Chapter 7: Hypernotes

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I find the biography of Darwin by Bowlby (1990a) to be especially satisfactory, perhaps because it seems to be so particularly interested in the psychology of Darwin the man as an individual and unusual human being, in contrast to much modern historical analysis and biography which attempts only to embed Darwin in a social world of which he was indeed a part, but sometimes only a rather distant part.

Nicknames and pet names were clearly very much in order in the Darwin family since later we are told, "Our little boy is a noble fat little fellow & my father has christened him Sir Tunberry Clumsy" (Burkhardt & Smith, 1986 p.279).

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Regrettably Darwin actually doesn't confirm that the result of the repeated experiment was the same as the first time, but that is the natural interpretation (Burkhardt & Smith, 1988 pp 415).

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Often Darwin had to be goaded into print by some other worker writing on a related topic, as indeed he even had to in 1859 with *The origin of species* itself, when Alfred Russel Wallace came up with precisely the same idea, albeit one that was far less thoroughly worked out and documented than the details Darwin would provide. Darwin would not have been comfortable in the modern world of 'publish or perish', of research accountability, and the need to produce papers regularly and frequently to demonstrate one's ability. But then he had a large private income, mostly from the proceeds of the Wedgewood pottery, and had no need for such worldly concerns.

The paper by Taine (1877), which makes no mention of handedness, was published in the April 1877 issue of the journal, and so Darwin must have rushed to prepare his paper and get it into print in the next issue of the quarterly journal, in July 1877 (Darwin, 1877). It has been commented that the "Biographical Sketch" might seem "rather cool, clinical, and possibly even exploitative", whereas a reading of the diaries themselves gives a very different impression of a Darwin who is "gentle, loving, and playful" (Keegan & Gruber, 1985 p.129). It is possible that Taine met Darwin, since he was an Anglophile, who] visited London and wrote a book about the England (Paxman, 1999 pp.190,213,229).

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There is an intriguing footnote in the transcription of Charles Darwin's diaries which refers to some strange, unsophisticated handwriting which is attributed to Emma Darwin having injured her thumb and "writing with her left hand following some injury to the thumb of her right hand" (Burkhardt & Smith, 1988 p.433). This seems incompatible with Darwin's clear statement that she was left-handed. Either the editor had forgotten that she was left-handed, and meant merely that she was writing with her non-dominant hand, or Emma was indeed naturally left-handed but had nonetheless been taught to write with her right hand, as was sometimes the case in the nineteenth century. Emma's daughter, Helen Titchfield does describe her mother's handwriting as being "like herself, firm, calm, and transparently clear. She did not write quickly, but with an even steady pace..." (Litchfield, 1915 vol I, p.62). That the writing was slow may mean it was written by a left-hander forced to use her right hand. Correspondence from Dr Sarah Wilmot, Associate Editor of the Darwin Correspondence Project, 11/4/2000, confirms that Emma was merely presumed to be right-handed, rather than it being confirmed.

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For scientific use, questionnaires typically have many more questions (up to about sixty), covering a range of different topics, and they are answered on a three or more usually a five-point scale (from 'Always right', through 'Usually right', 'Either', 'Usually left' to 'Always left'). In practice the results obtained are essentially similar to those at Waltham Forest. A minor problem at Waltham Forest was that some children ticked both right *and* left. I have counted those who ticked left only in computing the results, and have changed the instructions slightly in the present questionnaire. In the past I have not been convinced that lengthy questionnaires contribute much more than do brief questionnaires (McManus, 1979 Chapter 2), particularly for assessing direction of handedness, which is assessed almost perfectly by writing hand, as long as there is no history of having been forced to change hands. Longer handedness questionnaires do though have the advantage of attaining a distribution of scores which is more bimodal normal than J-shaped (McManus, 1979; McManus, 1996). I am not convinced that questionnaires properly differentiate different 'types' of handedness, and certainly not the large numbers of sub-types that have been proposed by Annett (1970). Even the differentiation of 'skilled' and 'unskilled, or 'fine' and 'coarse' movements proposed by several workers (Healey, Liederman, & Geschwind, 1986; Liederman & Healey, 1986; Steenhuis & Bryden, 1989) is, I suspect, merely due to the individual J-shaped distributions on each item effectively resulting in binary measures which give rise in factor analysis to difficulty factors (Maxwell, 1977,Bernstein & Teng, 1989). I think the sole exception to such criticisms is the finding that writing and throwing are separate, for which there is good external validation (Peters & Servos, 1989).

I am extremely grateful to the Vestry House Museum for permission here, and elsewhere, to quote from their exhibition, '*A sinister way of life? The story of left-handedness'*, 13th August - 16th November 1996, and to Nigel Sadler, then Keeper of the Museum, for permission to quote from his unpublished notes and files (Sadler, 1996). The questionnaire was distributed to children aged 6 to 15 in a number of schools in Waltham Forest. The graphs are based on 1238 males and 1654 females. There was no difference in incidence between the older and the younger participants, and to a good approximation the distribution is typical of that obtained with adult subjects.

Of the 2892 children in total, 285 (9.9%) were left-handed, scoring 5 or more on the scale. The numbers scoring 0 through to 10 were 1800, 515, 161, 80, 51, 36, 27, 36, 41, 62, 83. Of the 1238 males, 143 (11.6%) were left-handed, compared with 142 (8.6%) of the 1654 females. The difference is statistically significant (Chi-square = 7.01, 1 df, p=.008).

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Handedness researchers typically distinguish *direction* of hand preference, whether the right or the left hand is used preferentially, from *degree* of preference, the extent to which the dominant hand is preferred to the non-dominant hand (McManus, 1996). The definition of 'strong' or 'weak' preference is more arbitrary, and in the present account I have chosen 0 or 10 as a description of 'strong' as it makes the account easier.

The idea that people can be ambidextrous is an old one, and I am grateful to Michael Peters for pointing out to me one of the oldest known references to ambidexterity, in Homer's *Iliad*, where, during the fight with Achilles: "the warrior Asteropaeus hurled with both spears at once, since he was ambidextrous [περιδεξιός]" (Murray & Wyatt, 1999 21:162-3). As Michael says, since Asteropaeus lost then clearly ambidexterity is not all it is cracked up to be. A somewhat later reference from Greece, this time early Classical, is the poet Archilochos who was said to have been ambidextrous[1]. Probably four or five hundred years older, perhaps contemporary with Homer, is the description in the Bible of a group of Benjamites who may be seen as ambidextrous: "They carried bows and could sling stones or shoot arrows with the left hand or the right." *(1 Chronicles 12: 2).*

The tapping task shown was developed by Tapley and Bryden (Tapley & Bryden, 1985); examples of the test in use can be found in Van Horn (1992a) and in McManus *et al* (1993a). It is probably one of the best tasks for showing which hand is more skilled at the very fine repetitive movements which are typical of those involved in writing. I have yet to see anyone who approaches being described as ambidextrous on this task. My views on ambidexterity are rather like those of Gilbert and Sullivan in *Iolanthe* on politics:

> "...Nature always does contrive
> That every boy and every gal,
> That's born into the world alive,
> Is either a little Liberal,
> Or else a little Conservative!"

