" difference in size can be used to explain a "qualitative" difference in function between the hemispheres.

1.6 THE GENESIS OF HANDEDNESS

Most researchers accept that left-handedness is, at least, partly inherited (Hardyck & Petrinovich, 1977). Levy (1976) discusses arguments that support a genetic influence on handedness which include:

a) There are a number of functional and behavioral asymmetries present at or around birth and hence not explicable in terms of learning which correlate highly with handedness.

b) Handedness is related to anatomical asymmetries of the brain (v. Section 1.5.3), the nose, and to finger print patterns. It seems unlikely that if these factors are under genetic control handedness is not also under genetic control.

c) Family and adoption studies of handedness suggest a genetic factor.

Given the close relationship between patterns of lateral dominance and manual preference most recent genetic theories consider both together. This section examines three influential theories of handedness which acknowledge, to differing extents, the importance of genetic factors. Each of these theories makes specific predictions about the abilities of left and right-handers. The first of these theories (Levy & Nagylaki, 1972), is a simple genetic model while the second

(Annett, 1985) and third theories (Geschwind & Galaburda, 1985a, 1985b, 1985c) involve an interaction between genetic and environmental factors. The emphasis of these latter two theories differs; Annett's theory is principally concerned with the genetics of laterality while Geschwind and Galaburda concentrate on the mechanism of lateralization. It may be noted that Annett's theory is generally regarded as far more satisfactory than that of Levy and Nagylaki (Corballis, 1983).

1.6.1 The Levy-Nagylaki hypothesis

Levy and Nagylaki (1972) proposed a model in which hemispheric specialization for language and handedness depend on two genetic loci. One of these genes determines which hemisphere is dominant for language and the other determines whether hand control is contralateral or ipsilateral to the language dominant hemisphere. The alleles for language representation are represented by L (left hemisphere language) and l (right hemisphere language) while those for hand preference are represented by C (contralateral hand control) and c (ipsilateral hand control). The alleles L and C are assumed to be dominant.

According to this model, the genotypes LLCC, LLCc, LlCC, and LlCc will have left hemisphere control for speech and handedness and be right-handed. LLcc and Llcc will have left hemisphere control but be left-handed. The genotypes llCC and llCc will have right hemisphere control and be left-handed while, finally, llcc will be have right hemisphere control and be right-handed. It was proposed that those people with ipsilateral control of handedness would write in an inverted posture and consequently it has been suggested that writing posture can be used to classify left-handers as to speech lateralization (Levy & Reid, 1978) (but v. Section 1.5.2).

In order to account for the fact there seem to be a proportion of left-handers who have bilateral representation of language Levy and Nagylaki (1972) postulated that the full expression of the gene for hemispheric representation for language was dependant on the presence of the L and C alleles. Thus, in left-handers and those right-handers of genotype llcc language would not be as lateralized as in right-handers. Levy (1969, 1974) suggested that people who have some degree of bilateral language representation would be at a disadvantage in those functions which are the province of the right-hemisphere (v. Section 1.5.1). This is because competition for space between language and the other right hemisphere functions will mean that there will be less neural tissue available to subserve these functions.

1.6.2 Annett's Right Shift Theory

Annett (1985) proposes that the bias towards right handedness in humans arises as a by-product of the bias towards left hemisphere specialization for speech. This bias towards left hemisphere speech is due to a single gene, the right shift gene (rs+). When this gene is present on one or both chromosomes (rs++ or rs+-) speech is normally lateralized in the left hemisphere and that hemisphere has some sort of advantage that increases the chances of the right hand having greater skill. The right shift gene shows partial penetrance, its effects being more pronounced in the homozygote. Thus, genotype rs++ are more likely to have a more skillful right hand than genotype rs+-. Figure 1.5 shows the proposed distribution of hand skill for the three genotypes. It should be noted that the main determinants of these distributions is chance, the presence of the right shift gene merely has the effect of moving the distribution along the axis so that the mean is to the right of zero.

When this gene is absent (rs--), cerebral representation of language and the development of greater skill in one hand depend on chance. In addition, in the absence of this gene handedness and the laterality of speech are independent of one another. Approximately half of such people will have left hemisphere speech specialization, approximately half will have right hemisphere language specialization while a small proportion will have some degree of bilateral speech representation. There will be a normal distribution of skill between the hands with a mean at zero (Fig. 1.5). However, most of those who are evenly balanced between the two sides in skill will become right-handed due to cultural pressure.

The distribution of differences between the hands in skill shown in Figure 1.5 is a composite of the distributions produced by each of these three genotypes (rs++, rs+-, and rs--). Annett argues these L-R differences are, "the stable foundation on which preferences depend" (Annett & Kilshaw, 1984). Previous reports of a mismatch between hand preference and skill (v. Section 1.2) are attributed to inadequate classification of hand preference and inadequate measures of skill. As handedness is shown to be a totally continuous variable any definition of left-handedness will be entirely arbitrary. Figure 1.5 shows that estimates of the proportion of left-handers in the population (represented by the area under the curve to the left of the threshold) will vary according to the criteria used.

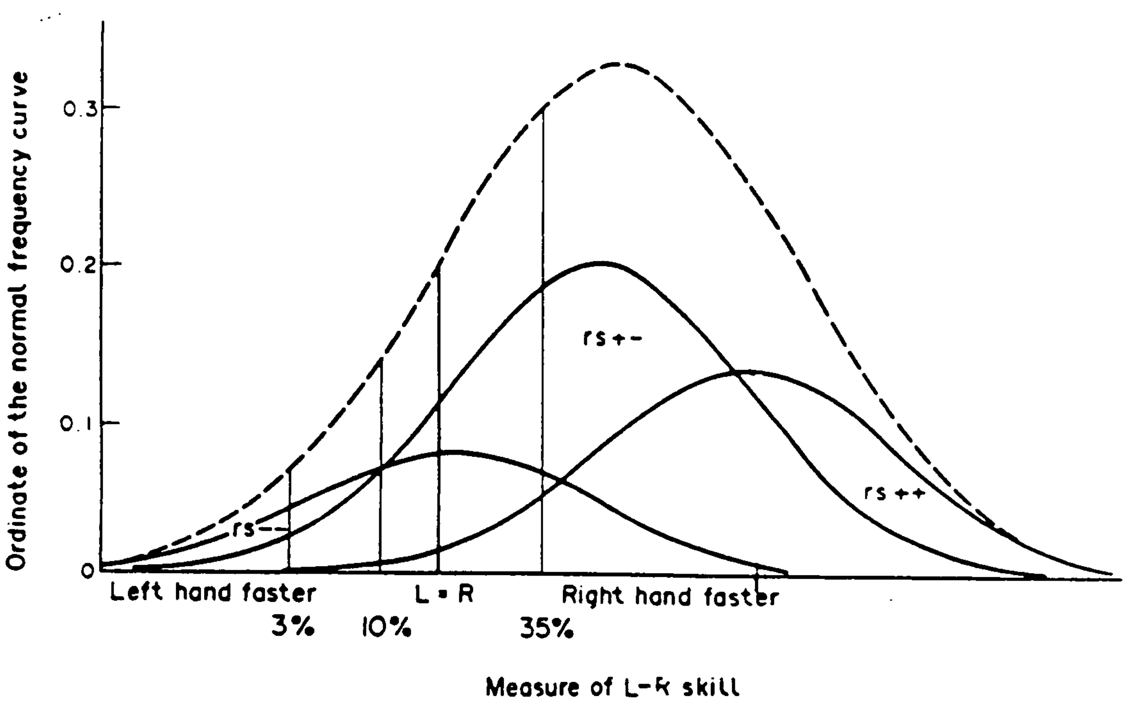

Figure 1.5 The distribution of L-R skill in the population, as measured by a task such as peg moving. The observed distribution (- - -) is a composite of the distributions of 3 genotypes, rs++, rs+-, and rs--. Various criteria are also indicated for 'left-handedness', consistent left-handedness (3% of the population), left-handed writing (10% of the population), and any non-right preference (35% of the population).

Annett (Annett & Kilshaw, 1982) has calculated the frequencies of the three possible genotypes in the population based on data from patients with loss of speech following unilateral lesions:

rs++ 0.3242 rs+- 0.4904 rs-- 0.1854

It is suggested that there is a balanced polymorphism for the right shift gene with the hetrozygote being the most advantageous genotype. Both the hetrozygotes have disadvantages compared to the homozygote but over the whole population the advantages and disadvantage of each genotype are compensated. Initially, Annett proposed that the disadvantage of the rs++ genotype may be an overcommitment to language at the expense of other vital skills such as the manufacture and use of tools. More recently, it has been suggested that the right shift gene promotes left hemisphere language specialization by some sort of handicap to the right hemisphere. Thus, those with genotype rs++, and to a lesser extent those with genotype rs+-, will have inferior right hemisphere capacities (v. Section 1.5.1) to those people who do not posses the right shift gene (rs--). A proportion of those with genotype rs-- are thought to be at some disadvantage in the development of speech and language. While most outcomes are probably satisfactory for the development of language there may be problems in certain cases. Such problems may arise if the various acoustic, visual, motor functions involved in the acquisition of language are located in different hemispheres as their coordination may be impeded.

It is important to note that the emphasis of the right shift theory is not on left and right-handers per se but on what actually underlies handedness, the presence or absence of the right shift gene. The right shift theory does not predict that right-handers will have inferior right hemisphere skills to left-handers. Rather, those of genotype rs++, and to a lesser extent genotype rs+-, will have a disadvantage when compared to those of genotype rs--; among those of genoptype rs-- more than half will be right-handed.

1.6.3 Geschwind and Galaburda's hypothesis

Geschwind and Galaburda (1985a, 1985b, 1985c) outlined a theory of lateralization in which it was proposed that cerebral dominance was based, in most instances, on asymmetry of structure. While genetic influences are acknowledged as being important this theory emphasises the role of factors that lie outside the gene pool of the fetus which can alter lateralization. The most important of these factors is considered to be the chemical environment in fetal life and, to a lesser extent, in infancy and early childhood.

It is proposed that the basic pattern of the adult brain is one with a strong left-right asymmetry, this asymmetry reflecting the neural substrates of language and handedness. Geschwind and Galaburda suggest that a characteristic feature of a dominant region may be to have more cells and possibly more extensive bilateral connections than the homologous region in the other hemisphere. Even in fetal life this pattern of asymmetry seems to be present.

The basic pattern of asymmetry may be altered by the chemical environment of the foetus. In particular, growth of the left hemisphere may be delayed by testosterone or some other male related factor. If growth of certain left hemisphere regions are delayed then it is proposed that the unaffected regions of the left hemisphere and in the homologous regions of the right hemisphere will show an increase in size as a result of the death of fewer neurones or possibly an increase in the size of neurones. Thus testosterone has the effect of diminishing the normal pattern of asymmetry in the brain. If the normal pattern of asymmetry is the foundation for the normal pattern of functional specialization, any change that tends to diminish these left-right asymmetries will promote the participation of the right hemisphere in language and handedness. Geschwind and Galaburda suggest that the group with symmetric brains will manifest random dominance for language and handedness. Support for this view comes from the anatomical data reviewed in Section 1.5.3 which showed left-handedness to be associated with less anatomical asymmetry than right-handedness or asymmetry in the opposite direction.

From the proportion of the population who do not show a left-sided planum superiority (v. Section 1.5.3) Geschwind and Galaburda estimate that approximately 35% of the population will show anomalous dominance (i.e. not a strong left preponderance) for language. A smaller proportion of the population are assumed to show random dominance for handedness. This is because language and handedness are assumed to be dependant on separate neuronal substrates which do not necessarily develop in the same periods. Geschwind and

Galaburda suggest that handedness may develop earlier and in a shorter period than language and so be less likely to become subject to retarding influences.

Excessive delays of growth of regions of the left-hemisphere will be more common in males since testosterone is male related. Thus the higher incidence of left-handedness amongst males is explained.

It is suggested that influences that delay the growth of regions of the left-hemisphere may be, "a mechanism of giftedness" (Geschwind & Galaburda, 1985a). These influences lead to a greater final extent of other areas in the same hemisphere and homologous regions in the right hemisphere. Geschwind and Galaburda believe that this could mean that these areas have augmented capacities. Thus, those people who have enlarged right hemisphere regions, some of whom will be left-handed, may have superior right hemisphere abilities (v. Section 1.5.1).

In addition to the influence testosterone has on lateralization, Geschwind and Galaburda also propose that testosterone affects the development of the immune system. Hence, there may be differences between handedness groups in there susceptibility to allergies, autoimmune disorders, and other conditions in which immunity plays a major role in pathogenesis.

1.7 HANDEDNESS AND ABILITY

The finding that there are differences between certain left and right-handers in the localization of function and morphological structure of the brain (v. Section 1.5) has lead to suggestions that left and right-handers may differ in their pattern of abilities. It has been suggested that these differences are so large that it would be surprising if they did not have any consequences for cognitive abilities (Harshman, Hampson, & Berenbaum, 1983).

There are two possible ways to investigate the link between handedness and ability (Annett & Kilshaw, 1982). The first is to classify subjects drawn from the general population into handedness groups and to ask whether the groups differ on measures of ability. The second is to identify groups having special abilities or disabilities and ask if the distribution of handedness differs from that in the general population. The following sections (1.7.1, 1.7.2, 1.7.3) discuss the evidence for differences between left and right-handers in three areas: spatial abilities, visuo-motor abilities, and occupational choice. The first two of these sections discuss studies that have used the former approach while the third section relates to studies that have used the latter approach.

1.7.1 Spatial abilities

Much of the current interest in the relationship between handedness and spatial abilities was instigated by Levy (1969) who published a study claiming that left-handers had inferior spatial abilities to right-handers. This seemed to support her 'competition' hypothesis.

Levy compared the performance of 15 right and 10 left-handed graduate science students on the performance and verbal sections of the WAIS. Whilst the two handedness groups did not differ in verbal I.Q. there were significantly different in their performance I.Q's with the mean of the right-handers scores being 13 points higher than that of the left-handers. Furthermore the mean discrepancy between verbal and performance I.Q.'s for the left-handers was significantly higher than that for the right-handers. Support for Levy's work was provided by Miller (1971) who found that a group of mixed-handers (n = 23) performed more poorly than a group of right-handers (n = 29) on a test of form relations which required spatial manipulation of two and three-dimensional shapes; in contrast there was no difference between the groups in a test of verbal abilities.

In the years following the publication of these studies both received a considerable amount of criticism. For example, it has been shown that on the digit sub-test of the WAIS the performance of some subjects is adversely affected by their hands obscuring the symbols, an disadvantage which is more common amongst left-handers (Bonier & Hanley, 1971). Both studies use highly selected small groups of subjects and neither distinguish between the sexes. As there is evidence that females often perform more poorly than males on spatial tasks (Maccoby & Jacklin, 1974) an over-representation of females among the mixed-handed group might have lead to an apparent effect of handedness.

Annett (1985) points out that the idea of a visuo-spatial deficit among left-handers seems to have become firmly fixed in the literature despite the publication of numerous studies producing negative findings. For example, Saunders, Wilson, and Vandenberg (1982) list 12 studies comparing the performance of left and right-handers on the spatial components of intelligence tests, only three of which produce positive results (including Levy's study). It has been suggested that the reason no clear relationship has emerged between handedness and spatial abilities is the methodological shortcomings of many of the studies (Burnett, Lane, & Dratt, 1982). In particular many studies have used very small numbers of subjects. Beaton (1985) points out that studies that use large numbers of subjects have generally produced negative results (e.g. Inglis & Lawson, 1984; n = 1880). In addition, rarely have adequate measures of handedness been employed (Burnett et al., 1982). While some studies have employed a handedness questionnaire, others have asked subjects to classify themselves as left or right-handed or have used the writing hand of subjects as the criterion. Thus, depending on the criteria used, groups identified as being left, right, or mixed handed may have differed from study to study.