So it is that for hand skill, everyone leans to some extent either a little to the left or a little to the right.

A formal meta-analysis of the incidence of left-handedness in one hundred different studies can be found in the unpublished paper of Seddon and McManus (1991a), a copy of which is available as a PDF file at www.righthandlefthand.com. A summary of the results can be seen in figure 1 of McManus (1991b).

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[1] Although the translation of the fragments by Davenport (1964a) does not contain any reference to his ambidexterity, it does have a charming version of a fragment that was referred to by Plutarch:

> "Fortune is like a wife:
> Fire in her right hand,
> Water in her left".

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The unpublished meta-analysis I carried out with Dr Beatrice Seddon (Seddon & McManus, 1991a – see above; see also McManus, 1991b figure 3) – found the sex difference to be constant across many societies and historical periods. It is perhaps the most important constant factor which has to be explained in the origin of handedness. Although when conditions are more common in males (e.g. haemophilia or colour blindness) it is due to the gene responsible being carried on the X chromosome, the 5:4 ratio is incompatible with any simple hypothesis such as that of Jones and Martin (2000a), who predicted a ratio of 1.61 males left-handers for every female left-hander. It might however reflect a modifier gene on the X chromosome (McManus and Bryden, 1992b).

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Although in an early study of ours we were unable to find any evidence for left-handedness being more common in male homosexuals (Marchant-Haycox, McManus, & Wilson, 1991), a meta-analysis of twenty such studies suggests there is an overall effect (Lalumière, Blanchard, & Zucker, 2000b), our study failing to find an effect because it was too small. In male homosexuals the overall odds ratio for left-handedness was 1.34, meaning that if 10% of male heterosexuals are left-handed then about 13% of male homosexuals will be left-handed. The effect was stronger and in the same direction in female homosexuals, with an odds ratio of 1.91, i.e. if 10% of female heterosexuals are left-handed then about 17.5% of female homosexuals will be left-handed. In interpreting the result it is worth noting that the effect size is smaller in more recent studies, raising the possibility of some methodological artefact or bias in the earlier studies, a phenomenon that has also been found in other meta-analysis (Van Horn & McManus, 1992).

Lalumière *et al* (2000b) have reported five separate studies in which transsexuals have a higher incidence of left-handedness.

In the 1980s Norman Geschwind proposed a very influential and still highly cited theory in which testosterone levels during early fetal life influenced very many aspects of development (Geschwind & Galaburda, 1987). The theory is difficult to pin down precisely (McManus & Bryden, 1991). At least one key highly counter-intuitive prediction which initiated the theory, that left-handers suffer more from allergic disorders (Geschwind & Behan, 1982), seems to have been falsified by a mass of data (Bryden, McManus, & Bulman-Fleming, 1994). That does not however mean that fetal testosterone levels cannot be involved in handedness in relation to homosexuality, gender identity and other related conditions. Although there is some suggestion that cerebral lateralisation in adults is related to testosterone levels (Moffat & Hampson, 1996; Moffat & Hampson, 2000) or to the use of drugs which might have altered testosterone levels *in utero* (Smith & Hines, 1998), what is properly required are studies in which fetal testosterone levels have been measured directly, as at amniocentesis. Such studies are rare, and tend not to find the expected results (Grimshaw, Bryden, & Finegan, 1995). For other aspects of sex differences and lateralisation see Kimura (1999a).

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For the record I should say that I score zero on the questionnaire given earlier. However I clearly have other lacunae of left-handedness, and can, for instance, play badminton equally badly with either my right or my left hand. Such inconsistencies of handedness are far from unusual. To cite two examples amongst sporting personalities, the right-handed tennis player, Ivan Lendl, now plays golf left-handed. Likewise the cricketer David Gower, renowned in his time for his elegant left-handed batting style, is actually right-handed on a standard handedness questionnaire (Harris, 1985).

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For the original research on inconsistent left-handers, see Peters (1987), Peters and Servos (1989) and Peters (1990b). Estimates of the incidence of inconsistent right-handedness are reported by McManus *et al* (1999b).

Havelock Ellis, who was born in 1859, himself attributed the difference between writing and throwing to an innate left-handedness, saying, “Although I am right-handed except in the single action of throwing a stone or ball, I am inclined to think that congenitally I may be left-handed, and that my right-handedness is the artificial result of training, the spontaneous tendency only showing itself in the untrained act of throwing.” (p.85). He also attributed his bad hand writing to the same factor: “I was, I believe, naturally left-handed; I have never been able to throw a ball with my right hand, and though I have never written with my left hand, my right-handed use of the pen was always the despair of my teachers” (p.84). The hand-writing was so bad that his headmaster, “would ask me if I wrote with the kitchen poker, and sometimes remark that I seemed to keep a tame spider to race over the page” (p.55) (Ellis, 1967).

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The terms used to define handedness have been confusing since at least the beginning of this century (Jones, 1909). My least favourite term in use is 'non-right hander', a term particularly in vogue in the 1970s and 1980s, which seems to have been popular because it seemed to make fewer judgements about what was and was not a left-hander. In practice it seems to solve nothing but merely provides the user with a veneer of pseudo-scientific precision. Its major problem is that almost any meaning can be attached to it, and there are several studies in which anyone who does not score zero on a questionnaire such as that in figure 2, is described as a 'non-right-hander'. The serious practical problem is that it gives the incompetent or unscrupulous researcher a choice of a wealth of measures, some or other of which may attain statistical significance due to chance alone. 'Non-right-handed' typically also confounds direction and degree of lateralisation.

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In the study of Porac and Coren (Porac & Coren, 1981 pp.32-49), 13% of right handers and 63% of left handers were left footed. For a recent critical review of the measurement of footedness see Gabbard and Hart (2000c).

The earliest reference to footedness seems to be in Thucydides' *History of the Peloponnesian War* (Warner, 1972 III, 22) in which a group of besieged Plataean soldiers attempted to escape from their city:

> "...they waited for a stormy night with wind and rain and no moon, and then they slipped out of the city... They were lightly armed and only wore shoes on the left foot, to stop them slipping in the mud".

Based on the analysis of Carey *et al* (2000d) of 216 top international players in the France '98 competition, 80% of whom used the right foot most of the time, a figure similar to that in the population as a whole (Porac & Coren, 1981).

It is a mathematical necessity that if 10% of people are left-handed and 20% are left-footed, then at least 10% of right-handers must be left-footed even if handedness and footedness are associated as strongly as possible. If handedness and footedness showed no association at all then 20% of right-handers would be left-footed. In practice the proportion of left-footed right-handers is closer to 10% than 20%, showing that handedness and footedness are correlated quite substantially.

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It may be that the sudden near universal popularity for mobile phones may make ear preference of rather greater interest for academic research. One recent piece of work on a slightly different task suggests that sales telephone operators who use the left ear differ in personality from those who prefer to use the right ear (Jackson, Furnham, & Miller, 2001).

Hugo Williams, in a piece in the TLS (Williams, 1994) has a nice description of the use of the hands in telephoning:

> "With my right hand out of action, I notice that no one dials a telephone number with their left hand. They pick up the phone with their right, swap over to dial, then swap back again to speak, the way the French swap their fork over after they have cut up their meat. People don't trust their left hand to per-form such an intimate task as dialling, any more than they trust their left hand to perform adequately in bed, unless it be for some mild perversion of habitude. If one hand ever had cause to be jealous of the other, it is surely the underprivileged left of the pushy, over-confident right."

An intriguing aspect of eye dominance is that very many people do not even realise that it exists. Indeed when carrying out the sighting task they often realise for the first time that in pointing at a distant object only one eye can be aligned with the pointing finger, so that the other eye has a different view of the scene, which means that there are two images of fingers, one of which is ignored by the brain. In the same way, eye dominance also seems to have been noticed relatively late in human history, the first proper description of it being due to Giovanni Battista della Porta (1593; see Wade (1998a for a translation), although Wade make a strong suggestion that Aristotle was aware of the phenomenon.

In sport there are some suggestions that cross-laterals, those with the dominant hand and the dominant eye on opposite sides, are less good at tasks such as putting in golf (Steinberg, Frehlich, & Tennant, 1995), target shooting with a rifle (Lucas, 1946, Sheeran, 1985) or archery (Christina et al., 1981), although there seems to be no effect on free-throw shooting in basketball (Shick, 1977).

From the point of view of trying to understand why people are lateralised, an intriguing question is why there is eye dominance at all. The two eyes are generally symmetric, as is

much of the brain to which they are connected, so why should one eye be preferred to the other? Although it is often suggested that people might prefer to look with the eye which sees better, the one with higher visual acuity, in fact there seems to be no association at all between having higher acuity in one eye and it being dominant (Porac & Coren, 1976). One possible explanation of eye dominance is that it has nothing at all to do with seeing as such, with visual perception, and is instead related to the way that we move our eyes. Moving the two eyes exactly together is quite a difficult task, and in most people one eye tends to move first to look at an object and the other then follows[2]. In a recent piece of research my colleagues and I found, somewhat to our surprise, that eye dominance relates rather more closely to the hand one throws with than the hand one writes with (McManus et al., 1999b). Why might that be? Although we don't normally think of it in such a way, there is little real difference in principle between throwing a ball with one's hand and moving one's eyes. In the case of eye movements, the ball being thrown is the eye-ball and it is being thrown within the eye socket, but otherwise the task is similar. It is then less surprising that there should be an association between the dominant eye and the hand used for throwing in general.

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About 56% of people chew more on the right side, and they are more likely to be right handed (Hoogmartens & Caubergh, 1987).

Although I know of no formal evidence on it, hand clasping seems to be pretty well constant in individuals across the life-span.

☞WWW☜ 7:17

Like hand-clasping, arm-folding seems to be completely constant across the life-span of individuals. A nice example can be seen in photographs of Picasso across his life-span, in many of which he likes to stand staring straight at the camera with his arms folded, always in the same way with the left wrist on top.

Picasso also provides a good example of another laterality, leg-crossing. Most people sit in a chair with one leg crossed over the other, and for most people this tends to be with right leg over the left, at least at first until the legs begin to ache when people will cross the other way. Leg-crossing seems to be constant through life, and there are pictures of Picasso taken in 1939, 1948, 1952, 1954 and 1957, in each of which he sits with the left leg crossed over the right. Leg-crossing is statistically related to handedness (Reiss, 1994) and should not be confused with the 'palthi' style in India of sitting cross-legged on the ground, where the palms of the feet point upwards (Chaurasia, 1976).

The study of ear wiggling also found that men are more able to wiggle their ears than women (Code, 1995).

[2] An interesting result of this is that the egocentre, that feeling of quite where is the 'I' which is us, and which seems to be somewhere an inch or two behind and between our two eyes is slightly more towards the side of the dominant eye – the right in most people (Barbeito, 1981). Although traditionally it has been presumed that both eyes are moved by a single control system in the brain, that no longer seems to be the case, each eye being controlled separately (Zhou & King, 1998).

☞WWW☜ 7:18

Although the direction of handedness seems to be fixed by about two years of age, the degree of handedness continues to increase throughout childhood (McManus et al., 1988). There is also some evidence that degree of handedness continues to increase even into late adulthood. Porac(1993b) found that elderly people become particularly strongly handed on tasks such as picking up a full glass of water, an explanation of which is that both hands are beginning to become weak or to tremor. In a young adult either hand has a sufficient reserve of skill in each hand to be able to cope with some tremor, whereas in the elderly that is not the case, and since the non-dominant hand has less reserve, so there is a shift towards using the dominant hand.

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For examples of fetuses sucking their thumb see http://pregnancy.about.com/health/ pregnancy/library/ultrasounds/blusindex.htm where there are images from 11 weeks of gestation onwards.

Of 274 fetuses in the study of Hepper *et al* (1991c), 22 (8%) sucked the left thumb, with the proportion being the same in the fetuses aged 15-21 weeks as in more mature fetuses. There was little change in the side of thumb sucking when the same fetus was observed three weeks later, suggesting the measure is reliable within an individual fetus.

Hepper has recently, in an as yet unpublished study (Hepper, Personal communication, 2001) , followed up the right and left thumb sucking children at the age of five and found a high correlation between side of the thumb sucking and eventual handedness, confirming that fetal thumb-sucking is indeed a valid measure of handedness.

In the later study of Hepper e*t al* (1998b) there were 63 fetuses which showed more movements on one side or the other. A further 9 fetuses showed equal movement on the left and the right.

☞WWW☜ 7:20

For a forceful modern statement of the case that handedness is due to a social rather than genetic factors see Provins (1997); however strongly stated though, I am afraid that I do not find the argument convincing.

The figures in the table are based on 63,250 children of two right-handers, 8,933 children of one right and one left-hander, 417 children of two left-handers (McManus & Bryden, 1992b). The paper also gives details of how there are subtle inter-relationships between handedness, the sex of the child and, in RxL parents, the sex of the parent who is left-handed. There is a tendency for left-handed mothers to be a little more likely to have left-handed children than left-handed fathers, although the possibility has been raised that this may only reflect uncertain paternity in the case of some fathers.

In the scientific literature it is more common to use odds ratios rather than the risk ratios I have cited in the text. However when the proportion of an event is relatively low, as it is in left-handedness, then the odds ratios and risk ratios are fairly similar numerically. Risk ratios

are also much easier for people to understand, and I have therefore used them in the book. For the family data the risk ratio for a left-handed child when one parent is right and one is left-handed is 2.05 times, being 19.5% divided by 9.5%. The odds ratio is slightly higher at 2.307, and takes into account the probabilities of having a right-handed child. Specifically the odds of having a left-hander are calculated as:

$$\frac{P(Left \mid RxL) \times P(Right \mid RxR)}{P(Right \mid RxL) \times P(Left \mid RxR)} = \frac{.195 \times .905}{.095 \times .805} = 2.307$$

Likewise the risk ratio for two left-handed parents compared with two right-handed parents is 2.75 times, whereas the odds ratio is 3.365 times.