Harshman et al. (1983) review the literature concerning the relationship between handedness and spatial ability and point out that it is inconclusive and inconsistent. A combination of methodological weaknesses and contradictory results, "pose a serious dilemma to anyone seeking a unifying interpretation" (Harshman et al., 1983).

1.7.2 Visuo-motor abilities

Comparatively few studies have investigated differences between left and right-handers in visuo-motor abilities. In a review, Annett (1985) points out that such studies should be carefully controlled so that they do not intrinsically favour left or right-handers. For example, Grant and Kaestner (1955) found that right-handers tracked right to left targets better than they did left to right targets while the reverse was true for left-handers. Overall, however, there was no difference between left and right-handers.

Flowers (1975) compared the performance of the preferred and non-preferred hand of right, left and mixed-handers on two tasks: aiming between targets and finger tapping. The only significant difference found between handedness groups was that mixed handers were slower than the consistent handers with their preferred hand on the aiming task. Peters and Durding (1979) also used a finger tapping task and reported that left-handers were significantly faster than right-handers using their non-preferred hand.

Annett (see Annett, 1985) has devised a peg moving task to compare the relative visuo-motor abilities of left and right-handers. Subjects are asked to move a row of pegs from one row to another using either their preferred or non-preferred hand. Kilshaw and Annett (1983) administered this task to 22 groups of subjects, classified by sex and age (total n = 1478). For 17 of these groups the non-preferred hand of left-handers was faster than that of the right-handers (binomial test, $P < 0.05$). For comparisons involving the preferred hand the pattern of results differed between males and females. Among males, the preferred hand of left-handers was significantly faster than the preferred hand of right-handers for 8 out of 11 groups while this was the case for only 3 out of 11 groups for females. When the groups were combined and classified by sex and hand preference for three of the four groups (males with preferred hand, males with non-preferred hand; females with non-preferred hand) left-handers were significantly faster than right-handers. A identical pattern of results was found when another body of data was analyzed in a similar manner (Kilshaw & Annett, 1983).

These findings led Annett to suggest that the action of the rs+ gene might be to impair the function of the right hemisphere (Annett, 1985). It should be noted, however, that left-handers may well have a superior non-preferred hand to right-handers since the design of many everyday items such as scissors and tin-openers forces left-handers to use their non-preferred hand.

1.7.3 Occupational choice

If left and right-handers do, indeed, differ in their pattern of abilities then one might expect a particular handedness group to be over-represented in particular occupations or academic disciplines. Unlike the laboratory based studies described above (Sections 1.7.1 & 1.7.2) it is possible to obtain data relatively easily from a large number of subjects using this approach. In addition, this approach has the advantage of being far more naturalistic than laboratory studies. A number of studies have compared the proportion of left and right-handers in various fields, particularly in the choice of academic discipline and professional career. Each of the influential researchers whose theories of handedness are discussed in Section 1.6 have used such studies to provide support for their theories.

Much of the research in this area concentrates on students and their academic discipline. The examination of studies of handedness and 'college major' detailed below reveals a contradictory set of results. Part of the reason for these inconsistencies may be methodological deficiencies which plague these studies. None of these studies consider males and females separately. Shettel-Neuber and O'Reilly (1983) point out that the subjects are often, "lower division students in introductory classes" and that there is evidence that between one third and one half of students change their 'majors' (Grites, 1982). In addition, none of these studies report the use of random sampling, specify their response rate (Shettel-Neuber & O'Reilly, 1983), or ever consider how proficient subjects are at their chosen discipline.

Peterson (1979) examined undergraduates (n = 1045) in an introductory psychology class and found that the proportion of left-handers among those majoring in science (4.4%, n = 92) was significantly lower than that among those majoring in music (14.9%, n = 47) or visual arts (design, architecture and art, 12.24%, n = 147). Oldfield (1969) also examined undergraduates majoring in music but found no evidence for an excess of left-handers among the musicians (n = 129) when a comparison was made with a sample of psychology undergraduates (n = 1128). Levy (1974) cites a communication from Swanson who reported that 11% of the student population at the University of Texas were left-handed, while 18% of law students and only 6% of art students were left-handed (n's are not given). Mebert and Michel (1980) found a significantly higher proportion of left-handers among a sample of art college students than in a sample of "liberal arts" undergraduates.

Shettel-Neuber and O'Reilly (1983) attempted to overcome the methodological shortcomings of many previous studies by examining the staff in 4 departments of the University of Arizona: architecture, art, law, and psychology (total n = 114). No difference was found, however, in the incidence of left-handedness between any of these groups. In another study investigating practicing members of an occupation Schlichting (1982) found no significant difference between the proportion of left-handers among Navy sonarmen and control groups of other sailors matched for age.

The most widely cited studies of handedness and occupational choice concern sport (see Chapters 4 & 5) and architecture (see Chapter 5). Sport has been given particular prominence because, at top levels, there is such intense selection pressure. Only athletes with truly outstanding abilities can reach these top levels. Thus an examination of the distribution of handedness at the top level of a particular sport allows the effects of handedness on performance to be assessed from the cumulative effects of many years of continual competition.

Studies claiming to have found an excess of left-handers among top sportsmen have examined tennis players (Annett, 1985; Azemar, Ripoli, Simonet, & Stein, 1983) and fencers (Azemar et al., 1983) while it has also been reported that left-handers have higher batting averages in baseball (McLean & Ciurczak, 1982). A major problem with these studies is that in all the sports examined left-handers have tactical advantages over their right-handed opponents as well as supposed neurological advantages. This point, however, is generally only mentioned briefly. For example, Annett (1985) attributes the excess of left-handers she finds among top tennis players to neurological advantages predicted by her Right Shift Theory (v. Section 1.6.2). Possible tactical advantages are merely touched upon briefly,

> "Of course, left-handed sportsmen might enjoy some advantages over right-handers because they can strike from the less frequent direction, but the findings for visuo motor-skill in peg moving suggest that they have absolute advantages also."

The weakness of this being that it is not known whether peg moving does actually correlate with accomplishments in tennis, the demands of the two being very different. Similarly, after Geschwind and Galaburda (1985a) detail why they believe left-handers have an advantage in sport they briefly point out that this is,

> "in contrast to the common view that this is entirely the result in competing against right-handed opponents."

Peterson and Lansky (Peterson & Lansky, 1974, 1977;

Lansky & Peterson, 1985) have published a number of studies claiming that there is an excess of left-handers among the architectural profession. As is the case for the analyses for sport mentioned above, these studies of architecture have various methodological shortcomings and the results are open to question (see Chapter 5).

Despite the weaknesses of these studies relating to sport and architecture they are widely cited in psychological literature (Annett, 1985; Carter-Saltzman, 1979; Corballis, 1983; Geschwind and Galaburda, 1985a, 1985b, 1985c; Witelson, 1980) and, indeed, in the press (e.g. Crooke, 1985; Harris, 1987; Anonymous, 1986). For this reason it was decided to reexamine the proportion of left-handers in sport and architecture.

CHAPTER 2

IS THE MAIL SURVEY A VALID METHOD OF COLLECTING HANDEDNESS DATA?

2.1 INTRODUCTION

Many of the studies which were reviewed in Section 1.7.3 obtained responses from every member of a particular sample of the population under consideration. Schlichting (1982), for example, considered U.S. Navy sonarmen and obtained handedness data from all of the 289 sonarmen who participated in advanced sonar training courses over a couple of months (v. Section 1.7.3). For such disciplined groups, obtaining responses from every member of the sample is relatively simple. There are other groups, however, for whom it is much more difficult to obtain responses from every member of a particular sample because they are scattered. For them, often, the only possible method of collecting handedness data is to use a mail survey. Annett (1985), for instance, attempted to investigate the distribution of handedness among vetinary surgeons in this way.

Yet there is a big problem with mail surveys. They rely on voluntary returns and this may introduce bias. The returns of a questionnaire may not, in fact, be representative of the sample from which it is drawn because non-response may not be a random process (Oppenheim, 1966). One factor that influences the response to mail questionnaires is the respondent's interest in the topic (Jobber, 1984). Studies which investigate the effects of interest on response rate usually send out a questionnaire in 'waves' and then compare the characteristics of the respondents to each wave. The usual finding is that recipients with a greater interest in the topic have a higher propensity to reply to an initial questionnaire. Stanton (1939), for example, studied ownership of classroom radios by teachers and found that 33% of respondents to the initial questionnaire owned radios while only 24% of respondents to the follow-up questionnaire did so. Fillipello, Berg, and Webb (1958) conducted a study concerning wine and found that 92% of respondents to the first mailing drank wine while only 78% of respondents to the second mailing were wine drinkers. Jobber (1984) reports that interest in the topic under investigation is derived from a number of factors including possessing or using the item, having a strong association with the item, and having positive attitudes to the topic under investigation.

It is clear that mail surveys of handedness will produce unrepresentative findings if left and right-handers differ in their propensity to return a questionnaire. As left-handers are a minority and thus may consider themselves to be special it is quite possible that they might be more interested in handedness and more likely to return a questionnaire. There is a magazine specifically for left-handers ("The Left-hander"), books are aimed at and written about left-handers (e.g. "The natural superiority of the left-hander"; DeKay, 1984) and there are several firms who cater specifically for left-handers (e.g. The Left-handed Company). Indeed, while undertaking research into handedness the author has noted that left-handers are much more likely to express interest than the right-handed.

Chapter 3 and Chapter 5 of this thesis are concerned with handedness among soccer goalkeepers and architects respectively; they are only accessible in large numbers through a mail survey. The mail surveys among them consisted of only one wave of mailings as we did not want to be too intrusive. In order to determine how representative such surveys might be we examined the responsiveness of students at the University of Durham. By sending repeated waves of a handedness questionnaire and by visiting non-respondents it was hoped to obtain handedness data from as many of the population as possible and thus compare those who responded in the first wave with the remainder.

2.2 METHOD

In Stage 1, the 10-item version of the Edinburgh Handedness Inventory (v. Section 1.3.2) was sent to all the students residing in three mixed sex colleges at Durham University (n = 1017). The questionnaire explained that we were investigating the distribution of handedness among student populations. The recipients were asked to complete the questionnaire and return it via the free University internal mail system. The study began two weeks into the third, and final, term of the academic year.

In Stage 2 another copy of the questionnaire was sent to those who had not replied within two weeks. A note was attached which explained that we were anxious to get as many returns as possible in order to make our survey valid. After a further three weeks we sent those who had still not replied another copy of the questionnaire, this time with a covering letter explaining the purpose of our study. Furthermore we visited the rooms of non-respondents, asking them to fill in our questionnaire. If they were not in, a copy of the questionnaire was pinned to their door with a covering note explaining how anxious we were to get a reply and that we would return the next morning to collect the questionnaire. Each non-respondent's room was visited at least twice.

2.3 RESULTS

Completed questionnaires were obtained from 880 (86.5%) of the possible population of 1017 students. In Stage 1 we received 370 replies to the first questionnaire (221 male, 149 female). Stage 2 produced a further 510 replies (307 male, 203 female). Overall, replies were received from 84% of the males and 91% of the females.

The responses were analyzed in two ways. First, item by item Chi-squared comparisons were made for each sex between Stage 1 and Stage 2 (Table 2.1). It can be seen that for both sexes the pattern of responses to Stage 1 and Stage 2 were very similar. In the case of female responses (n = 352) there were no significant differences between the two stages, while for the male responses (n = 528) two comparisons did reach the 0.05 probability level ('holding scissors', $chi^2 = 7.78$, d.f. = 2; 'striking a match', $chi^2 = 7.67$, d.f. = 2). In both of these cases the difference arose from the pattern of 'left' and 'either' responses and not from the total number of 'right' responses (Table 2.1).

In a second set of analyses the laterality quotient (v. Section 1.3.2) was calculated (this was not possible in 69 cases as the questionnaires were not filled in correctly). Comparisons were made between laterality quotients for Stages 1 and 2 using the Mann-Whitney U test (a parametric test was not used because populations of laterality quotient scores are not normally distributed). For both males and females this comparison did not reveal any difference between the response for Stage 1 and Stage 2 (males, P = 0.31, ; females, P = 0.64).

Table 2.1 The responses of male (this page) and female (following page) respondents in Stage 1 and Stage 2 to the items of the Edinburgh Handedness Inventory.

	Males				
	n	% R	% L	% E	Chi^2 Stage 1 vs. Stage 2 (2 d.f.)
Writing					
Stage 1	221	84.5	14.5	1.0	
Stage 2	307	88.9	11.1	0.0	2.13▪
Drawing					
Stage 1	221	84.6	15.4	0.0	
Stage 2	307	88.3	11.1	0.6	1.50▪
Throwing					
Stage 1	221	86.9	11.3	1.8	
Stage 2	307	89.6	7.8	2.6	2.16
Scissors					
Stage 1	221	85.6	7.2	7.2	
Stage 2	306	80.4	4.9	14.7	7.78*
Toothbrush					
Stage 1	221	79.6	11.3	9.1	
Stage 2	306	80.4	6.9	12.7	4.49
Knife					
Stage 1	221	83.7	10.9	5.4	
Stage 2	307	86.0	6.5	7.5	3.81
Spoon					
Stage 1	221	80.1	11.3	8.6	
Stage 2	307	80.4	8.5	11.1	1.86
Broom					
Stage 1	221	55.6	14.5	29.9	
Stage 2	307	60.6	12.4	27.0	1.33
Match					
Stage 1	221	80.6	12.2	7.2	
Stage 2	307	77.2	8.5	14.3	7.67*
Box					
Stage 1	221	45.7	11.3	43.0	
Stage 2	307	45.6	16.6	37.8	3.38

* $P < 0.05$ (two directional).
▪ 1 d.f. (i.e. a comparison was made between 'right' and 'non-right' responses due to the small expected frequencies of 'either' responses).

Table 2.1 (cont.)

	Females				
	n	% R	% L	% E	Chi² Stage 1 vs. Stage 2 (2 d.f.)
Writing					
Stage 1	149	83.9	14.8	1.3	
Stage 2	203	88.2	11.8	0.0	1.34▪
Drawing					
Stage 1	149	85.2	14.8	0.0	
Stage 2	203	87.2	12.3	0.5	0.28▪
Throwing					
Stage 1	149	85.9	8.1	6.0	
Stage 2	203	85.2	8.4	6.4	0.03
Scissors					
Stage 1	149	91.3	7.4	1.3	
Stage 2	203	85.7	9.4	4.9	3.93
Toothbrush					
Stage 1	149	78.5	12.1	9.4	
Stage 2	203	81.3	10.3	8.4	0.42
Knife					
Stage 1	149	85.2	12.1	2.7	
Stage 2	203	83.2	9.4	7.4	4.17
Spoon					
Stage 1	149	79.2	11.4	9.4	
Stage 2	203	76.4	10.8	12.8	1.00
Broom					
Stage 1	149	51.7	16.1	32.2	
Stage 2	203	59.1	16.8	24.1	2.90
Match					
Stage 1	149	77.9	8.7	13.4	
Stage 2	203	75.4	12.3	12.3	1.18
Box					
Stage 1	149	47.0	10.1	42.9	
Stage 2	203	46.9	11.1	42.0	0.29

▪ 1 d.f. (i.e. a comparison was made between 'right' and 'non-right' responses due to the small expected frequencies of 'either' responses).

2.4 DISCUSSION

This study examined whether respondents to the first wave of a handedness questionnaire are representative of the total population to which it is sent. The results clearly show that in the present case this was so, as item by item comparisons failed to reveal any systematic differences for either sex. Similarly, when a general measure of hand preference, the laterality quotient, was employed no evidence was found for a difference between Stage 1 and Stage 2 replies.

Handedness information was obtained from 84% of the male and 91% of the female target population. It is, however, likely that this is an underestimate as any student who was not in his or her room during the 8 week period of this study would have been counted as a non-respondent. Thus a student who was ill, away on a course perhaps, or had changed rooms would not have been able to reply to the survey. Nevertheless, one must consider the non-respondents as any extreme handedness bias among this wayward group would invalidate the findings. This is especially important for the male students as a higher proportion failed to return the questionnaire.