The data showing that half of all left-handers have no left-hander in the family were collected as part of the National Childhood Encephalopathy study (Madge et al., 1993, McManus, 1995). In part the lack of left-handed relatives reflects the relatively small number of children in modern families which make it very difficult to see the ways that even strongly genetic characteristics are inherited. If Darwin had only two children instead of ten then even with a one in five chance of each child being left-handed he could well have ended up with only right-handed children. Nevertheless, Ogle (1871) asked 57 left-handers about their relatives and even in the late nineteenth century only 27 (47%) knew of a left-handed relative (first cousin or closer); even so, Ogle concluded that left-handedness was “an hereditary affection” (see Harris, 2000 p.150).

☞WWW☜ 7:21

Aristotle (Armstrong, 1935 1194.b.32) continues, “If in general and at most times left retains the familiar character of left, and right of right, the distinction is natural one”. Strictly, Aristotle is saying that handedness is congenital, rather than inherited, but in this case that can really only mean it was in some sense inherited.

Sir Charles Bell (Bell, 1834 p.142)says, “That the preference for the right hand is not the result of education, we may learn from those who by constitution have a superiority on the left. They find a difficulty in accommodating themselves to the modes of society: and although not only the precepts of parents, but every thing they see and handle, conduce to make them choose the right hand, yet, will they rather use the left ...". The same argument was later put forward by Broca (see Harris, 1991 p.9) and by Hertz (1960 p.91).

Although I do not think Amar Klar (1996a) was the first person to put forward the data showing that grandparents have an influence on the handedness of children, Klar certainly made the point clearly and forcibly. Klar's data are not entirely convincing though as he has to rely on data from Rife (1940) as a control group, which is less than satisfactory. I therefore present here previously unpublished data from the two surveys of Cambridge undergraduates described by McManus (1985a), and called ICM1(propositi) and ICM2 (propositi). In each case the analysis looks at all individuals in the family (i.e. propositi and siblings), and is restricted to families in which both parents are right-handed.

	ICM2-propositi		ICM1-propositi	
	Grandparents both right-handed	One or more left-handed grandparents	Grandparents both right-handed	One or more left-handed grandparents
Right-handed	688	119	2166	156
Left-handed	80	22	285	43
Per cent left-handed (Total)	**10.42%** (768)	**15.60%** (141)	**11.63%** (2451)	**21.61%** (199)

In both studies the proportion of left-handed offspring is higher if there is a grandparent who is left-handed, than if all grandparents are right-handed (ICM1: Chi-square = 16.90, 1 df, p<.001), ICM2: Chi-square = 3.216, 1 df, p=.073), the combined result being highly significant (chi-square = 20.12, 2 df, p<<.001).

☞WWW☜ 7:22

Although I have presented the argument in its strong form, whereby *all* left-handedness is pathological, the argument also applies in a weaker form in which a minority of people have a genetic or other tendency to be left-handed – unilateral cerebral trauma which is as likely to occur in the right as the left hemisphere will still result in an increased rate of left-handedness. The argument was first put forward by Satz (1972); see also Satz, Baymur, & Van der Vlugt, 1979, Silva & Satz, 1979, and Soper & Satz, 1984.

☞WWW☜ 7:23

Before finding out about the National Child Development Study, I spent several fruitless months trying to test the idea by obtaining data from the maternity hospital where as a medical student I had done my obstetrics. Despite the hospital having a sophisticated computer system which would have allowed babies to be followed up at the age of five years, when their handedness would be known, permission was refused on what was called 'ethical grounds'. It was argued that even by writing from the maternity hospital and asking if a child was left-handed, I might be implying, if they were, that the child's obstetric care had been sub-standard, and clearly that would have to be unethical. Although ethical committees in medical research have helped prevent much of the scandalous maltreatment of patients in scientific research that were reported so vividly by Pappworth (8478 /d) in his book *Human guinea pigs*, they also seem to provide an opportunity for people with a host of other less acceptable motivations to prevent research which, for what ever reason, they would prefer not to be done. The vagaries of ethical committees are well seen in the fact that the same research project can be accepted by many ethical committees as satisfactory whereas they are rejected by other committees as unethical (Alberti, 2000). Something has to be wrong.

The ESRC's Research Data Archive at the University of Essex is now the UK Data Archive (www.data-archive.ac.uk).

Although the total sample in the NCDS was over 16,000, information on handedness and/or both complications were only available for the still very substantial sample of over 11,000 individuals. For full details see McManus (1981 Chapter 3).

The NCDS data also showed something else which I have subsequently undermine very many other theories which suggest that handedness might somehow be environmental in whatever form. Epidemiologists have found in general that there are few stressors or noxious events which do not occur more frequently in individuals from the lower social classes (IV and V in the British Registrar-General's system) than in the higher social classes (I and II). And yet in the NCDS it is very clear that there is simply no association between left-handedness and social class (McManus, 1981), producing serious problems for many possible environmental hypotheses about the origin of left-handedness.

Despite my general scepticism that pathological left-handedness can explain all or even a large number of cases of left-handedness, it nevertheless is still possible that pathological factors account for a small minority of cases of left-handedness. The elegant analysis of Bishop (1984) suggests that perhaps one in twenty left-handers (*i.e.* about one in two hundred of the population as a whole) may be left-handed as a result of pathological factors.

☞WWW☜ 7:24

Given what I was saying earlier about the difficulty of deciding whether children at this age are right or left handed, it might be that I simply wrong in saying one is right handed and the other left-handed. Franziska is very consistent in her use of the left hand, transferring spoons and other things from the right to the left hand. Anna however is somewhat more variable. Of course by the time the book is published we should know for certain...

There has always been fascination, even at the lay level, in the difference of handedness of identical twin pairs. As a recent example, consider the question in *The Guardian*'s *Notes and Queries* section, where someone asked, “I have identical four-year old twin girls, but one seems to be left- while the other is right-handed. Can anyone explain this?”. As always in such columns, willingness to reply and knowledge bear little correlation, and the first reply was breathtaking for its ignorance and its ability dogmatically to impart potentially devastating information at a distance: “One will have her heart on the right-hand side of her chest (known as a 'cardiodexter'). All other asymmetries are likewise reversed.” (Brimicombe, 2000). One doesn't get much more wrong than that. Fortunately John Galloway wrote in a few weeks later with an accurate answer.