Methods used to estimate missing responses in mail surveys include comparisons with known values for the population and extrapolation of existing data. In the present case it is possible to make comparisons between our results and those of a handedness survey which obtained a 100% rate of return and used the same questionnaire (Bryden, 1977). A comparison between Bryden's data for male undergraduates shows that there is a very close correspondence for the items generally considered high in reliability and validity and which perform well in factor analysis (v. Section 1.3.2). For example, the percentages of 'left' responses in Bryden's (1977) survey and in the total set of responses in the present study were, respectively, for writing (11.6% vs. 12.5%), drawing (11.5% vs. 12.9%), and throwing (10.4% vs. 9.3%).

These comparisons provide indirect evidence that the small proportion of non-respondents in the present study did not bias the results in any systematic way. Thus it would appear that for this population of subjects the respondents to the first wave of a handedness questionnaire may be regarded as representative of the total population. It would, of course, be rash to apply these findings uncritically to all mail surveys, but in this instance, handedness, the results support the validity of data obtained using mail surveys such as those described in Chapter 3 and Chapter 6.

CHAPTER 3

IS THERE A LEFT-HANDED ADVANTAGE IN 'FAST BALL' SPORTS?

3.1 INTRODUCTION

> From the Memoirs of William Hickey (1749 - c. 1830). His father arranges for him to have fencing lessons with Signor Telligori, an Italian then in high repute in London (c. 1768).
> "Upon his first visit, my father being in the room, I took up the foil in my left-hand, having always been what is termed 'left-handed'. My father instantly exclaimed,
> 'Look at the awkward boy. Change hands sir; surely you cannot suppose that Mr Telligori will attempt to instruct a left-handed fellow.'
> But the Italian directly replied,
> 'Oh yes, I will, Sir, and recommend you by all means to let him be so taught; for, as a manly exercise and accomplishment, the effect will be precisely the same, and should he ever be obliged to use his sword in serious attack or defense of himself, the advantage from his doing so with the left-hand will be great and manifest.'" (Quenell, 1975).

It is often said that there is an unusually high proportion of left-handers among top sportsmen and sportswomen (Annett, 1985; Azemar et al., 1983; Mclean & Ciurczak, 1982). The most obvious explanation for this imbalance is that in many sports the right-hander will be relatively unaccustomed to facing a left-hander and so the right-hander may have to reverse his or her usual strategies. For example, a 'southpaw' (left-handed) boxer has a different stance to an 'orthodox' (right-handed) boxer. This means that he can produce punches from directions and angles that differ from those used by an 'orthodox' boxer (Porac & Coren, 1981). In addition, the symmetry of many team games means that left-handed or left-footed players may have an automatic advantage in certain positions on the pitch. For example, in a soccer team of eleven, it is desirable to have at least three left-footed players (i.e. left back, left midfield, left wing), a proportion which is higher than that found in the general population.

It has, however, been suggested that left-handers have an intrinsic advantage over right-handers due to superior spatio-motor skills and that the relatively high proportion of top left-handed athletes is, in part, a reflection of this innate superiority. Both the influential theories of Annett (v. Section 1.6.2) and Geschwind and Galaburda (v. Section 1.6.3) have used the relative frequecy of left-handed athletes to support their views and both offer detailed explanations for this supposed imbalance. Annett (1985) suggests that the right hemisphere impairment found in many right-handers (v. Section 1.6.2) could handicap a number of the components of skilled performance including the capacity for visuo-spatial thinking, the fine control of both hands, and the ability to make fast reactions to both sides. As such impairments will clearly affect sporting prowess the proportion of left-handers amongst top competitors should be boosted as a result of the exclusion of this group of right-handers with impaired abilities. Geschwind and Galaburda (1985a, 1985b, 1985c) propose that left-handers may have augmented right-hemisphere functions (v. Section 1.6.3), among them spatial abilities (v. Section 1.5.1). In addition, Geschwind and Galaburda (1985a) suggest that left-handers may have a higher degree of overall skill in those tasks which require the use of both hands due to a higher rate of bilateral representation of axial motor control.

The present study had two aims. The first was to determine whether there was a higher than normal proportion of left-handed players in sports which make heavy demands upon rapid and accurate visuo-spatial co-ordination. The sports chosen were tennis, for which extensive world rankings are compiled for both male and female players, and cricket, which is well documented and provides detailed information on players over many decades. In both of these sports left-handed players might be thought to have an strategic advantage whenever facing a right-handed player because of their relatively unfamiliar style of play. These strategic advantages, coupled with possible innate neurological advantages, lead to the clear prediction that there will be an excess of left-handed players in the top levels of these sports. Previous reports of the frequency of left-handed players in cricket have been only anecdotal (Annett & Kilshaw, 1982) and while tennis has been examined in more detail (Azemar et al., 1983; Annett, 1985) the findings are far from conclusive.

Azemar et al. (1983) reported finding a higher proportion of left-handed players among various divisions of the 1980 ATP World rankings (males) than in a control group. No statistical support was provided for their conclusions and the figure of 6% left-handed for the control players appears considerably lower than that obtained from larger surveys of handedness (Annett, 1970; Bryden, 1977). In addition, Azemar et al. (1983) found that there was a significant increase in the proportion of left-handed players between the top 25 and the top 4 World rankings (males) for 1980. Annett (1985) reports that the proportions of left-handed male players in the 1978 Wimbledon programme (15.6%, n = 128) and the proportion of left-handed male Wimbledon Champions, counting by years and not individual players, between 1946 and 1978 (15.1%, n = 33) are approximately twice the figure of 8.1% she obtained in a survey of 2321 male and female undergraduates and service recruits. It should be noted the comparison figure of 8.1% included both males and females and does not take into account the 2.6% who reported playing with a racket in 'either' hand (Annett, 1970). Furthermore, she found no differences when the same comparisons were made for female tennis players. Annett (1985) also analyzed the 1982 ATP rankings (males) and found a significantly higher proportion of left-handers among those players ranked 1-185 than in those ranked 186-369. However, this data is weakened by the accidental omission of certain left-handed players among those ranked 186-369.

The second aim of this study was to examine the proportion of left-handers in a sport which makes great demands on spatio-motor skills and yet for which there is no automatic advantage for the rarer left-handed player. Soccer goalkeepers were chosen because, like tennis-players and cricketers, they are required to make accurate responses to a fast moving ball but, in contrast, they should display no inherent side bias. Not only does the goalkeeper have to use both hands for many 'saves' but an analysis of 150 goals scored in the English First Division showed that there was no significant difference between the side of the pitch the ball came from or the side of the goal it went into (Wilkinson, personal communication). Lastly, goalkeeping requires no specialised equipment (unlike a sport such as hockey where all the sticks are 'right-handed'), and so is free from any equipment bias which might influence handedness. In order to provide detailed information on handedness a questionnaire containing the Edinburgh Handedness Inventory (v. Section 1.3.2) was sent to 273 professional goalkeepers in the English and Scottish Football Leagues. If left-handers do indeed have intrinsically superior spatio-motor skills then one would predict that there would be a higher than average proportion of left-handers among professionl goalkeepers as well as among cricketers and tennis players.

3.2 METHOD

Information concerning the handedness of tennis players and cricketers was taken from yearbooks which also provided the rankings or standings of the players in the previous season. Given the evidence that men are more likely to be left-handed than women (v. Section 1.4.4) care was taken to treat data about the different sexes separately.

3.2.1 Tennis

Bibliographical information and the previous year's World rankings were obtained for male professional tennis players from the Official Men's International Professional Tennis Council Media Guides for 1987 and 1986 (Lansberry,1987, 1986) and the Slazinger World of Tennis 1981 Guide (Barret, 1981). Similar information on top female tennis players was provided by the 1986 Women's Tennis Association Media Guide (Gossett, Kay & Page, 1986) and the 1981 Slazinger World of Tennis 1981 Guide. It should be noted that every entry in the 1987 men's guide (Lansberry, 1987) and the 1986 women's guide specifies which hand is used to hold the racket. The 1986 men's guide (Lansberry, 1986) listed handedness information for all but one of the 329 players described while the 1981 guide (Barrett, 1981) omitted handedness information for three male and two female players (out of a total of 192 males and 221 females).

3.2.2 Cricket

The Wisden Cricketers' Almanac (Brookes, 1938; Preston, 1950; Preston, 1962, 1974; Woodcock, 1986) provided detailed information concerning the playing handedness of batsmen and bowlers and their relative performances for a particular season (1937, 1949, 1961, 1973, 1985). The interval of twelve years between each season served to limit the number of cricketers who might be counted twice while the starting year (1937) was a consequence of The Wisden Cricketers' Almanac not providing handedness information before the 1935 edition. Each edition of The Wisden Cricketers' Almanac gives the bowling and batting averages of First Class County cricketers for a particular season and indicates whether a player bats or bowls left-handed. It should be noted that, unlike baseball, there are no 'switch-hitters' in cricket who bat with a different hand depending on the handedness of the bowler. The qualification for inclusion in the bowling averages is that a player must have bowled in at least 10 innings and have taken at least 10 wickets.

The batting information provided by The Wisden Cricketers' Almanac merely details which of the batsman's two hands are closer to the bottom of the cricket bat handle. There are, however, well known examples of players (e.g. David Gower) who are right-handed by most other measures and yet bat left-handed. The reverse combination is also found (e.g. Tim Robinson). In order to determine whether batting handedness is an accurate predictor of general handedness the 10-item Edinburgh Handedness Inventory (v. Section 1.3.2) was sent to the 42 cricketers in The Wisden Cricketers' Almanac 1987 (Wright, 1987) listed as batting left-handed. In addition, the Playfair Cricket Annuals for 1988 and 1968 (Frindall, 1988; Ross, 1968) were consulted, as these list the hand used by almost every player, apart from wicket-keepers, to hold the bat and bowl, regardless of batting and bowling ability.

Holding a cricket bat is not an item on any standard handedness questionnaire and in order to provide normative data, 765 male students (aged 11-18 years) at four schools in which cricket is compulsory (in London, Durham, and Newcastle) were asked whether they were 'right-handed', 'left-handed' or had no preference for batting (bottom hand on handle), bowling, and writing.

3.2.3 Football (soccer)

The original 22-item version of the Edinburgh Handedness

Inventory (v. Section 1.3.2) was sent to 273 goalkeepers in all four divisions of the English Football League and all three divisions of the Scottish Football League. The listing of goalkeepers was obtained from the Rothmans' Football Yearbook 1987-8 (Dunk, 1987). Two further questions were added to determine whether the goalkeepers attached any importance to laterality:

a) Do you find it easier/prefer to save shots going to a particular side of the goal and if so which?

b) Do you find it easier/prefer to catch crosses coming from a particular side of the goal and if so which?

The recipients were informed that these questions referred to their left/right sides.

3.3 RESULTS

Given that there are likely to be various tactical advantages that left-handers enjoy in both tennis and cricket, statistical comparisons for both of these sports were made one directional, i.e. a higher proportion of left-handers amongst the professional players was expected. Unless otherwise stated all comparisons had one degree of freedom.

3.3.1 Tennis

The media guides provided handedness information for 316 (1987), 328 (1986), and 189 (1981) male players (Table 3.1) and 189 (1986) and 119 (1981) female players. Given the closeness of the years it is, however, inevitable that many of the same players appeared in more than one guide. As a consequence an additional set of data was acquired by pooling the information from each yearbook for a particular sex and including each player only once. This pooled analysis provided a total of 500 male professional players and 252 female players.

Statistical comparisons were made with the results from large handedness surveys (Annett, 1970; Bryden, 1977). Both of these questionnaire surveys asked which hand was used to hold a racket. The Bryden study used the Crovitz-Zener questionnaire (Crovitz & Zener, 1962) and obtained responses from 608 male and 471 female undergraduates, while the Annett study used the Annett (1970) questionnaire and obtained responses from 674 male and 419 female undergraduates and 630 male service recruits. The detailed results for the items 'holding a racket' and 'throwing a ball' by sex were provided by Annett (personal communication). In order to provide as large a comparison group as possible the responses from these two surveys were combined making 1912 male and 890 female responses (Table 3.1).

Table 3.1 shows the proportion of left-handed male and female professional players and the results of Chi-squared comparisons with the control data for all players in a particular yearbook and for just those players in the top 100 rankings for that year. There are a small number of professional (1 male, 1 female) and amateur (58 male, 14 female) tennis players who use both hands equally. These 'ambidextrous' responses, which were too few to analyze separately, were divided equally between the 'right' and 'left' responses. For males two of the comparisons with the control data are significant, those for the players in the top 100 rankings in 1981 and for all the players in the 1987 yearbook (Table 3.1), whilst for females only one of the comparisons with the controls is significant, that for all the players in the 1981 yearbook (Table 3.1).

Table 3.1 The preferred hand used to hold a racket by World ranked tennis professionals (Pros). The figures show handedness information for the total number of male (upper) and female (lower) professional players for whom handedness information is provided in the media guides for 1981, 1986, and 1987 and handedness information for just those players in the top 100 rankings in a particular year. Control data from Annett (1970) and Bryden (1977).

		Top 100 Pros			All Pros			
	Controls	1981	1986	1987	1981	1986	1987	1981+6+7
Male								
n	1912	85	100	100	189	328	316	500
% L	8.9	16.5	14.0	13.0	11.6	12.5	13.6	12.2
% E	3.0	0.0	1.0	0.0	0.0	0.3	0.3	0.2
Chi^2		3.14*	2.11	0.68	0.28	1.68	3.45*	1.63
								(1981+6)
Female								
n	890	90	98		119	189		252
% L	8.0	11.1	11.2		12.6	11.1		10.7
% E	1.6	1.1	0.0		0.8	0.0		0.4
Chi^2		1.18	0.65		2.72*	1.03		1.28

* $P < 0.05$ (one directional).

As it has been claimed that handedness differs between the upper and lower halves of the rankings (Annett, 1985) and that there is a significant rise in the proportion of left-handed players between the top 25 and the top 4 rankings (Azemar et al., 1983) comparisons were made between these groups. No differences were found, however, for any of the years examined.

3.3.2 Cricket

Normative data was provided by 765 schoolboys aged 11-18 years. The percentage of those who held a cricket bat left-handed (left hand at bottom of handle) was 8.8% while 2.1% said that they used either hand equally. Similarly, the percentage of those who bowled left-handed was 10.2% while 1.2% could bowl equally with both hands. In comparison, 12.9% of the same sample preferred to write left-handed and 1.2% used either hand. This figure for bowling may be compared with the item 'throwing a ball' from the surveys of Annett (1970) and Bryden (1977) who found that 9.6% of males threw left-handed and 1.6% used either hand (total n = 1921). Those few schoolboys who reported batting or bowling with 'either' hand were divided equally between 'right' and 'left' responses as there were no comparable professional players.

Bowlers

The incidence of left-handed bowlers in the years 1985 (n = 139), 1973 (n = 119), 1961 (n = 141), 1949 (n = 137) and 1937 (n = 150) ranged from 15.3 to 26.1%. Statistical comparisons were made with the results from our survey of schoolboy cricketers (left-handed = 10.6%). This comparison revealed that there was an unusually high proportion of left-handed bowlers in First Class cricket in every season examined (1985, $chi^2 = 8.09$, $P < 0.005$; 1973, $chi^2 = 21.18$ $P < 0.001$; 1961, $chi^2 = 5.37$, $P < 0.025$; 1949, $chi^2 = 11.40$, P

< 0.001) with the single exception of 1937 ($chi^2 = 2.46$, $0.1 > P > 0.05$). Similar, but even more significant results were found when using the item 'throwing a ball' (1937, $chi^2 = 3.51$, $P < 0.05$; min chi^2 1949-1986 = 7.24, $P < 0.005$).

A final series of comparisons were made between the bowlers in the top and bottom halves of the bowling averages for a given season. There was no evidence that there was a disproportionate number of left-handers among the top half of the bowling averages for any season examined (1985, $chi^2 = 2.38$; 1973, $chi^2 = 0.98$; 1961, $chi^2 = 1.13$; 1949, $chi^2 = 0.14$; 1937 $chi^2 = 1.28$; all comparisons two directional).

Batsmen

The 25 replies from the 42 professional cricketers listed as batting left-handed in The 1987 Wisden Cricketers' Almanac highlighted the fact that handedness in batting can be a very misleading measure of overall handedness. Of the 25 replies all but 2 players were right-handed for virtually every item on the questionnaire, i.e. the vast majority of 'left-handed' batsmen in the survey were, in fact, right-handed by nearly all other measures.

In order to identify the true handedness of batsmen, therefore, the preferred bowling hand as provided by the 1988 and 1968 Playfair Cricket Annuals was used. Evidence that bowling preference is a good indicator of general handedness came from the finding that 93.2% of the 765 schoolboys were consistent across writing and bowling. Similarly, for all but one of the 23 handedness inventory replies received from professional cricketers, for whom bowling information was available, there was a perfect correlation between bowling and throwing a ball.

The bowling listings in The Playfair Cricket Annuals are far more extensive than those provided by The Wisden Cricketers' Almanac, detailing the bowling hand of all but 11% of the players, excluding wicketkeepers. Only those players in the top two thirds of the combined career batting averages for 1968 and 1988 were considered in order to focus on those players who were primarily batsmen or allrounders. Players who occurred in both editions were only counted once and then their 1988 career average was used. Comparisons with the schoolboy bowling data (n = 765, left-handed = 10.8%) showed that there was a significantly higher proportion of left-handers, as measured by bowling hand, among the professional batsmen (n = 371, left-handed = 15.6%, chi^2 = 5.26, P < 0.025). Similar, but more highly significant, results were obtained using the data from the large scale surveys of Annett (1970) and Bryden (1977) for the item 'throwing a ball' (chi^2 = 8.49, P < 0.005).

Given that bowlers comprise more than one third of a cricket team and it was found that many more professional bowlers are left-handed than would be predicted by chance, a more stringent division was adopted in order to exclude nearly all players who are primarily bowlers. When only the players in the upper half of the combined career averages were considered (n = 278), neither the comparison with the schoolboy data nor the comparison with the item 'throwing a ball' reached significance ('schoolboy', $chi^2 = 0.62$, 'throwing', $chi^2 = 1.21$). Furthermore, when the players in just the top one third of the rankings (n = 186) were considered the Chi-squared statistics were further reduced ('schoolboy', $chi^2 = 0.35$; 'throwing', $chi^2 = 0.68$).

A comparison was also made between the proportion of left-handers, as measured by bowling hand, in the top third and middle third of the combined career averages. Again, there was no evidence of a disproportionate number of left-handers among the best players ($chi^2 = 3.02$). In fact, the proportion of left-handers was greater among the lower cohort.

As there can be no differences in the tactical advantages enjoyed by players who bat left-handed and are left-handed (as measured by bowling) and those players who bat left-handed but are right-handed (as measured by bowling) the career averages of both groups of players were compared. Similarly, a comparison was made between the averages of players who bat right-handed and are right-handed with those who bat right-handed but are left-handed. Again, in order to reduce the number of specialist bowlers in these analyses, first those players in the upper two thirds of the rankings were considered. Neither of these comparisons were significant [players batting left-handed and bowling left-handed (n = 21) vs. players batting left-handed and bowling right-handed (n = 51), t = -1.22, P = 0.23, d.f. = 29.2; players batting right-handed and bowling right-handed (n = 262) vs. players batting right-handed and bowling left-handed (n = 37), t = -1.31, P = 0.19, d.f. = 297.0]. Similar analyses were also carried out with players in the top half and the top third of the batting averages and again none of the comparisons reached significance (min P = 0.24).

In contrast to handedness, as measured by bowling, a far greater proportion of professional cricketers bat left-handed than would be expected by chance. The analyses of The Wisden Cricketers' Almanac showed that in every season examined since 1949 the proportion of left-handed batsmen was remarkably stable and lay between 18.7% and 19.6% (min n = 224, max n = 258). Chi-squared comparisons with the schoolboy batting data (n = 765, left-handed = 9.8%) were highly significant (min chi^2 = 14.24, $P < 0.001$). When only those players in the top two thirds, top half, and top third of the averages were considered there still was a significantly higher proportion of left-handed batsmen among the professional cricketers for every season examined since 1949 (min chi^2 = 4.77, $P < 0.025$). It may, however, be noted that the proportion of left-handed batsmen in the 1937 season was appreciably lower at 11.2% (all players) and did not differ significantly from the control data for any of the comparisons made.

3.3.3 Football

Of 273 professional goalkeepers who were sent the Edinburgh Handedness Inventory, 167 (61%) sent replies. It was possible to compare directly the responses for 14 items ('writing', 'drawing', 'throwing', 'holding scissors', 'holding a toothbrush', 'holding a knife without a fork', 'holding a spoon', 'holding a broom', 'striking a match', 'opening a box', 'holding a hammer', 'holding a tennis racket', 'holding a knife with a fork', and 'threading a needle') with the results of a previous study (Bryden, 1977) in which 620 male undergraduates were surveyed using both the 10-item version of the Edinburgh Handedness Inventory and the Crovitz-Zener Questionnaire (Crovitz & Zener, 1962). All responses have been divided into three categories, 'left', 'right', and 'either'. It should be noted that for three items ('hammering', 'holding a knife', 'threading a needle') minor differences do exist between the wording of these two questionnaires and these differences might complicate consideration of the control data.

Table 3.2 shows the frequency of 'left', 'right', and 'either' responses for these questionnaire items. All of the subsequent comparisons with the control data had two degrees of freedom with the exceptions of writing and drawing, for which there were too few 'either' responses, and so the data was treated in a manner similar to that used for the tennis analyses. For eight of the fourteen comparisons there was a significant difference between the control subjects and the goalkeepers but in all of these cases the difference reflected a lack of 'left' and 'either' responses amongst the professional goalkeepers (Table 3.2). The same pattern of results was found when comparisons were made between 'right' and 'non-right' ('left' and 'either' combined) responses (Table 3.2). Once again, for particular items the goalkeepers gave a significantly higher proportion of 'right' responses than the control group, and in all but one case ('holding a knife with a fork') the controls, not the goalkeepers, contained the greater proportion of non right-handers.

The handedness of the goalkeepers, as defined by preferred writing hand, was also compared with their preference for the direction of crosses and shots on goal. The goalkeepers were asked to make one of three possible responses, 'left', 'right', or 'indifferent'. This additional analysis revealed no handedness differences for preferences of direction of crosses ($chi^2 = 0.94$, 2 d.f., two directional), but a significantly higher proportion of left-handed goalkeepers did report finding it more difficult to save shots to their left ($chi^2 = 6.78$, 2 d.f., $P < 0.05$, two directional).

Table 3.2. The responses of the professional goalkeepers and the control group for the 14 items for which comparisons with control data were possible. Control data from Bryden (1977).

	n	% R	% L	% E	Chi^2 R vs L vs E (2 d.f.)	Chi^2 R vs Non-R (1 d.f.)
Writing						
Goalkeepers	167	90.4	9.6	0.0	N/A	0.63
Controls	620	88.1	11.6	0.3		
Drawing						
Goalkeepers	167	90.4	9.6	0.0	N/A	0.83
Controls	619	87.1	11.5	1.4		
Throwing						
Goalkeepers	167	87.4	6.0	6.6	3.25	0.88
Controls	620	84.5	10.3	5.2		
Scissors						
Goalkeepers	167	86.2	6.0	7.8	1.02	0.98
Controls	619	83.0	7.8	9.2		
Toothbrush						
Goalkeepers	167	86.2	7.2	6.6	6.06*	6.06*
Controls	619	77.5	11.8	10.7		
Knife w/o fork						
Goalkeepers	167	87.4	9.6	3.0	11.86***	6.84**
Controls	619	78.3	9.7	12.0		
Spoon						
Goalkeepers	167	83.8	9.0	7.2	7.02**	5.63*
Controls	619	75.2	10.3	14.5		
Broom						
Goalkeepers	167	74.3	10.8	14.9	50.59***	50.20***
Controls	616	43.4	20.1	36.5		
Match						
Goalkeepers	167	85.6	7.8	6.6	16.41***	14.2***
Controls	616	71.3	9.9	18.8		
Box						
Goalkeepers	166	62.1	8.4	29.5	15.12***	15.12***
Controls	617	45.1	12.3	42.6		
Hammer						
Goalkeepers	166	86.8	6.6	6.6	15.53***	1.21
Controls	620	83.2	14.7	2.1		
Racket						
Goalkeepers	167	89.2	6.6	4.2	5.50*	0.36
Controls	608	87.5	10.7	1.8		
Knife with fork						
Goalkeepers	166	79.5	14.5	6.0	2.42	1.57
Controls	618	83.7	10.2	6.1		
Needle						
Goalkeepers	167	80.8	8.4	10.8	13.73***	7.43***
Controls	604	70.2	20.9	8.9		

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ (two directional).

3.4 DISCUSSION

The present study examined the frequency of left-handed players in three sports: cricket, tennis, and football. Although a clear excess of left-handed bowlers was found in cricket, the findings for tennis, football, and those for batsmen in cricket all cast doubt on the notion that left-handers have an inherent, neurological advantage in fast ball sports.

Although it has been suggested that there are many more left-handed professional tennis players than would be expected by chance, this effect is, at best, slight. Indeed, the size and significance of this effect appear to depend largely on the year being examined and the size of the sample being considered. It should be emphasized that when the largest possible sample of either male or female professional players was considered there was no excess of left-handed players. This finding appears to contradict previous claims of a clear excess of left-handed players when smaller, select, samples have been considered (Annett, 1985; Azemar et al., 1983) although, as has been pointed out, there are deficiencies in both of these studies. It has also been reported that there are more left-handed players in the top half of the World rankings (Annett, 1985) and that there is a significant increase in the proportion of left-handers at the very top of the rankings (Azemar et al., 1983). This was carefully reexamined in the present study and no support for these claims was found for any of the years examined. In conclusion, while there may be a slight advantage to left-handed players this effect is neither strong nor consistent.

The most parsimonious explanation of any left-handed advantage is that it is tactical rather than the consequence of any specific spatio-motor superiority. Tennis literature often refers to this supposed 'leftie advantage' (Crooke, 1985; Navratilova & Carillo, 1984). Navratilova points out that right-handers must reverse their usual strategies when facing a left-hander (Navratilova & Carillo, 1984). For example, many players have pet shots such as hitting the ball backhand cross court to their opponent's relatively weaker backhand. If they play this shot when facing a left-hander it will go to the left-handers forehand. The most frequently cited advantage that the left-hander is supposed to have is due to his or her serve which swings away from the weaker backhand of the right-hander. However, it should be noted that the same is true of the right-hander's serve to the left-hander, though the left-hander will be more accustomed than the right-hander to returning this 'awkward' serve. Whether or not left-handers have tangible advantages in tennis may be irrelevant as the very popularity of the notion that there is a 'leftie advantage' may give the left-hander a slight psychological edge when facing a right-handed opponent.

The analyses for cricket assumed that bowling handedness reflects general handedness, and in particular that it should correlate highly with the item 'throwing a ball'. The findings for batting had, however, to be treated differently as batting handedness is a poor predictor of general handedness. With these considerations in mind it was found that there was a consistently higher proportion of left-handed bowlers among the professional cricketers than would be expected by chance. This difference was found both for comparisons with our schoolboy bowling survey and for the item 'throwing a ball' from two large surveys (Annett, 1970; Bryden, 1977). It should be noted that the ages of those playing professional cricket and those participating in the two surveys (Annett, 1970; Bryden, 1977) were approximately similar.

While this proportion of left-handed bowlers might reflect an innate superiority one must consider the various, accepted, strategic advantages that such players enjoy. The left-handed bowler has the benefit of unfamiliarity and in particular he is able to bowl at a different angle and to move the ball in the opposite direction to his right-handed counterpart. It is, however, interesting to note that the proportion of left-handed bowlers in 1937 was noticeably lower and much closer to those levels found in the control groups. This apparent relative decrease in left-handed bowlers may well reflect a greater degree of pressure for children in the past to 'conform' and use their right hand (v. Section 1.4.3).

The assessment of handedness in batsmen is complicated by the clear evidence that many 'left-handed' batsmen are, in fact, right-handed by almost any other measure. The survey of the individual batting and bowling averages in The Playfair Cricket Annuals revealed that 71.4% of the players listed as batting left-handed (n = 98) were right-handed (as measured by bowling) while 15.5% of the players listed as batting right-handed (n = 458) were left-handed (as measured by bowling). For this reason batting handedness was ignored and bowling was taken as an estimate of general handedness. While this was possible for 90% of the cricketers, excluding wicketkeepers, listed in The Playfair Cricket Annuals, bowling handedness was not listed for a small minority of batsmen. More detailed examination revealed that this 10% of players was very evenly distributed between the top (37.5%), middle (32.8%), and bottom (29.7%) thirds of the combined career averages. As a consequence the differential effects of omitting these players from the rankings is likely to be negligible.

Using the criterion of being in the top two thirds of the career batting averages to identify specialist batsmen it was found that there was a higher than chance proportion of left-handers (as measured by bowling hand) among the professional batsmen. However, analyses were also performed using more stringent criteria (only those players in the top half and the top third of the averages) as it is likely that the initial criterion might not exclude all bowlers. This was because bowlers comprise more than one third of a team.

Using these more stringent criteria the significant effect disappeared, i.e. there was no evidence of an excess of left-handers (as measured by bowling hand) among top batsmen. Furthermore, when a comparison was made between the proportion of left-handers in the top (12.3%) and middle thirds (18.9%) of the batting averages no significant difference was found, and in fact the proportion of left-handers was greater among the middle third.

An alternative method of investigating whether left-handers make better batsmen is to compare the averages of those players who bat left-handed and are left-handed by other measures with those players who bat left-handed but are right-handed by other measures. Similarly, comparisons can be made between players who bat right-handed and are right-handed with those players who bat right-handed but are left-handed. Such analyses using only those players in the top two thirds, top half, and top one third of the averages showed there to be no significant differences between these groups.

A similar set of comparisons has been made for baseball (McLean & Ciurczak, 1982) and it was found that those players who bat left-handed and throw left-handed (i.e. left-handers) had significantly higher career batting averages than those players who bat left-handed but throw right-handed (i.e. right-handers). As there are no tactical differences between these two groups it was argued that this comparison may reveal a neurological difference between left and right-handers (McLean & Ciurczak, 1982). However, this difference in baseball can also be explained by a consideration of the stance of the batter. Given the correlation between hand and foot preference (Porac & Coren, 1981) it is likely that the back foot of right-handers batting left-handed will be their non-preferred foot. In contrast, the back foot of left-handers batting left-handed will be their preferred foot. As the back foot in baseball supports the weight of the body and provides balance those players whose back foot is their preferred foot may have a slight advantage. This is not the case in cricket where either foot may be required to provide balance and support. Whether or not this fully accounts for the findings from baseball is unclear, but it may also be noted that no such difference was found between the career averages of those baseball players who bat right-handed and throw right-handed (i.e. right-handers) and those baseball players who bat right-handed and throw left-handed (McLean & Ciurczak, 1982). Such a difference might be expected if left-handers do, indeed, have an innate neurological superiority.

A clear excess of players who bat left-handed was found among the top professional cricketers. As batting handedness is a poor indicator of general handedness and no evidence was found for an excess of left-handers among top batsmen (using a more reliable indicator of handedness) this excess suggests that players who bat left-handed enjoy some sort of tactical advantage. The combination of a player batting right-handed and a player batting left-handed not only requires the bowler repeatedly to realign his deliveries but it also necessitates frequent fielding changes. These factors may help the bowler to lose his line and length and the fielders their concentration (Eastwood, 1972).