In our review of handedness in twins (McManus & Bryden, 1992b) we found that of 2,900 pairs of identical twins, 75.3% were R-R, 3.0% were L-L, and 21.7% were R-L. For 2589 pairs of non-identical twins, 75.4% were R-R, 2.0% were L-L, and 22.6% were R-L. Although the proportions of identical twins may look very similar to those expected by chance (a binomial distribution), this is not actually the case for identical twins, there only being .901 of the R-L cases expected as a result of chance. For non-identical twins the proportions are much more similar to chance expectation, .993 of expected R-L pairs. It should be noted that these figures are calculated separately for each study and then averaged, rather than being calculated on data aggregated across all studies (McManus & Bryden, 1992b). A recent meta-analysis of 28 studies of handedness in twins, with a total of 9,969 pairs, has confirmed that identical twin

pairs are more likely to be concordant (L-L or R-R) than are non-identical twin pairs (Sicotte, Woods, & Mazziotta, 1999). The same meta-analysis also found a small but significant increased rate of left-handedness in twins compared with singletons, although the effect was identical in size in identical and non-identical twins.

A recent study has looked at a large number of twins and found some evidence that in discordant monozygotic twins the left-handed twin tends to be the first-born twin (James & Orlebeke, 2002). The mechanism for such a finding is still not clear, although it does not seem to be due to the first-born twin also being the heavier.

☞WWW☜ 7:26

My account of the genetics of handedness is written entirely from a personal point of view and I have, for obvious reasons, concentrated on my own genetic model (McManus, 1979, McManus, 1984, McManus, 1985a). This is the point to say that there is one major alternative, the model of Marian Annett, which has been described in several places. The present model is Annett's third, the two earlier models (Annett, 1964, Annett, 1978) both failing for various reasons. The current model, in which the RS gene is additive, was first described by Annett and Kilshaw (1983). For recent reviews see the papers by Annett (1995, 1996b, 1998c), and her recent book (Annett, 2002). This is not the place to go into my criticisms of the model, but an account of the various differences between us can be found in several places (McManus, 1985b, McManus, 1991b, McManus & Bryden, 1992b, McManus, Shergill, & Bryden, 1993a), and will also appear in a review in *Cortex* by me of the 2002 book.

☞WWW☜ 7:27

Essentially the calculations for twins are those of a binomial in which the probability of being left-handed is 0, 0.25 and 0.5 for the DD, DC and CC genotypes. As a result 0, 3/8 or 1/2 of the pairs are discordant. However *DD*, *DC*, and *CC* are not equally common in the population. If 10% of people are left-handed then 20% of the gene-pool must consist of *C* alleles and 80% of D alleles. Therefore at 64% of people are *DD*, 32% are *DC* and 4% are *CC*. Therefore amongst monozygotic twins, 83.0% of pairs will both be right-handed, 3.0% will both be left-handed, and 14.0% will be discordant, one being right-handed and the other left-handed.

On a similar basis, if 10% of the population is left-handed then left-handedness will occur in 7.8% of the children of two right-handed parents, 18.9% of the children of one right and one left-handed parent, and 30.0% of the children of two left-handed parents.

☞WWW☜ 7:28

There are several people who have thought seriously about the issue of finding the genes responsible for handedness, and a recent review has emphasised the low power of many of the approaches (Van Agtmael, Forrest, & Williamson, 2001). Amar Klar (1996a) and Tim Crow (1998d) have also looked in detail for the gene, although my personal feeling is that they are limited by either the wrong genetic model in Klar's case, or searching primarily on the X chromosome in Crow's case. Part of the problem in searching for a gene, at least if additive models such as my own and Annett's are correct, is the relatively low power of conventional family studies (Van Agtmael, Forrest, & Williamson, 2001). Over the years I have tried with

colleagues to get research funding to look for the gene for left-handedness, and invariably the grant has been turned down because expert referees who are geneticists say, *ex cathedra*, that it is obvious that handedness must be cultural rather than genetic. Such are the problems of peer review by peers who are not experts in the field.

☞WWW☜ 7:30

A similar phenomenon to that found in autism (McManus et al., 1992,Cornish & McManus, 1996) has also been found in fragile-X syndrome, in which the symptoms often show a similarity to those found in autism (Cornish, Pigram, & Shaw, 1997).

Studies of apraxia (see chapter 8), in which patients lose the ability to make skilled movements with both hands after damage to one half of the brain, typically the left, usually assume that whatever is responsible for praxis, that is skilled motor actions, is also responsible for handedness. That assumption is however becoming less likely with the identification of several right-handed patients in whom there is damage to the *right* hemisphere and yet they show a loss of skill with the right hand (Rapscak, Gonzalez-Rothi, & Heilman, 1987, Marchetti & Della Sala, 1997, Raymer et al., 1999). The implication is that something to do with hand *preference* is in the left hemisphere (or, at least, is controlling the right side of the body), whereas something to do specifically with *skilled* hand movements is in the right hemisphere. Since these patients describe themselves as right-handed and use the right hand preferentially for skilled activities, it seems that preference has to be prior to skill. Detailed analyses of brain activity during movements of the right hand, the left hand, and both hands in a bimanual task, suggest that the supplementary motor cortex is specifically involved in the bimanual tasks, and is in the left hemisphere in right-handers (Jäncke et al., 2000). The few anomalous cases described above may well be individuals in whom the supplementary motor cortex is in the right hemisphere, impairing certain skilled actions, but the mechanism for preference still allows the right hand to be dominant; the prediction would be that they are the DC or CC genotype.

☞WWW☜ 7:31

This is the case of Pieroccini (1903), reported by Hécaen and de Ajuriaguerra (1964b) who do not give any further reference. I also am sure that about twenty years ago I also saw a similar phenomenon reported in children with arm defects due to thalidomide but am unable any longer to find the reference.

Peters, M. (E-mail communication, 2000). I am grateful to Michael and Anne Peters for telling me this anecdote and allowing me to repeat it here. A not dissimilar case is that described by Brugger *et al* (2000e) in which a woman born without forelimbs nevertheless ate using a ring attached to her right upper arm, steered an electric wheelchair with her right upper arm, and in general could be described as 'right-handed'.

If handedness is primarily a preference rather than a skill difference then other stories can also be told about its possible neural origins. For instance, one of the great ignored areas of the brain is the cerebellum, the 'little brain', found at the back of the head below the cerebral hemispheres and presumed in most introductory textbooks not to do much of any great intellectual sophistication. That may be, but in recent years it has begun to be rehabilitated as it has become apparent that the cerebellum has as many neurones as the cerebral cortex, and

that damage to it can affect a range of high level functions. So certain were researchers at one time that the cerebellum did little of interest that they did not even bother to include it in the field of view looked at by PET scanners. Occasionally, usually due to luck more than anything else, the cerebellum was included in the images and to the horror of many researchers it was found to be active in complex cognitive tasks, a finding that has since been replicated in better machines which could visualise the cerebellum properly. Why should this matter for handedness? Mainly because there are strong suggestions that one of the areas which is abnormal in autism is the cerebellum, and that abnormalities of the cerebellum are associated with atypical handedness (McManus & Cornish, 1997).