In conclusion, there is an excess of left-handers among professional bowlers. This excess, however, may be accounted for without recourse to neurological explanations. Similarly, there is a significant excess of professional cricketers who bat left-handed but this may also be explained by a consideration of strategic factors. When a much more reliable indicator of general handedness is used, no evidence was found for an excess of left-handers among top batsmen.

While handedness data were readily available from guide books for tennis players and cricketers, no such source of information exists for professional soccer goalkeepers. As the goalkeepers were scattered around the country a mail survey was used. This obtained responses from 61% of those contacted. In order to assess whether such a method of collection of handedness data is valid the study described in Chapter 2 was undertaken. This showed there to be no difference between respondents and non-respondents to a one wave handedness questionnaire, thus strengthening the results of the survey of goalkeepers.

When the goalkeepers' responses were compared with those of the controls, eight out of the fourteen comparisons showed a significant difference between the two groups. But, it must be noted that for all of these cases there were more right-handers among the goalkeepers than the controls, a result contrary to the notion that there should be an excess of left-handers in 'fast ball' sports. In fact, when these results are considered in the light of studies which have investigated the factor structure, reliability, and validity of questionnaire items (v. Section 1.3.2), the goalkeepers and the controls did not differ on those items show to be the most satisfactory indicators of 'handedness', i.e. 'writing', 'drawing', 'throwing a ball', 'holding scissors', and 'holding a tennis racket'. The only exception, in fact, was that of 'holding a toothbrush' for which there were more right-handers among the goalkeepers.

Another study which has considered handedness in sports which require rapid, precise spatio-motor skills has noted the seemingly very high proportion of left-handed elite fencers (Azemar et al., 1983). For example, in the 1981 World Championships, 35% of the male (n = 127) and 32.3% of the female (n = 102) entrants in the foil competition were left-handed. Similar high proportions were found for the men's epee events (24.2%, n = 130) but not, it should be noted, for the sabre (12.5%, n = 95). Although the authors suggest that these findings reflect neurological advantages possessed by the left-handers, it is evident that left-handed fencers, like left-handed boxers, will have clear strategic advantages. This was recognised as early as the 18th century as the quotation at the beginning of this chapter shows.

Frank Charnock, coach of the London and Thames Fencing Club, believes that a number of factors account for the differential distribution of left-handers between the sabre, foil, and epee events. In each of these disciplines the parts of the body of the opponent which can be hit to score points differs. The target is smallest in foil events; hits only count in the area between the collar bone and the waist. In the sabre event the head, arms, and thighs also score while in the epee all parts of the body count. Right-handers have the greatest difficulty facing left-handers in the foil since the target area on the left-hander is proportionately far more diminished than it would be in the epee or sabre. The left-hander presents a very small target and so the right-hander has to alter significantly his usual line of attack. In the epee and sabre events this effect is less disruptive since the target area on the left-hander is greater.

A number of other factors also influence the relative distribution of left-handedness in these events. Until quite recently, when people took up fencing, they always started using the foil. Charnock believes that, as left-handers enjoy such a strategic advantage, many right-handers become frustrated at being continually beaten by left-handed fencers. Thus, they take up the epee or sabre. The sabre is particularly unattractive to left-handers. It is only since the last Olympics that scoring in the sabre event was judged electronically. Previously, bouts were judged visually by referees. Many left-handers felt that judges missed many of their scoring moves as they were not used to their stance (Charnock, personal communication). It will be interesting to observe whether the proportion of left-handedness rises in the sabre event in the future.

The present study has considered in detail three different sports which require the participants to make very rapid and very accurate spatio-motor responses. Although the precise demands of the sports differ, the same pattern of results is found throughout. That is, a variable excess of left-handed players is present when such players have clear strategic advantages, e.g. cricket (bowlers) and tennis, but these effects may be remarkably slight (tennis). Furthermore, when one considers a sport in which there should be no strategic advantage (soccer goalkeepers), no evidence was found for an excess of left-handed players. The most parsimonious explanation for the present findings is that any superiority of the left-hander in these sports reflects the nature of the game and not an innate neurological advantage.

CHAPTER 4

IS THERE A LEFT-HANDED ADVANTAGE IN 'BALLISTIC' SPORTS?

4.1 INTRODUCTION

In Chapter 3 it was argued that previous reports of a left-handed 'advantage' in tennis (Annett, 1985; Azemar et al., 1983), cricket (Annett & Kilshaw, 1982), fencing (Azemar et al., 1983), and baseball (McLean & Ciurczak, 1982) can be fully explained in terms of tactical factors and that there is no reason to invoke any additional neurological advantages. It is clear that in order to demonstrate unambiguously that left-handers have an innate advantage in sport, research should focus on those sports in which other biasing factors can be excluded.

In the present study handedness was examined in four sports: snooker, darts, ten-pin bowling, and golf. These sports were chosen because they offer no strategic advantage to the rarer left-handed player. These sports also differ from the majority of those previously examined in that they emphasise 'ballistic' rather than 'fast ball' skills. Ballistic activities are under little or no control by feedback mechanisms (Guiard, Diaz & Beaubaton, 1983) whilst many activities in 'fast ball' sports require rapid adjustment and hence place much greater emphasis on feedback mechanisms. Such a distinction is similar to that made by Poulton (1957) between 'open' and 'closed' skills. This distinction is based largely on the predictability of the environment in which the skill is performed.

Sports emphasising 'open' skills and hence occurring in a unstable and unpredictable environment include soccer, tennis, baseball (batting), cricket (batting), and fencing.

In addition, all of these sports are 'adversarial', i.e. the actions of a competitor are dependent on those of his or her opponent. As a consequence these sports almost inevitably contain some strategic advantage for the rarer left-handed or left-footed player.

In contrast, many 'closed' or 'ballistic' sports, e.g. darts, golf, snooker, and ten-pin bowling do not contain a strategic bias. This is mainly because most 'closed' sports are not 'adversarial'. Although it is true that in snooker the actions of a competitor are dependent on those of the opponent (i.e. the position of the balls from the last shot) there is no known tactical bias favouring either hand. As a consequence any excess of left-handers in the above 'ballistic' sports must reflect factors other than tactical.

4.2 METHOD

4.2.1 Snooker and Darts

Handedness information was obtained by looking through a large number of specialist sports magazines (Snooker Scene, 1975 - 1987; Darts World, 1980 - 1987; Darts Player, 1985-1987) and noting the handedness of players from pictures (in the case of snooker the handedness of a player was taken as corresponding to the hand that holds the cue rather than the hand that 'bridges'). Care was taken to double check the 'handedness' of each player in case any of the pictures had been printed back to front. Additional handedness information was obtained from televised darts and snooker competitions. In the case of snooker, our findings were checked and supplemented by two sports journalists who had an extensive knowledge of the game, whilst for darts this information was checked and supplemented by a sports journalist, two professional players, the secretary of the World Professional Darts Players Association, and the Secretary of the Scottish Darts Association.

4.2.2 Ten-Pin Bowling

Handedness information for the top male players in the U.S.A. was obtained from the Professional Bowlers Association Tour Official Program (1987) which lists bibliographic information for every active player who has Touring Pro 1 status or who is eligible to compete in the Firestone Tournament of Champions.

The handedness information for female professional bowlers was obtained directly from the Ladies Professional Bowling Tour (Vint, personal communication) which provided a list of the top prize winners for 1987 and indicated those who bowled left-handed.

4.2.3 Golf

As there are no published records of the handedness of top golfers we spoke to a professional golfer (Peter Dawson), known to play left-handed, and sent letters to the editors of golf magazines in the U.K. and the U.S.A. asking them if they knew how many top professionals played left-handed. We also contacted manufacturers of golf clubs (John Letters, Titleist, MacGregor, Ping, and Gratex) in order to determine the relative sales of left and right-handed clubs. This information allowed us to estimate the proportion of amateur golfers who play left-handed.

In addition, a survey of amateur golfers was undertaken at three golf courses in London. A day was spent at each course and every male player was asked to fill in a simple questionnaire which asked them their golfing handicap, whether they would classify themselves as left, right or mixed-handed and whether they played golf left or right-handed. The questionnaire was kept unusually simple in order to ensure replies from every golfer.

4.2.4 Control data

None of the precise actions used in the four sports are included in handedness questionnaires. Nevertheless, in the cases of darts and bowling the demands appear sufficiently similar to the item 'throwing a ball' which is found in several large handedness surveys (Annett, 1970); Bryden, 1977). In order to confirm this assumption a simple handedness questionnaire was given to 210 male and 173 female undergraduates at classes in a variety of subjects at the University of Durham. This questionnaire asked for the preferred hand for writing, throwing a ball, holding a snooker cue, throwing a dart, and throwing a ten-pin bowling ball. If the subject had not attempted a particular sport he or she was instructed to leave a blank. All of the students present at the various classes completed a questionnaire.

4.3 RESULTS

4.3.1 Control data

The handedness survey given to 210 male and 173 female students showed that the item 'throwing a ball' was not only an accurate predictor for preferred handedness in darts and bowls, but that it was also highly accurate for snooker. From a total of 210 male students the distribution of handedness for darts ('right' 89.0%, 'either' 2.4%, 'left' 8.6%) was very similar to that for throwing ('right' 86.7%, 'either' 4.8%, 'left' 8.1%; chi^2 = 1.73, d.f. = 2). An even closer correspondence was found between the 210 replies for snooker ('right' 87.1%, 'either' 4.8%, 'left' 8.1%) and throwing ('right' 86.7%, 'either' 4.8%, 'left' 8.1%; chi^2 = 0.03, d.f. = 2). As might be expected the 199 replies from male students who played ten-pin bowling also showed a very similar pattern to the responses for throwing from the same students (bowling, 'right' 88.4%, 'either' 3.5%, 'left' 8.1%; throwing a ball 'right' 86.7%, 'either' 4.8%, 'left 8.1%'; chi^2 = 0.61, d.f. = 2). This correspondence was less clear cut in the 164 female students who had played ten-pin bowling (bowling, 'right' 82.3%, 'either' 3.0%, 'left' 13.4%; throwing, 'right' 78.7%, 'either' 7.9%, 'left' 13.4%; chi^2 = 3.78, d.f. = 2, $P > 0.10$), but inspection of the scores shows that this slight difference lay mainly in the number of 'either' responses which were parcelled out when comparisons were made with the professional players.

The results from this student survey helped confirm the value of the item 'throwing a ball', for which there is information from several very large samples (Annett, 1970; Bryden, 1977). The Bryden study used the Crovitz-Zener questionnaire (Crovitz & Zener, 1962) and obtained responses from 617 male and 484 female undergraduates for the item 'throwing a ball'. The Annett study used the Annett (1970) questionnaire and obtained responses from 674 male undergraduates, 630 male service recruits and 419 female undergraduates. The results of these two surveys were then combined. As there were no 'either' responses among the professional players the 'either' responses among the controls were divided equally among the 'left' and 'right' responses. This provided an identical estimate of 10.4% male (n = 1921) and 10.4% female (n = 903) control subjects throwing left-handed (Fig 4.1).

4.3.2 Snooker

Handedness information was obtained for all of the top 117 players in the Official World Snooker Ranking List (1987) of the World Professional Billiards and Snooker Association and for a further 8 players up to rank 129, where the rankings end. Of the top 117 players, 11 (9.4%) played left-handed while 11 (8.8%) of the total sample of 125 players played left-handed (Fig. 4.1).

Comparisons, using the Chi-squared test, with the male control data from the surveys of Bryden (1977) and Annett (1970) for 'throwing' showed there to be no significant difference in the incidence of left-handedness in these groups whether the top 117 (chi^2 = 0.12) or all 125 of the snooker players (chi^2 = 0.33) were considered. Similarly, there was no evidence of a change in handedness distribution when just the top 10, top 25 and top 50 players were considered.

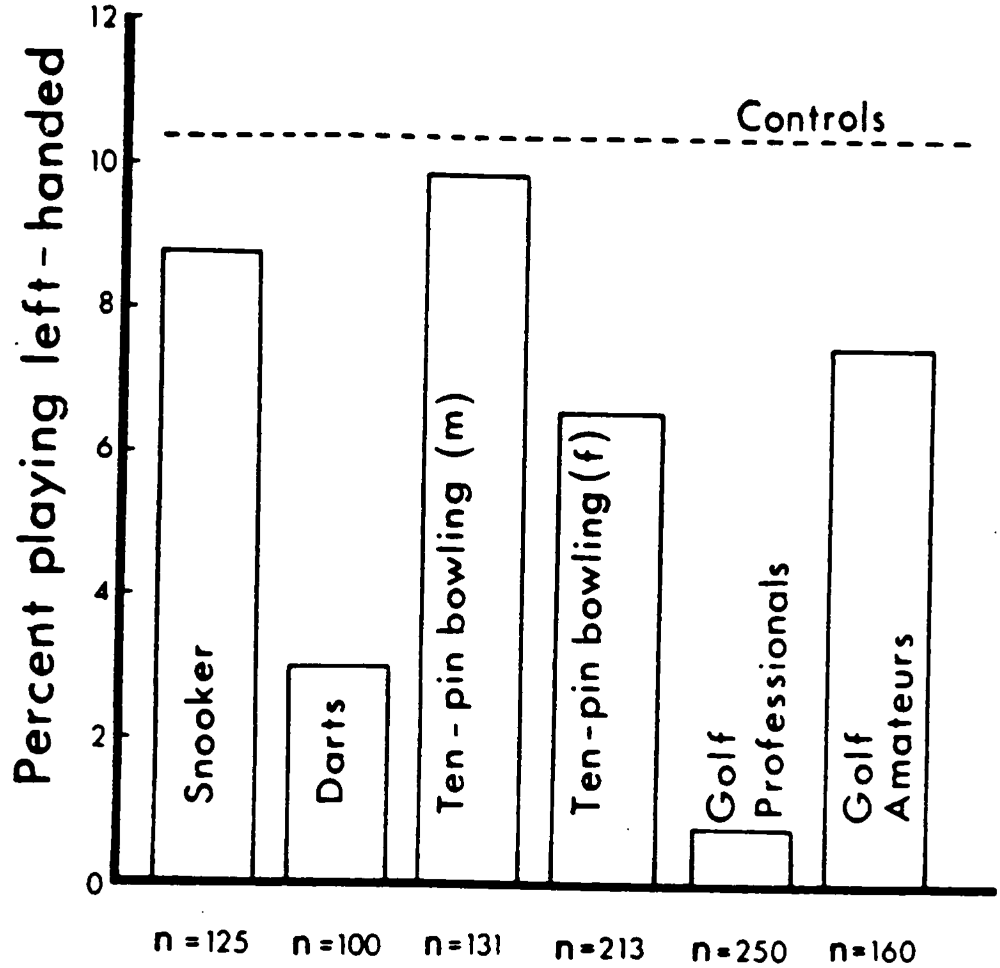

Fig. 4.1 Percentages of sportsmen and sportswomen playing left-handed in the four sports considered in this chapter. The data for each sport comes from the largest relevant sample size (m = male, f = female).

4.3.3 Darts

As world rankings for darts generally only include the top 20 ranks, international appearances for England, Scotland and Wales were used as a measure of the proficiency of a player. Out of the 55 players who are listed in the British

Darts Organization 1987-1988 Official Darts Diary as having appeared 10 or more times for their country only 3 (5.5%) threw left-handed. Handedness data for a larger sample of 100 players was also obtained. This sample consisted of the 50 most successful English players in terms of international matches won and the 25 most successful Welsh internationals and the 25 most successful Scottish internationals. Only 3 of these 100 players threw left-handed (Fig. 4.1). Furthermore, there were no left-handers in the British Darts Organization world rankings at the time that this data was being collected (November 1987, n = 20).

Chi-squared comparisons showed there to be no significant difference between the incidence of left-handedness in the 1921 controls (10.4%) and the 55 players (5.5%) who had appeared 10 or more time for their country (chi^2 = 1.43). In contrast, when the larger population of 100 international players were considered it was found that a significantly lower proportion of the darts players were left-handed, as measured by throwing hand ($chi^2 = 5.73$, d.f. = 1, $P < 0.02$).

4.3.4 Ten-Pin Bowling

The tour guide included biographies of 131 male bowlers while the rankings of female bowlers covered the top 213 earners in the 1987 season. Of these, 13 (9.9%) of the men bowled left-handed while 14 (6.6%) of the women bowled left-handed (Fig. 4.1). Again, no significant difference was found when the male and female bowlers were compared with their respective control data for the item 'throwing a ball' (males, chi^2 = 0.03; females, chi^2 = 2.78). In addition no significant differences were found when just the top 50 male and the top 50 female players were considered.

4.3.5 Golf

The editor of Golf World provided handedness statistics for the American professional golf tour while Peter Dawson provided information for the European tour. There were no golfers who played left-handed amongst the top 100 players on the American tour in 1985 nor have there been any golfers who play left-handed amongst the top 250 players on the European tour in the 1980's. There were, however, two golfers who played left-handed on the European tour in the 1970's (Fig. 4.1), Peter Dawson and Bob Charles, both of whom have now retired from the circuit.

Estimates of the proportion of amateur golfers who play left-handed come from our survey of amateur golfers which found that 7.5% of all the golfers surveyed (n = 160) played left-handed and from a survey undertaken in the U.S.A. which estimated that 5.5% of amateurs play left-handed (Wiren, personal communication). These figures are in general accordance with the proportion of left-handed golf clubs manufactured by the five golf club manufacturers we contacted, which range from 3% to 12% of total output. It should be noted that the highest figure refers to a company which specialises in left-handed clubs.

It would appear that a best estimate of the proportion of amateurs who play golf left-handed would be somewhere between 4% and 8%. Given this, there is clearly a lower than normal proportion of professional golfers who play left-handed. For example, a Chi-squared comparison between the results of our survey of amateur golfers and the highest proportion we obtained of professionals who play left-handed (2 out of 250) is significant well beyond the 0.001 level ($chi^2 = 13.28$).

A total of 160 amateur golfers completed the questionnaire (there were no refusals); 16.2% reported themselves as being left-handed, 13.8% as mixed-handed, whilst only 7.5% actually played golf left-handed (Fig. 4.1). It is interesting to note that if the amateur players are divided into two groups corresponding to the poorer players (those with handicaps greater than ten) and the better players (those with handicaps of ten or less) there is a significantly higher proportion of left and mixed-handers among the better players ($chi^2 = 9.77$, d.f. = 2, $P < 0.01$), even though the proportion of players who actually play golf left-handed is approximately the same in both groups. That is, comparatively more left-handed golfers were playing 'right-handed' in the more proficient group.

4.4 DISCUSSION

This study examined the frequency of left-handed players at the top levels of four sports: snooker, darts, ten-pin bowling, and golf. For snooker and bowling the proportion of top left-handers matched that found in the general population. In contrast, for darts and especially golf there appeared to be a lower than expected proportion of top competitors who played left-handed. In order to appreciate this pattern of results it is important, however, to consider the nature of the various sports.

There are several types of advantage or disadvantage that left-handers may enjoy in sport, e.g. tactical, coaching, equipment, or innate. Thus in order to demonstrate the supposed innate advantage that left-handers may enjoy, one must first exclude these other possibilities. As has already been explained these four sports were selected because they ruled out any strategic advantage or disadvantage to either hand. We can also probably exclude any coaching bias from three of the four sports (snooker, darts, and ten-pin bowling) as most players are self-taught. However, Eastwood (1972) suggests that this is not the case for golf and reports a newspaper article stating that professional coaches find it difficult and may even avoid giving instruction to left-handers.

There may be a slight equipment bias in ten-pin bowling as most standard balls are designed for right-handers although left-handers can also use them. But, as most players of moderate ability will buy their own ball and have holes drilled to their own specifications this equipment bias is probably negligible. It has also been suggested that left-handed bowlers may actually have an advantage as they bowl down the left, and hence less worn, side of the lane (Beam, 1983). While the effects of these factors are impossible to quantify they appear slight. Furthermore, it was clear that the proportion of top male and female players who bowled left-handed fitted very closely to the normal proportion for the most appropriate item, 'throwing a ball'.

There is a clearer equipment bias in golf which acts against left-handers and this may well account for the relatively low proportion of amateur golfers playing left-handed and the extraordinary low proportion of top golfers who play left-handed. A set of golf clubs is either 'right-handed' or 'left-handed'. As most players start with a borrowed set of clubs they are more likely to use a right-handed set. Furthermore, as golf is a two handed game, left-handers are able 'switch' to a right-handed set. Indeed, this 'switch' may even be an advantage as nearly all professionals acknowledge that it is the left-side which is important in controlling the swing (Saunders, 1986). There is, however, no reason to suggest that the layout of golf courses favours right-handers (Charles & Wallace, 1985).

The remarkably low proportion of professional golfers who played left-handed can partly be explained by the coaching and equipment biases mentioned above. In addition, it is felt that until recently, left-handed golf clubs were generally inferior and this may have stopped players reaching the top (Charles & Wallace, 1985). It will be interesting to see whether, with improvements in equipment, the proportion of professionals playing left-handed increases in future years.

It is also important to appreciate that in those sports in which both hands are used, e.g. golf, cricket, and baseball (batting) the fact that a player adopts an orthodox stance does not necessarily mean that he or she is right-handed. This was evident from our survey of amateur golfers. In addition, it has long been known that some professional golfers who play right-handed are actually left-handed (e.g. Ben Hogan, Johnny Miller, and Neil Coles). From considering the golf swing there is, indeed, a case to be made that the left-hander who plays golf right-handed may actually have an advantage over the right-hander who plays golf right-handed. This is because the left (upper) hand can control and lead the swing (Saunders, 1986). This possibility was borne out in our survey of amateur players which showed that among the better players there was a significantly higher proportion of left and mixed-handers, most of whom had made this 'switch' to playing right-handed. Conversely, right-handers might be more proficient when playing golf left-handed; presumably they are prevented from making this 'switch' by the relative unavailability of left-handed clubs. It is, therefore, interesting to note that both of the professional golfers we identified as playing left-handed are, in fact, right-handed on most other measures. This was also found in the analyses of cricket batsmen in the previous chapter; many professional cricket players who bat left-handed are, in fact, right-handed by other measures.

The two remaining sports examined in this chapter, darts and snooker, appear to be free of bias. The only exception is that in snooker there will be occasions when the white ball is close to a cushion and easier to play with a certain hand. As a consequence the rare left-hander may have an advantage in some 'safety' play. Nevertheless, there was no evidence of an excess of left-handers amongst top darts or snooker players. Indeed, there appeared to be a lower than expected proportion of top darts players who play left-handed. Such a finding might actually appear to contradict the predictions of Annett (v. Section 1.6.2) and Geschwind and Galaburda (v. Section 1.6.3).

The demands in these two sport are, however, different. Success in snooker involves more than simply the ability to make an accurate ballistic movement. Players have to plan ahead so that the cue ball is in a favorable position for future shots. Steve Davis, world No. 1 at the time of writing, is reported as saying that he thinks two shots ahead, a skill comparable to 'spatial visualization', which involves the ability to mentally rotate, manipulate and twist two and three-dimensional stimulus objects (McGee, 1977).

The findings of this and the previous chapter emphasise the need to consider a sport in detail before observations about the percentage of left-handed players can be used to support psychological theories. Previous investigators who have reported a significantly higher than normal proportion of left-handers in various sports (Annett, 1985; Azemar et al., 1983, McLean & Ciurczak, 1982) have often paid insufficient regard to the tactical and physical demands placed on left-handers, preferring to speculate on neurological advantages. While the present study cannot rule out a left-handed linked advantage in spatial skills, it has failed to find any inherent advantage within a series of ballistic sports. Indeed in some ballistic sports there may even be a disadvantage. These results, coupled with those of the previous study of 'fast-ball' sports (Chapter 3) fail to support the popular notion that left-handers have superior visuo-motor skills.

CHAPTER 5

IS THERE A LEFT-HANDED ADVANTAGE IN ARCHITECTURE?

5.1 INTRODUCTION

Chapters 3 and 4 of this thesis examined the incidence of left-handedness among top athletes. A second area in which there is a widely held belief that there is an excess of left-handers is in the architectural profession. A number of widely cited studies have claimed to have found an advantage to left-handers in this field (Peterson & Lansky, 1974, 1977; Lansky & Peterson, 1985). These studies, like those concerning athletes, contain various deficiencies and have not been replicated by other researchers.

Peterson and Lansky (1974, 1977; Lansky & Peterson, 1985) have examined the proportion of left-handers among various groups of students and lecturers at the School of Architecture at the University of Cincinnati. In their 1974 study they examined the proportion of left-handers among students in each of the 7 years in the school. While no difference was found between the proportion of left-handers in the first year class (10.8%) and an estimate of that in the general population (10.0%), it is reported that there was a general increase in the proportion of left-handers over the years, again compared to an "assumed" norm of 10% (Peterson & Lansky, 1974). However the criteria used to assess the handedness of the architectural students and that used to arrive at the population estimate differ. The handedness of the students was assessed on a five-point scale with three anchoring points: "I am totally right-handed", "I use either hand equally", or "I am totally left-handed". Any subject ticking either of the last two statements was classified as being left-handed. In contrast, the population estimate was based on the consensus of reports in the literature for a unimanual activity such as writing (v. Section 1.4.1). This difference in assessment has lead Beaton (1985) to suggest that this result should not be taken seriously.

It is also reported that 29.4% of the members of staff in the School of Architecture in 1974 were left-handed (n = 17) (Peterson & Lansky, 1974). This figure of 29.4% persists in 1985, despite a 50% turnover in staff since 1974 (Lansky & Peterson, 1985). A much lower proportion of left-handers was found by Shettel-Neuber and O'Reilly (1983) among members of staff at the University of Arizona School of Architecture (left-handed = 4%, n = 23). While handedness data were not obtained from two members of staff, even if both had been left-handed this figure would have only risen to 12%. It should be noted that Shettel-Neuber and O'Reilly (1983) used a similar method of assessment to Peterson and Lansky (1974).

The most compelling evidence for a left-handed advantage in the architectural profession was reported in 1977 (Peterson & Lansky, 1977). It was found that a significantly higher proportion of left-handers completed the architecture course at Cincinnati between 1970 and 1976. As left and right-handers are defined according to the same criteria this finding is much more convincing than the earlier report of a increase in the proportion of left-handers over the years. It should be noted, however, that Peterson and Lansky (1974, 1977) do not distinguish between the sexes in this analysis or their earlier (1974) study. Given the evidence that there are differences in the distribution of handedness between males and females (v. Section 1.4.4) this may have affected the results. Peterson and Lansky (1977) also report that 21% of the males in the entering class in 1976 were left-handed. Although not explicitly stated, the proportion of left-handers among the females in the 1976 entering class was considerably lower at 5.3%.

No explanation is offered for these findings apart from the suggestion that, in some way, right-handedness "goes more" with the left-hemisphere of the brain while left-handedness "goes more" with the right hemisphere (Peterson and Lansky, 1974). It should, however, be noted that such a pattern of results is consistent with the theories of Annett (v. Section 1.6.2.) and Geschwind and Galaburda (v. Section 1.6.3).

If there is some sort of left-handed advantage in architecture then one would expect to find a higher than normal proportion of left-handers among practicing architects. Although Peterson and Lansky report in 1974 that they were, "currently collecting data from practicing professionals" such work was never completed due to difficulties in obtaining help from the American Institute of Architects (Lansky, personal communication). As such a study has never been undertaken it was decided to obtain handedness data from a large sample of practicing architects.

5.2 METHOD

The company secretaries of 70 architectural firms in

London and Newcastle upon Tyne were sent letters explaining the present study and asking if they would be willing to distribute a questionnaire to all their architectural staff. It was stressed that it was really important to achieve as a high a response rate as possible so as to rule out 'response bias'. Those who agreed to help were sent copies of the 10-item Edinburgh Handedness Inventory (v. Section 1.3.2) to which had been added 2 further questions:

a) Are you fully qualified (i.e. registered with The Architectural Registration Council of the United Kingdom)?

b) If not, at what stage of your training are you at (e.g. have you completed your Part 1 or Part 2 exemptions)?

5.3 RESULTS

31 firms agreed to participate in this study. 257 completed questionnaires from qualified architects (236 males, 21 females) and 105 questionnaires from architectural students (78 males, 25 females) were obtained. These 257 replies reflect a response rate of at least 50% from qualified architects.

The 'right', 'left', and 'either' responses from the male architects and architectural students were compared item by item with the results of Bryden's survey (1977) of 620 male university students (Table 5.1). Given the results of previous investigations (Chapters 3 & 4) it was decided to make these comparisons two directional. In two cases, 'writing' and 'drawing', the small number of 'either' responses invalidated the use of the Chi-squared test. Six of the eight comparisons that were possible between the qualified architects and the control data revealed evidence of significant differences between the two sets of handedness responses. In addition, one of the ten comparisons made between the architectural students and the controls also provided evidence of a difference in handedness ('holding a broom', $P < 0.01$). It should be emphasised that for all of these items the difference reflected a lack of 'left' and/or 'either' responses among the qualified architects and architectural students (Table 5.1).

The same pattern of results was obtained when comparisons were made between 'right' and 'non-right' responses. Here too, the qualified architects and the architecture students gave a significantly higher proportion of 'right' responses for particular items. In no case was there a higher proportion of 'non-right' responses among the qualified architects or the architectural students (Table 5.1).

The small number of returns from female qualified architects and architectural students (21 and 25 respectively) precluded meaningful statistical analysis. There was, however, no evidence of an excess of left-handers of left-handers (as judged by writing hand) among either of these groups (qualified architects, 'left' = 4.8%, 'either' = 0%; architectural students, 'left' = 3.8%, 'either' = 7.4%).

Table 5.1. The responses of qualified architects, architectural students and controls (all male) to the Edinburgh Handedness Inventory. Control data from Bryden (1977).

	n	% R	% L	% E	Chi² R vs L vs E (2 d.f.)	Chi² R vs Non-R (1 d.f.)
Writing						
Controls	620	88.1	11.6	0.3		
Architects	236	89.0	11.0	0.0	N/A	0.40
Students	78	88.5	10.2	1.3	N/A	0.01
Drawing						
Controls	619	87.1	11.5	1.4		
Architects	236	88.1	10.6	1.3	N/A	0.17
Students	78	89.7	10.3	0.0	N/A	0.45
Throwing						
Controls	620	84.5	10.3	5.2		
Architects	236	89.4	9.3	1.3	6.97*	3.37
Students	78	85.9	10.3	3.8	0.25	0.10
Scissors						
Controls	619	83.0	7.8	9.2		
Architects	236	88.6	5.5	5.9	4.03	3.92*
Students	78	83.3	6.4	10.3	0.25	0.00
Toothbrush						
Controls	619	77.5	11.8	10.7		
Architects	236	84.3	8.1	7.6	4.81	4.80*
Students	78	78.2	12.8	9.0	0.25	0.02
Knife						
Controls	619	78.3	9.7	12.0		
Architects	236	87.7	8.9	3.4	15.03***	9.70**
Students	78	84.6	11.5	3.9	4.70	1.64
Spoon						
Controls	619	75.1	10.4	14.5		
Architects	236	85.6	8.0	6.4	12.64**	10.92***
Students	78	78.2	11.5	10.3	1.09	0.36
Broom						
Controls	616	43.4	20.1	36.5		
Architects	236	74.2	9.7	16.1	64.94***	64.87***
Students	78	64.1	14.1	21.8	12.13**	13.73***
Match						
Controls	616	71.3	9.9	18.8		
Architects	236	84.3	8.5	7.2	19.03***	15.46***
Students	78	76.9	7.7	15.4	1.10	1.10
Box						
Controls	617	45.1	12.3	42.6		
Architects	236	61.0	11.5	27.5	19.00***	17.40***
Students	78	43.6	15.4	41.0	0.59	0.06

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, (two directional).