☞WWW☜ 7:32

The asymmetries are in the nigrostriatal system, of which the substantia nigra is in the brain stem, but the corpus striatum is not. The direction of rotation is towards the side opposite to that with the higher dopamine level (Glick, 1983). An intriguing finding is that although Glick assumed originally that there was a 50:50 mixture of right and left turning animals, a review of over 600 rats who had taken part in a number of studies found that 55% turned to the right, a significant difference from 50% (p.18).

☞WWW☜ 7:33

In the studies (Schaeffer, 1928; see Ludwig (1932 pp.327-330.), 57% of people turned to the right and 43% to the left, the size of the circles being surprisingly small, a diameter of about 18 metres when walking or swimming, and about 50 metres when driving. Ludwig speculates that one side is somewhat stronger than the other, and that the difference is accentuated as the person becomes tired, when walking or swimming (but not driving), accounting for the ever tightening spiral. Schaeffer (1931) also carried out studies of protozoa and found that in the majority of cases they spiralled to the right.Bracha et al., 1987. Slight turning tendencies can also be recognised in subjects wearing a backpack attached to a set of detectors, and suggest that slight noises to one side, or carrying a heavy object on one side can cause veering (Millar, 1999). A similar tendency of right handers to turn to the right can be seen in the stepping test used by Previc and Saucedo (Previc & Saucedo, 1992).

Although it is possible that turning tendencies might underlie handedness, there is the potential problem that when reaching out with the right hand the turn is anti-clockwise, whereas the spontaneous direction for turning for right-handers is clockwise. The difficulty is not however insurmountable, and may reflect differences in the shoulder girdle and the pelvic girdle in their role in balance and movement.

☞WWW☜ 7:34

Lauren Harris, in an imaginative and scholarly reconstruction of Darwin's possible thinking, concludes that Darwin would probably have followed Ogle and Ferrier in being sympathetic to Broca's finding (Harris, 2000 pp.157-160).

References

Alberti, K. G. M. M. 2000, "Multicentre research ethics committees: has the cure been worse than the disease?", *British Medical Journal*, **320**, 1157-1158.

Annett, M. 1964, "A model of the inheritance of handedness and cerebral dominance", *Nature*, **204**, 59-60.

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

Annett, M. 1978, *A single gene explanation of right and left handedness and brainedness,* Coventry: Lanchester Polytechnic.

Annett, M. 1995, "The right shift theory of a genetic balanced polymorphism for cerebral dominance and cognitive processing", *Cahiers de Psychologie Cognitive/ Current Psychology of Cognition*, **14**, 427-480.

Annett, M. 1996b, "In defence of the right shift theory", *Perceptual and Motor Skills*, **82**, 115-137.

Annett, M. 1998c, "Handedness and cerebral dominance:the right shift theory", *Journal of Neuropsychiatry*, **10**, 459-469.

Annett, M. 2002, *Handedness and brain asymmetry: The right shift theory,* Hove: Psychology Press.

Annett, M. & Kilshaw, D. 1983, "Right and left-hand skill: II. Estimating the parameters of the distribution of L-R differences in males and females", *British Journal of Psychology*, **74**, 269-283.

Armstrong, G. C. 1935, *Aristotle, vol XVIII: Magna Moralia,* Cambridge, MA: Harvard University Press.

Barbeito, R. 1981, "Sighting dominance: an explanation based on the processing of visual direction in tests of sighting dominance", *Vision Research*, **21**, 855-860.

Bell, C. 1834, *The hand: its mechanism and vital endowments as evincing design,* London: John Murray.

Bernstein, I. H. & Teng, G. 1989, "Factoring items and factoring scales are different: spurious evidence for multidimensionality due to item categorization", *Psychological Bulletin*, **105**, 467-477.

Bishop, D. V. M. 1984, "Using non-preferred hand skill to investigate pathological left-handedness in an unselected population", *Developmental Medicine and Child Neurology*, **26**, 214-226.

Bowlby, J. 1990a, *Charles Darwin: a new biography,* London: Hutchinson.

Bracha, H. S., Seitz, D. J., Otemaa, J., & Glick, S. D. 1987, "Rotational movement (circling) in normal humans: sex difference and relationship to hand, foot and eye preference", *Brain Research*, **411**, 231-235.

Brimicombe, M. 2000, "Notes and Queries: Mirror-image twins", *The Guardian*, **April 20th, 2nd section**, 16-16.

Brugger, P., Kollias, S. S., Muri, R. M., Crelier, G., & Hepp-Reymond, M.-C. 2000e, "Beyond re-membering: Phantom sensations of congenitally absent limbs", *Proceedings of the National Academy of Sciences of the USA*, **97**, 6167-6172.

Bryden, M. P., McManus, I. C., & Bulman-Fleming, M. B. 1994, "Evaluating the empirical support for the Geschwind-Behan-Galaburda model of cerebral lateralization", *Brain and Cognition*, **26**, 103-167.

Burkhardt, F. & Smith, S. 1986, *The correspondence of Charles Darwin vol 2 1837-1843,* Cambridge: Cambridge University Press.

Burkhardt, F. & Smith, S. 1988, *The correspondence of Charles Darwin vol 4 1847-1850,* Cambridge: Cambridge University Press.

Carey, D. P., Smith, G., Smith, D. T., Shepherd, J. W., Skriver, J., Ord, L., and Rutland, A. 2000, "Two-footedness in world soccer: A preliminary analysis of France '98", *Journal of Sport Sciences*, in press.

Chaurasia, B. D. 1976, "La position 'palthi' et ses relations avec les croisements des mains et des bras", *Anthropologie*, **80**, 325-334.

Christina, R. W., Feltz, D. L., Hatfield, B. D., & Daniels, F. S. 1981, "Demographic and physical characteristics of shooters," p. 89 in *Psychology of motor behavior and sport*, G. Roberts & D. Landers, eds., Champaign, IL: Human Kinetics.

Code, C. 1995, "Asymmetries in ear movements and eyebrow raising in men and women and right- and left-handers", *Perceptual and Motor Skills*, **80**, 1147-1154.

Cornish, K. M. & McManus, I. C. 1996, "Hand preference and hand skill in children with autism", *Journal of Autism and Developmental Disorders*, **26**, 597-609.

Cornish, K. M., Pigram, J., & Shaw, K. 1997, "Do anomalies of handedness exist in children with Fragile-X syndrome?", *Laterality*, **2**, 91-101.

Crow, T. J. 1998d, "Sexual selection, timing and the descent of man: A theory of the genetic origins of language", *Cahiers de Psychologie Cognitive/ Current Psychology of Cognition*, **17**, 1079-1114.

Darwin, C. 1877, "A biographical sketch of an infant", *Mind*, **2**, 285-294.

Davenport, G. 1964a, *Carmina Archilochi: The fragments of Archilochos,* Berkeley, CA: University of Califronia Press.

Ellis, H. 1967, *My Life (first published 1940),* London: Neville Spearman.

Gabbard, C. & Hart, S. 2000c, "Examining the notion of foot dominance," pp. 249-265 in *Side bias: A neuropsychological perspective*, M. K. Mandal, M. B. Bulman-Fleming, & G. Tiwari, eds., Dordrecht: Kluwer.