5.4 DISCUSSION

Contrary to previous reports of an excess of left-handers in the architectural profession (Peterson & Lansky, 1974, 1977; Lansky and Peterson, 1985) the present study found no evidence for an abnormal proportion of left-handers among either qualified architects or architectural students. Indeed, those significant differences between the control group and the architects were all in the opposite direction, i.e. for these items there was an excess of right-handers among the architects. It should, however, be noted that for those items regarded as the best indicators of handedness and with the highest reliability and validity (v. Section 1.3.2) a much more similar distribution of 'left', 'right' and 'either' responses were found in the control and architectural groups (Table 5.1).

The present study differed from previous ones in a number of ways. First, qualified, practicing architects as well as architectural students were considered. In contrast, previous studies have concentrated on students, considering only a small number of qualified architects (the staff of the architectural school). If, indeed, there is an excess of left-handed students entering Schools of Architecture (Peterson & Lansky, 1977) and proportionately more left-handers complete the course successfully (Peterson & Lansky, 1977) then one would expect to find an excess of left-handers among qualified architects. An examination of the returns revealed a similar pattern of results in both the qualified architects and the students, and neither revealed an excess of left-handers.

A second difference between this and previous studies lies in the method of sampling. In the University of Cincinnati studies (Peterson & Lansky, 1974, 1977; Lansky & Peterson, 1985) handedness data from all relevant staff and students was obtained. In contrast, in the present study replies were received from about 50% of those contacted. This constraint arose from the need to obtain co-operation from a large number of firms; we wanted to minimise the intrusiveness of the study. For this reason it was not thought either feasible or proper to press the company secretary to obtain responses from all of the architects in the firm.

In order to assess whether the responses to a single wave of a mail questionnaire are representative of the population to which it is sent the study described in Chapter 2 was undertaken. This showed there to be no significant differences between the respondents to the first wave and the non-respondents. Thus, the fact that this study found no evidence for an excess of left-handers cannot be attributed to a bias caused by the of the method of sampling. The results of the present study, like those of the sports studies described previously (Chapters 3 and 4), call in question a widely held belief; namely that there is an excess of left-handers among architects.

CHAPTER 6

CONCLUSIONS

6.1 OVERVIEW

This thesis has examined the proportion of left-handers in a number of sports and in a single profession, architecture. In these activities previous reports have suggested an excess of left-handers. Such findings are seen as consistent with the influential theories of Annett (1985) and Geschwind and Galaburda (1985a, 1985b, 1985c), both of which predict that left-handers will be over represented in occupations which make demands on spatial abilities.

The research undertaken for this thesis found no evidence to support the notion of an innate neurological advantage for left-handers in either those sports examined or architecture. This lack of agreement may probably be attributed to some methodological shortcomings and incorrect interpretations of results in those previous studies.

Among cricket batsmen, soccer goalkeepers, ten-pin bowlers, snooker players, golfers, darts players, and in architecture, no evidence was found for an excess of left-handers. In fact, a significantly lower than normal proportion of left-handers was found for one of the analyses of top darts players. In addition, certain analyses for particular items among the soccer goalkeepers and architects reached significance; in every instance this reflected a lack of 'non-right' (i.e. fewer 'left' or 'either') responses among the experimental group rather than the control group. It is questionable, however, whether much significance should be attached to these results; only two relatively small groups of darts players were examined, while those items which reached significance among the goalkeepers and the architects were generally those shown to have low reliability, validity, and factor loading on the 'handedness factor' identified in factor analytic studies (v. Section 1.3.2).

Although a significant excess of left-handers was found among cricket bowlers, this is readily explained in terms of the obvious tactical advantages that left-handed bowlers enjoy. A number of analyses involving tennis players also reached significance. These effects, however, were highly capricious even though the statistical analyses were one directional (i.e. an a priori prediction was made about the direction in which the totals would be ordered). As in the case of cricket bowlers, there are highly plausible tactical advantages that left-handed tennis players enjoy and there is no need to invoke possible innate advantages.

While these findings cannot rule out the possibility of a left-handed linked advantage in spatial tasks they suggest that if, indeed, it exists it is probably very small.

6.2 WERE THE COMPARISONS MADE VALID?

The conclusions reached above would clearly be unwarranted if the comparisons made in this thesis were inappropriate in any way. The following sections examine the nature of the comparisons made between the experimental and control groups.

6.2.1 Should a general measure of laterality have been used?

All the comparisons in this thesis, with one exception, have been made 'item by item' between the experimental group and controls. An alternative approach would have been to compare the groups on a single, overall measure of laterality such as the laterality quotient (v. Section 1.3.2). This approach was not adopted for a number of reasons.

The most compelling reason was that data was relatively easily available for tennis players, cricketers, snooker players, darts players, and ten-pin bowlers for a particular item; namely the way they 'played' their sport. It would have been a practical impossibility to obtain responses to a handedness questionnaire from members of these groups in sufficient numbers to allow meaningful comparisons to be made. Previous studies which have only considered a single item have produced significant and sometimes quite eye-catching results. For example, Annett (1985) reported that 16.1% of Wimbledon male entrants in 1978 played tennis left-handed in contrast to a figure of 8.1% among a group of controls (v. Section 3.1). As the purpose of this thesis was to reexamine such claims the same methodology was adopted.

It is important to recognise that there are serious deficiencies inherent in the general measures of laterality that are currently available, and this includes the laterality quotient. There is, for example, no general agreement on which items should be used to construct a index of lateral preference. Bryden (1983) questions whether discovering which hand is used to hold a broom or open a box is actually diagnostic of anything at all. In addition, a number of items included in the Edinburgh Handedness Inventory have been shown to have low reliability and validity and do not load highly on the 'handedness' factor identified in factor analysis (v. Section 1.3.2), yet responses to these items are given equal weight in the calculation of the laterality quotient. Annett (1985), also adds that calculation of the laterality quotient also depends on the subjects' estimates of degrees of preference and this can be highly capricious (v. Section 1.3.2.1).

6.2.2 Was the control data appropriate?

Section 1.4 examined the evidence for differences in the incidence of handedness between various demographic groups. If the demographic characteristics of the experimental groups and the control groups employed in this thesis differed to any great extent this may well have biased the results. Probably the most widely cited demographic factor which may affect handedness is sex (v. Section 1.4.4); for this reason care was taken to treat the sexes separately in all comparisons. It is also important to consider whether the control and experimental groups were matched in terms of the other demographic factors which may have an influence on handedness; namely, age, nationality, and educational level.

6.2.2.1 Age differences

Section 1.4.2 showed that the incidence of left-handedness is higher among younger subjects. Bryden (1977) describes the majority of his subjects as being, "between the ages of 19 and 24". This means that these subjects are currently aged between 30 and 35. Annett's (1970) subjects were first year undergraduates and service recruits, presumably the majority of both groups were approximately 20 years old and thus, at the time of this present research, are in their mid to late 30's. Thus the controls are contemporaries of, or slightly older than, all the sportsmen considered in Chapter 3, namely the tennis players, goalkeepers, and cricketers. The players of the 'ballistic' sports considered in Chapter 4 are probably, on average, older than the players of the 'fastball' sports. However, it is unlikely that many of these competitors were much over the average age of the controls. The only sport for which the dates of birth of the competitors were actually available, was ten-pin bowling (males). In this sport the mean age of the competitors was 37; a very similar figure to that of the controls.

The group considered in this thesis with probably the oldest members was that of the qualified architects since the oldest could have been nearly 65 years old. The questionnaires sent to the architects did not ask for the respondents' date of birth as it was intended to make the questionnaire anonymous and as unobtrusive as possible. It may, however, be noted that the proportions of right-handers (as judged by writing hand) among the qualified architects (89.0%) and the architectural students (88.5%) are similar.

6.2.2.2 National differences

The control groups used were Canadian (Bryden, 1977) and British (Annett, 1970). The cricketers, the snooker players, the goalkeepers, the darts players, and the architects were primarily British, the ten-pin bowlers were American. As Section 1.4.3 shows, there seems to be no difference between the handedness of subjects from Britain, Canada, and America. Thus, there is no reason to suppose that nationality differences may have biased these comparisons in any way.

Two of the experimental groups were of more varied origin. The tennis players were drawn from all over the world and the golfers from all over Europe. There is, however, no evidence to suggest that the incidence of left-handedness differs across Europe and the fact that the tennis players came from such a wide range of countries makes it unlikely that the results were biased in any systematic way. It should be noted that previous reports of an excess of left-handers among top tennis players (Annett, 1985; Azemar et al., 1983) were based on comparisons with control groups also drawn from only one country (Britain and France respectively).

6.2.2.3 Educational level

Section 1.4.5 discussed the evidence which suggests that the incidence of left-handedness may be elevated in samples of University students. In the light of such evidence Annett (1985) suggested that comparisons between University samples and other groups might lead to rather conservative estimates of differences.

Bryden's (1977) subjects were all university students; so were Annett's group of female subjects and half her group of males; the others were service recruits. Only one experimental group examined in this thesis, the architects, all had a university level of education although a number of the cricketers were graduates or actually at university. It is important to note that Annett did not find a significant difference in the distribution of handedness between the male students and the service recruits in her sample (Annett, personal communication). For example, for the item 'holding a racket', one of the few items for which separate data are available for the students and service recruits from Annett's (1970) survey, the proportion of right-handers is very similar (students, 89.9% right-handed; service recruits, 87.8% right-handed). Both of these are very similar to that of Bryden's (1977) survey of students (87.5% right-handed).

If a number of the comparisons between the controls and the experimental groups had been close to significance then the differing educational levels of the groups might well have brought the validity of the results into question. Yet, with the exception of the cricket and tennis analyses (which can be explained without recourse to neurological factors), all the comparisons showed there to be a lower or identical proportion of left-handers among the experimental group compared with the controls. Unless the control data provided a significant overestimate of the proportion of left-handedness in the general population, which seems unlikely, the different educational level of experimental groups and controls seems to have little or no effect on the results. Even when an experimental group of a similar educational level to the controls, the architects, was considered, no evidence was found for an abnormal proportion of left-handers.

The above sections show that although the demographic characteristics of the control and experimental groups differed in certain cases there is no evidence that this biased the results in any systematic way.

6.3 HOW USEFUL IS THIS APPROACH?

Studies of handedness and occupational choice have certain advantages over laboratory studies in that they are more naturalistic. Data can be obtained from large numbers of subjects, and if an activity like top class sport is examined, all the subjects will have outstanding abilities. In addition, many sports provide rankings making it possible to identify, for example, the 100 best players in the world. In contrast, selection of subjects for laboratory tests of abilities is more difficult. Great care must be taken to ensure that the sample is unbiased.

The tacit assumption behind studies investigating the distribution of handedness among various occupations and academic disciplines is that if a particular handedness group is over represented then this implies that group must have certain augmented capacities. Thus, studies of athletes and architects which have reported excesses of left-handers have often ascribed this to a left-handed advantage in spatial skills.

Such an assumption depends on selection processes that ensure that only those with really outstanding abilities are represented in a particular group. Top athletes will, undoubtedly, have outstanding spatial skills in comparison to the rest of the population because the competition at the top levels of sport is so great. Selection pressures, although less extreme, also exist among architects who must successfully complete a seven year course before they qualify.

Researchers who have investigated sports and architecture have, however, ignored the possibility that there may be other selection pressures operating in these fields in addition to those which eliminate all but those with outstanding spatial abilities. Success in sport and in professions such as architecture depend on a number of abilities. These abilities, some of which might be correlated with handedness include concentration, personality, motivation, the ability to cope with stress, and susceptibility to particular injuries or illnesses. It has been reported, for example, that the incidence of migraine and hayfever may differ between left and right-handers (Geschwind & Behan, 1982). Such complaints could be disruptive for those competing in sports events or taking exams. Hence, any systematic difference in handedness amongst top athletes and architects may not be totally attributable to differences in spatial abilities. Laboratory studies, in contrast, have the advantage of being able to concentrate on measuring a very narrow range of abilities in isolation.

Thus studies of handedness and occupational choice are potentially flawed. On their own they cannot unequivocally demonstrate that left and right-handers differ in specific abilities; it is possible that measures of sporting prowess tap a number of factor which correlate with handedness. Such studies are of value, however, if used in conjunction with carefully controlled laboratory studies. If a clear pattern were to emerge from laboratory studies then studies of handedness and occupational could be used to investigate whether differences observed in the laboratory are of sufficient magnitude to affect real life. Such research would be of interest to occupational psychologists and sports coaches alike.

6.4 CONCLUSION

One has to be cautious in the interpretation of studies investigating left-handedness in different fields of activity. Yet those modern studies which have found abnormal proportions of left-handers in certain groups have sometimes been uncritically accepted. This thesis began with a brief description of some of the stereotypes held about left-handed people in the past but today there is still the danger that they will be replaced by others, apparently more 'scientific'. Corballis (1983) writes of "New myths for old" and this is precisely what we must guard against in our research into handedness and occupational choice.

REFERENCES

REFERENCES

Annett, J., Annett, M., Hudson, P.T.W., & Turner, A. (1979). The control of movement in the preferred and non-preferred hands. Quarterly Journal of Experimental Psychology, 31, 641-652.

Annett, M. (1970). A classification of hand preference by association analysis. British Journal of Psychology, 61, 303-321.

Annett, M. (1985). Left, right, hand and brain: The right shift theory. London: Lawrence Earlbaum Associates.

Annett, M., & Kilshaw, D. (1982). Mathematical ability and lateral asymmetry. Cortex, 18, 547-568.

Annett, M., & Kilshaw, D. (1984). Lateral preference and skill in dyslexics: Implications of the right shift theory. Journal of Child Psychology and Psychiatry, 25, 357-377.

Anonymous, (1986). From hand to mouth. Economist, 20th December, 25-28.

Armstrong, J.S., & Overton, T.S. (1977). Estimating nonresponse bias in mail surveys. Journal of Marketing Research, 14, 396-402.

Ashton, G.C. (1982). Handedness: An alternative hypothesis. Behavior Genetics, 12, 125-147.

Azemar, G., Ripoll, H., Simonet, P., & Stein, J. F. (1983). Etude neuropsychologique du comportement des gauchers enescrime. Cinesiologie, 22, 7-18.

Bakan, P. (1971). Handedness and birth order. Nature, 229, 195.

Bakan, P., Dibb, G., & Reed, P. (1973). Handedness and birth stress. Neuropsychologia, 11, 363-366.

Barret, J. (Ed.) (1981). 1981 Slazinger World of Tennis. London: McDonald Futura.

Barsley, M. (1979). Left-handed people. North Hollywood: Wilshire Book Co.

Beam, K.E. (1983). How to: Left-handed bowling. Left-hander Magazine, 8, 14-17.

Beaton, A. (1985). Left side/ right side: A review of laterality research. London: Batsford Academic & Educational.

Beaton, A.A., & Moseley, L.G. (1984). Anxiety and the measurement of handedness. British Journal of Psychology, 75, 275-278.

Bell, J. (1974). Our president, the south paw. San Francisco Examiner and Chronicle, October 20th.

Beukelar, L.J., & Kroonenberg, P.M. (1986). Changes over time in the relationship between hand preference and writing hand among left-handers. Neuropsychologia, 24, 301-303.

Blau, A. (1946). The master hand: A study of the origin and meaning of right and left sidedness and its relation to personality and language. Research Monograph No. 5. New York: American Orthopsychiatric Association, Inc.

Borod, J.C., Caron, H.S., & Koff, E. (1984). Left-handers and right-handers compared on performance and preference measures of lateral dominance. British Journal of Psychology, 75, 177-186.