Geschwind, N. & Behan, P. 1982, "Left-handedness: association with immune disease, migraine and developmental learning disorder", *Proceedings of the National Academy of Sciences of the USA*, **79**, 5097-5100.

Geschwind, N. & Galaburda, A. M. 1987, *Cerebral Lateralization: Biological mechanisms, associations, and pathology,* Cambridge, Massachusetts: MIT Press.

Glick, S. D. 1983, "Cerebral lateralization in the rat and tentative extrapolations to man," pp. 7-26 in *Hemisyndromes: psychobiology, neurology, psychology,* M. S. Myslobodsky, ed., New York: Academic Press.

Grimshaw, G. M., Bryden, M. P., & Finegan, J. K. 1995, "Relations between prenatal testosterone and cerebral lateralization in children", *Neuropsychology*, **9**, 68-79.

Harris, L. J. 1991, "Cerebral control for speech in right-handers and left-handers: an analysis of the views of Paul Broca, his contemporaries, and his successors", *Brain and Language*, **40**, 1-50.

Harris, L. J. 2000, "On the evolution of handedness: A speculative analysis of Darwin's views and a review of early studies of handedness in "the nearest allies of man"", *Brain and Language*, **73**, 132-188.

Harris, N. 1985, "David Gower found to be right-handed", *Sunday Times*.

Healey, J. M., Liederman, J., & Geschwind, N. 1986, "Handedness is not a unidimensional trait", *Cortex*, **22**, 33-53.

Hepper, P. G., McCartney, G. R., & Shannon, E. A. 1998b, "Lateralized behaviour in first-trimester human foetuses", *Neuropsychologia*, **36**, 531-534.

Hepper, P. G., Shahidullah, S., & White, R. 1991c, "Handedness in the human fetus", *Neuropsychologia*, **29**, 1107-1111.

Hertz, R. 1960, *Death and the right hand,* Aberdeen: Cohen and West.

Hécaen, H. & de Ajuriaguerra, J. 1964b, *Left-handedness: manual superiority and cerebral dominance,* New York: Grune and Stratton.

Hoogmartens, M. J. & Caubergh, M. A. 1987, "Chewing side preference in man correlated with handedness, footedness, eyedness and earedness", *Electromyography and Clinical Neurophysiology*, **27**, 293-300.

Jackson, C. J., Furnham, A., and Miller, T. 2001, "Moderating effect of ear preference on personality in the prediction of sales performance", *Laterality*, in press.

James, W. H. & Orlebeke, J. F. 2002, "Determinants of handedness in twins", *Laterality*, **in press**.

Jäncke, L., Peters, M., Himmelbach, M., Nösselt, T., Shah, J., & Steinmetz, H. 2000, "fMRI study of bimanual coordination", *Neuropsychologia*, **38**, 164-174.

Jones, E. 1909, "An attempt to define the terms used in connection with right-handedness", *Psychological Bulletin*, **6**, 130-132.

Jones, G. V. & Martin, M. 2000a, "A note on Corballis (1997) and the genetics and evolution of handedness: Developing a unified distributional model from the sex-chromosomes gene hypothesis", *Psychological Review*, **107**, 213-218.

Keegan, R. T. & Gruber, H. E. 1985, "Charles Darwin's unpublished 'Diary of an infant': an early phase in his psychological work," pp. 127-145 in *Contributions of a history of developmental psychology: International Wm. T Preyer Symposium*, G. Eckhardt & et al, eds., Berlin: Mouton.

Kimura, D. 1999a, *Sex and cognition,* Cambridge, MA: MIT Press.

Klar, A. J. S. 1996a, "A Single Locus, *RGHT*, Species Preference for Hand Utilization in Humans", *Cold Spring Harbor Symposia on Quantitative Biology*, **61** , 59-65.

Lalumière, M. L., Blanchard, R., & Zucker, K. J. 2000b, "Sexual orientation and handedness in men and women: a meta-analysis", *Psychological Bulletin*, **126**, 575-592.

Liederman, J. & Healey, J. M. 1986, "Independent dimensions of hand preference: reliability of the factor structure and the handedness inventory", *Archives of Clinical Neuropsychology*, **1**, 371-386.

Litchfield, H. E. 1915, *Emma Darwin: A century of family letters, 1792-1896,* London: John Murray.

Lucas, P. H. 1946, "The importance of the dominant eye", *Optometric Weekly*, **37**, 1132-1132.

Ludwig, W. 1932, *Das Rechts-Links-Problem im Tierreich und beim Menschen,* Berlin: Verlag Julius Springer.

Madge, N., Diamond, J., Miller, D., Ross, E., McManus, I. C., Wadsworth, J., & Yule, W. 1993, *The National Childhood Encephalopathy Study: A ten year follow-up. A report on the behavioural and educational outcomes after serious, acute, neurological illness in early childhood,* London: Developmental Medicine and Child Neurology, Supplement No.68, vol 35, No.7, MacKeith Press.

Marchant-Haycox, S. E., McManus, I. C., & Wilson, G. D. 1991, "Left-handedness, homosexuality, HIV infection and AIDS", *Cortex*, **27**, 49-56.

Marchetti, C. & Della Sala, S. 1997, "On crossed apraxia. Description of a right-handed apraxic patient with right supplementary motor area damage", *Cortex*, **33**, 341-354.

Maxwell, A. E. 1977, *Multivariate analysis in behavioural research,* London: Chapman and Hall.

McManus, I. C. 1979, *Determinants of laterality in man,* University of Cambridge: Unpublished PhD thesis.

McManus, I. C. 1981, "Handedness and birth stress", *Psychological Medicine*, **11**, 485-496.

McManus, I. C. 1984, "The genetics of handedness in relation to language disorder," pp. 125-138 in *Advances in Neurology, vol 42: Progress in Aphasiology*, F. C. Rose, ed., New York: Raven Press.

McManus, I. C. 1985a, *Handedness, language dominance and aphasia: a genetic model. Psychological Medicine, Monograph Supplement No.8,*

McManus, I. C. 1985b, "Right- and left-hand skill: failure of the right shift model", *British Journal of Psychology*, **76**, 1-16.

McManus, I. C. 1991b, "The inheritance of left-handedness," pp. 251-281 in *Biological asymmetry and handedness (Ciba foundation symposium 162)*, G. R. Bock & J. Marsh, eds., Chichester: Wiley.

McManus, I. C. 1995, "Familial sinistrality: the utility of calculating exact genotype probabilities for individuals", *Cortex*, **31**, 3-24.

McManus, I. C. 1996, "Handedness," pp. 367-376 in *The Blackwell Dictionary of Neuropsychology*, J. G. Beaumont, P. M. Kenealy, & M. J. C. Rogers, eds., Oxford: Blackwell.

McManus, I. C. & Bryden, M. P. 1991, "Geschwind's theory of cerebral lateralization: Developing a formal causal model", *Psychological Bulletin*, **110**, 237-253.