Brackenbridge, C. J. (1981). Secular variation in handedness over ninety years. Neuropsychologia, 19, 459-462.

Brookes, W. H. (Ed.) (1938). The Wisden cricketers' almanac 1938. London: J. Whitaker and Sons Ltd.

Bryden, M. P. (1977). Measuring handedness with questionnaires. Neuropsychologia, 15, 617-624.

Bryden, M.P. (1982). Laterality: Functional asymmetry in the intact brain. New York: Academic Press.

Burnett, S.A., Lane, D.M., & Dratt, L.M. (1982). Spatial ability and handedness. Intelligence, 6, 57-68.

Burt, C. (1937). The backward child. New York: MacMillan.

Carter-Saltzman, L. (1979). Patterns of cognitive functioning in relation to handedness and sex related differences. In M.A. Wittig & A.C. Petersen (Eds), Sex related differences in cognitive functioning. New York: Academic Press.

Charles, B., & Wallace, J. (1985). The Bob Charles left-handed golf book. London: Angus & Robertson.

Corballis, M.C. (1983). Human laterality. New York: Academic Press.

Coren, S., & Porac, C. (1977). Fifty centuries of right-handedness: The historical record. Science, 198, 631-632.

Coren, S., & Porac, C. (1978). The validity and reliability of self-report items for the mesurement of lateral preference. British Journal of Psychology, 69, 207-211.

Coren, S., Porac, C., & Duncan, P. (1979). A behaviorally validated self-report inventory to assess four types of lateral preference. Journal of Clinical Neuropsychology, 1, 55-64.

Crooke, J. (1985). The pocket guide to tennis tactics. London: Bell & Hyman.

Crovitz, H. F., & Zener K. (1962). A group-test for assessing hand- and eye-dominance. American Journal of Psychology, 75, 271-276.

DeKay, J.T. (1984). The natural superiority of the left-hander. London: Frederick Muller Ltd.

Dunk, P. (Ed.) (1987). Rothmans' football yearbook 1987-88. London: Queen Anne Press.

Eastwood, P. (1972). Studies in games playing: Laterality in a games context. In H. T. A. Whiting (Ed.), Readings in sports psychology. London: Henry Kimpton.

Ellis, S.J., Ellis, P.J., & Marshall, E. (1988). Hand preference in a normal population. Cortex, 24, 157-163.

Fillipello, F., Berg, H.W., & Webb, A.D. (1958). A sampling method for household surveys. Food Technology (London), 12, 387-390.

Fleminger, J.J., Dalton, R., & Standage, K.F. (1977). Age as a factor in the handedness of adults. Neuropsychologia, 15, 617-624.

Flowers, K. (1975). Handedness and controlled movement. British Journal of Psychology, 66, 39-52.

Frindall, W. (Ed.) (1988). The Playfair cricket annual 1988. London: Queen Anne Press, Macdonald & Co. Ltd.

Geschwind, N., & Behan, P. (1982). Left-handedness: Association with immune disease, migraine, and developmental learning disorder. Proceedings of the National Academy of Sciences, USA, 79, 186-187.

Geschwind, N., & Galaburda, A.M. (1985a). Cerebal laterlization: Biological mechanisms, associations and pathology: I. A hypothesis and a program for research. Archives of Neurology, 42, 428-459.

Geschwind, N., & Galaburda, A.M. (1985b). Cerebal lateralization: Biological mechanisms, associations and pathology: II. A hypothesis and a program for research. Archives of Neurology, 42, 521-552.

Geschwind, N., & Galaburda, A.M. (1985c). Cerebal lateralization: Biological mechanisms, associations and pathology: III. A hypothesis and a program for research. Archives of Neurology, 42, 634-654.

Geschwind, N., & Levitsky, W. (1968). Human brain: Left-right asymmetries in temporal speech region. Science, 161, 186-187.

Gossett, P., Kay, M. & Page, J. (Eds) (1986). 1986 Womens Tennis Association media guide. Florida: Womens Tennis Association.

Grant, D.A., & Kaestner, N.F. (1955). Constant velocity tracking as a function of subjects' handedness and the rate and direction of the target course. Journal of Experimental Psychology, 49, 203-208.

Grites, T.J. (1982). On the scene: Being 'undecided' might be the best decision they could make. School Counselor, 29, 41-45.

Guiard, Y., Diaz, G. & Beaubaton, D. (1983). Left-hand advantage in right-handers for spatial constant error: Preliminary evidence in a unimanual ballistic aimed movement. Neuropsychologia, 21, 111-115.

Hardyck, C., Goldman, R., & Petrinovich, L.F. (1975). Handedness and sex, race, and age. Human Biology, 47, 369-375.

Hardyck, C., & Petrinovich, L.F. (1977). Left-handedness. Psychological Bulletin, 84, 385-405.

Harris, L.J. (1980). Left-handedness: Early theories, facts, and fancies. In J. Herron (Ed.), Neuropsychology of left-handedness. New York: Academic Press.

Harris, N. (1987). Are sport's left-handers the architects of the playing field? The Sunday Times.

Harshman, R.A., Hampson, E., & Berenbaum, S.A. (1983). Individual differences in cognitive abilities and brain organization, part 1: Sex and handedness differences in ability. Canadian Journal of Psychology, 37, 144-192.

Hatta, T., & Nakatsuka, Z. (1975). Note on hand preference in Japanese people. Perceptual and Motor Skills, 42, 530.

Heim, A.W., & Watts, K.P. (1976). Handedness and cognitive bias. Quarterly Journal of Experimental Psychology, 28, 355-360.

Hicks, R.E., & Barton, A.K. (1975). A note on left-handedness and the severity of mental retardation. Journal of Genetic Psychology, 127, 323-324.

Inglis, J., & Lawson, J.W. (1984). Handedness, sex, and intelligence. Cortex, 20, 447-451.

Jackson, J.H. (1876). Case of large tumour without optic neuritis and with left hemiplegia and imperception. Royal London Opthalmic Hospital Report, 8, 434.

Jobber, D. (1984). Response bias in mail surveys: Further evidence. Psychological Reports, 54, 891-894.

Kilshaw, D., & Annett, M. (1983). Right and left hand skill I: Effects of age, sex, and hand preference showing superior skills in left-handers. British Journal of Psychology, 74, 253-268.

Kimura, D. (1979). Neuromotor mechanisms in the evolution of human communication. In H.D. Steklis & M.J. Raleigh (Eds), Neurobiology of social communication in primates. New York: Academic Press.

Lansberry, R. (Ed.) (1986). The offical 1986 M.I.P.T.C. media guide. Raleigh: Edwards Broughton Company.

Lansberry, R. (Ed.) (1987). The offical 1987 M.I.P.T.C. media guide. Raleigh: Edwards Broughton Company.

Lansky, L.M., Feinstein, H., & Peterson, J.M. (1988). Demography of handedness in two samples of randomly selected adults. Neuropsychologia, 26, 465-477.

Lansky, L.M., & Peterson, J.M. (1985). Some comments on Shettel-Neuber and O'Reilly's "Handedness and career choice: Another look at supposed left/ right differences". Perceptual and Motor Skills, 60, 141-142.

Leiber, L., & Axelrod, S. (1981). Not all sinstrality is pathological. Cortex, 17, 259-272.

Levander, M., & Schalling, D. (1988). Hand preference in a population of Swedish college students. Cortex, 24, 149-156.

Levy, J. (1969). Possible basis for the evolution of lateral specialization of the human brain. Nature, 224, 614-615.

Levy, J. (1974). Psychobiological implications of bilateral asymmetry. In S. Diamond & J. G. Beaumont (Eds), Hemispheric function in the human brain. London: Paul Elek.

Levy, J. (1976). A review of evidence for a genetic component in handedness. Behavior Genetics, 6, 429-453.

Levy, J., & Nagylaki, T. (1972). A model for the genetics of the hand. Genetics, 72, 117-128.

Levy, J., & Reid, M. (1978). Variations in cerebral organization as a function of handedness, hand posture in writing, and sex. Journal of Experimental Psychology: General, 107, 119-144.

Leyton, E. (1986). Compulsive Killers. New York: New York University Press.

Lombroso, C. (1903). Left-handedness and left-sidedness. North American Review, 177, 440-444.

Maccoby, E.E., & Jacklin, C.N. (1974). The psychology of sex differences. Stanford: Stanford University Press.

McFarland, K. & Anderson, J. (1980). Factor stability of the Edinburgh Handedness Inventory as a function of test-retest performance, age, and sex. British Journal of Psychology, 71, 135-142.

McGee, M.G. (1977). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. Psychological Bulletin, 86, 889-918.

McLean, J.M., & Ciurczak, F.M. (1982). Bimanual dexterity in major league baseball players : a statistical study. New England Journal of Medicine, 307, 1278-1279.

McMeekan, E.R.L., & Lishman, W.A. (1975). Retest reliabilities and the interrelationship of the Annett hand preference questionnaire and the Edinburgh Handedness Inventory. British Journal of Psychology, 66, 53-59.

Mebert, C.J., & Michel, G.F. (1980). Handedness in artists. In J. Herron (Ed.), Neuropsychology of left-handedness. New York: Academic Press.

Miller, E. (1971). Handedness and the pattern of human ability. British Journal of Psychology, 62, 111-112.

Nass, R.D., & Gazzaniga, M.S. (1987) Cerebral lateralization and specialization in the human central nervous system. In F. Plum (Ed.), Handbook of physiology - The nervous system V. U.S.A.: O.U.P.

Navratilova, M., & Carillo, M. (1984). Tennis my way. Great Britain: Allen Lane.

Nice, M. M. (1915). The speech of a left-handed child. Psychological Clinic, 9, 115-117.

Oldfield, R.C. (1969). Handedness in musicians. British Journal of Psychology, 60, 91-99.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. Neuropsychologia, 9, 97-113.

Oppenheim, A.N. (1966). Questionnaire design and attitude measurement. London: Heinemann.

Peters, M. (1980). Why the preferred hand taps more quickly than the non-preferred hand: Three experiments on handedness. Canadian Journal of Psychology, 34, 62-71.

Peters, M., & Durding, B.M. (1979). Left-handers and right-handers compared on a motor task. Journal of Motor Behavior, 11, 103-111.

Peterson, J.M. (1979). Left-handedness: Differences between student artists and scientists. Perceptual and Motor Skills, 48, 961-962.

Peterson, J.M., & Lansky, L.M. (1974). Left-handedness among architects: Some facts and speculation. Perceptual and Motor Skills, 38, 547-550.

Peterson, J.M., & Lansky, L.M. (1977). Left-handedness among architects: Partial replication and some new data. Perceptual and Motor Skills, 45, 1216-1218

Porac, C., & Coren, S. (1981). Lateral preferences and human behavior. New York: Springer-Verlag.

Poulton, E.C. (1957). On prediction in skilled movements. Psychological Bulletin, 54, 467-478.

Preston, H. (Ed.) (1950). The Wisden cricketers' almanac 1950. London: Sporting Handbooks Ltd.

Preston, N. (Ed.) (1962). The Wisden cricketers' almanac 1962. London: Sporting Handbooks Ltd.

Preston, N. (Ed.) (1974). The Wisden cricketers' almanac 1974. London: Sporting Handbooks Ltd.

Provins, K.A. (1967). Motor skills, handedness, and behavior. Australian Journal of Psychology, 19, 137-150.

Provins, K.A., & Cunliffe, P. (1972). Motor performance tests of handedness and motivation. Perceptual and Motor Skills, 35, 143-150.

Quennell, P. (Ed.) (1975). Memoirs of William Hickey. London: Routledge & Paul Kegan.

Raczkowski, D., Kalat, J.W., & Nebes, R. (1974). Reliability and validity of some handedness questionnaire items. Neuropsychologia, 12, 43-47.

Ross, G. (Ed.) (1968). The Playfair cricket annual 1968. London: The Dickens Press.

Satz, P. (1972). Pathalogical left-handedness: An explanatory model. Cortex, 8, 121-135.

Satz, P., Achenbach, K., & Fennell, E. (1967). Correlations between assessed manual laterality and predicted speech laterality in a normal population. Neuropsychologia, 5, 295-310.

Saunders, B., Wilson. J.R. & Vandenberg, S.G. (1982). Handedness and spatial ability. Cortex, 18, 79-90.

Saunders, V. (1986). Strengthen the left side for better results. Golf World, August, 94-96.

Schlichting, C.L. (1982). Handedness in navy and student populations. Perceptual and Motor Skills, 55, 699-702.

Segalowitz, S.J., & Bryden, M.P. (1983). Individual differences in hemispheric representation of language. In S.J. Segalowitz (Ed.), Language functions and brain organization. New York: Academic Press.

Shettel-Neuber, J., & O'Reilly, J. (1983). Handedness and career choice: Another look at supposed left/ right differences. Perceptual and Motor Skills, 57, 391-397.

Silva, D.A., & Satz, P. (1979). Pathalogical left-handedness: Evaluation of a model. Brain and Language, 7, 8-16.

Silverberg, R., Obler, L.K., & Gordon, H.W. (1979). Handedness in Israel. Neuropsychologia, 17, 83-92.

Sperry, R.W. (1974). Lateral specialization in the surgically separated hemispheres. In F.O. Schmidt and F.G. Worden (Eds), The neurosciences: Third study program. Cambridge, Mass.: MIT Press.

Spiegler, B.J., & Yeni-Komshian, G.H. (1983). Incidence of left-handed writing in a college population with reference to family patterns of hand preference. Neuropsychologia, 6, 651-659.

Springer, S.P., & Deutsch, G. (1981). Left brain, right brain. New York: W.H. Freeman and Company.

Steingruber, H.J. (1975). Handedness as a function of test complexity. Perceptual and motor skills, 40, 263-266.

Stanton, F. (1939). Notes on the validity of mail questionnaire returns. Journal of Applied Psychology, 23, 95-104.

Stekel, W. (1911). Die sprache des traumes. Eine darstellung der smybolik und deutung des traumes in ihren beziehengen zur kranken und gesunden seele fur azarte und psychologen. Wiesbaden: J.F. Bergmann.

Tan, L.E. (1983). Handedness in two generations. Perceptual and Motor Skills, 56, 867-874.

Teng, E.L., Lee, P.-H., Yang, K.-S., & Chan, P.C. (1976). Handedness in a Chinese population: Biological, social, and pathological factors. Science, 193, 1148-1150.

Verhaegen, P., & Ntumba, A. (1964). A note on the frequency of left-handedness in African children. Journal of Educational Psychology, 55, 89-90.

VonBonin, G. (1962). Anatomical asymmetries of the cerebral hemispheres. In V.B. Mountcastle (Ed.), Interhemispheric relations and cerebral dominance. Baltimore: John Hopkins Press.

Wada, J.A., Clark, R., & Hamm, A. (1975). Cerebral hemispheric asymmetry in humans. Archives of Neurology, 32, 239-246.

Walker, S.F. (1980). Lateralization of functions in the vertebrate brain: A review. British Journal of Psychology, 71, 239-367.

White, K., & Ashton, R. (1976). Handedness assessment inventory. Neuropsychologia, 14, 261-264.

Wile, I.S. (1934). Handedness: Right and left. Boston: Lothrop, Lee, & Shepard.

Witelson, S.F. (1980). Neuroanatomical asymmetry in left-handers: A review and implications for functional asymmetry. In J. Herron (Ed.), Neuropsychology of left-handedness. New York: Academic Press.

Woo, T.L., & Pearson, K. (1927). Dextrality and sinistrality. Biometrica, 19, 192-198.

Woodcock, J. (Ed.) (1986). The Wisden cricketers' almanac 1986. London: John Wisden and Co.

Wright, G. (Ed.) (1987). The Wisden cricketers' almanac 1987. London: John Wisden and Co.

Young, J.Z. (1962) Why do we have two brains? In V.B. Mountcastle (Ed.), Interhemispheric relations and cerebral dominance. Baltimore: Johns Hopkins Press.