McManus, I. C. & Bryden, M. P. 1992b, "The genetics of handedness, cerebral dominance and lateralization," pp. 115-144 in *Handbook of Neuropsychology, Volume 6, Section 10: Child neuropsychology (Part 1)* , I. Rapin & S. J. Segalowitz, eds., Amsterdam: Elsevier.

McManus, I. C. & Cornish, K. M. 1997, "Fractionating handedness in mental retardation: What is the role of the cerebellum?", *Laterality*, **2**, 81-90.

McManus, I. C., Murray, B., Doyle, K., & Baron-Cohen, S. 1992, "Handedness in childhood autism shows a dissociation of skill and preference", *Cortex*, **28**, 373-381.

McManus, I. C., Porac, C., Bryden, M. P., & Boucher, R. 1999b, "Eye dominance, writing hand and throwing hand", *Laterality*, **4**, 173-192.

McManus, I. C., Shergill, S., & Bryden, M. P. 1993a, "Annett's theory that individuals heterozygous for the right shift gene are intellectually advantaged: Theoretical and empirical problems", *British Journal of Psychology*, **84**, 517-537.

McManus, I. C., Sik, G., Cole, D. R., Mellon, A. F., Wong, J., & Kloss, J. 1988, "The development of handedness in children", *British Journal of Developmental Psychology*, **6**, 257-273.

Millar, S. 1999, "Veering re-visited: noise and posture cues in walking without sight", *Perception*, **28**, 765-780.

Moffat, S. D. & Hampson, E. 1996, "Salivary testosterone levels in left- and right-handed adults", *Neuropsychologia*, **34**, 225-233.

Moffat, S. D. & Hampson, E. 2000, "Salivary testosterone concentrations in left-handers: an association with cerebral language lateralization?", *Neuropsychology*, **14**, 71-81.

Murray, A. T. & Wyatt, W. F. 1999, *Homer: Iliad Books 13-24,* Cambridge, MA: Harvard University Press.

Ogle, W. 1871, "On dextral pre-eminence", *Medical-Chirurgical Transactions (Transactions of the Royal Medical and Chirurgical Society of London)*, **54**, 279-301.

Paxman, J. 1999, *The English: A portrait of a people,* London: Penguin Books.

Peters, M. 1987, "A nontrivial motor performance difference between right-handers and left-handers: attention as intervening variable in the expression of handedness", *Canadian Journal of Psychology*, **41**, 91-99.

Peters, M. 1990b, "Subclassification of non-pathological left-handers poses problems for theories of handedness", *Neuropsychologia*, **28**, 279-289.

Peters, M. & Servos, P. 1989, "Performance of subgroups of left-handers and right-handers", *Canadian Journal of Psychology*, **43**, 341-358.

Porac, C. 1993b, "Are age trends in adult hand preference best explained by developmental shifts or generational differences?", *Canadian Journal of Experimental Psychology*, **47**, 697-713.

Porac, C. & Coren, S. 1976, "The dominant eye", *Psychological Bulletin*, **83**, 880-897.

Porac, C. & Coren, S. 1981, *Lateral preferences and human behaviour,* New York: Springer Verlag.

Porta, G. B. d. 1593, *De refractione, optices parte: liber novem,* Naples: Horatii Salvania.

Previc, F. H. & Saucedo, J. C. 1992, "The relationship between turning behavior and motoric dominance in humans", *Perceptual and Motor Skills*, **75**, 935-944.

Provins, K. A. 1997, "Handedness and speech: A critical reappraisal of the role of genetic and environmental factors in the cerebral lateralization of function", *Psychological Review*, **104**, 554-571.

Rapscak, S. Z., Gonzalez-Rothi, L. J., & Heilman, K. M. 1987, "Apraxia in a patient with atypical cerebral dominance", *Brain and Cognition*, **6**, 450-463.

Raymer, A. M., Merians, A. S., Adair, J. C., Schwartz, R. L., Williamson, D. J. G., Rothi, L. J. G., Poizner, H., & Heilman, K. M. 1999, "Crossed apraxia: Implications for handedness", *Cortex*, **35**, 183-199.

Reiss, M. 1994, "Leg-crossing: Incidence and inheritance", *Neuropsychologia*, **32**, 747-750.

Rife, D. C. 1940, "Handedness, with special reference to twins", *Genetics*, **25**, 178-186.

Sadler, N. 1996, *A sinister way of life: Research into left-handedness in schools in Waltham Forest.,* Vestry House Mueseum, Waltham Forest: Unpublished manuscript.

Satz, P. 1972, "Pathological left-handedness: An explanatory model", *Cortex*, **8**, 121-135.

Satz, P., Baymur, L., & Van der Vlugt, H. 1979, "Pathological left-handedness: cross-cultural tests of a model", *Neuropsychologia*, **17**, 77-81.

Schaeffer, A. A. 1928, "Spiral movement in man", *Journal of Morphology*, **45**, 293-398.

Schaeffer, A. A. 1931, "On molecular organisation in Ameban protoplasm", *Science*, **74**, 47-51.

Seddon, B. & McManus, I. C. The incidence of left-handedness: a meta-analysis. 1991.

Sheeran, T. J. 1985, "Effect of pure and crossed dextrality on marksmanship skill", *Perceptual and Motor Skills*, **61**, 1171-1174.

Shick, J. 1977, "Relationship between hand-eye dominance and lateral errors in basketball free-throw shooting", *Perceptual and Motor Skills*, **44**, 549-550.

Sicotte, N. L., Woods, R. P., & Mazziotta, J. C. 1999, "Handedness in Twins: A Meta-analysis", *Laterality*, **4**, 265-286.

Silva, D. A. & Satz, P. 1979, "Pathological left-handedness: Evaluation of a model", *Brain and Language*, **7**, 8-16.

Smith, L. L. & Hines, M. Language lateralization and handedness in women prenatally exposed to diethylstilbestrol(DES). 1998.

Soper, H. V. & Satz, P. 1984, "Pathological left-handedness and ambiguous handedness: a new explanatory model", *Neuropsychologia*, **22**, 511-515.

Steenhuis, R. E. & Bryden, M. P. 1989, "Different dimensions of hand preference that relate to skilled and unskilled activities", *Cortex*, **25**, 289-304.

Steinberg, G. M., Frehlich, S. G., & Tennant, L. K. 1995, "Dextrality and eye position in putting performance", *Percept.Mot.Skills*, **80**, 635-640.

Taine, H. A. 1877, "Taine on the acquisition of language by children", *Mind*, **2**, 252-259.

Tapley, S. M. & Bryden, M. P. 1985, "A group test for the assessment of performance between the hands", *Neuropsychologia*, **23**, 215-221.

Van Agtmael, T., Forrest, S. M., & Williamson, R. 2001, "Genes for left-handedness: How to search for the needle in the haystack?", *Laterality*, **6**, 149-164.

Van Horn, J. D. 1992a, *Brain structural abnormality and laterality in schizophrenia,* University College London: Unpublished PhD thesis.

Van Horn, J. D. & McManus, I. C. 1992, "Ventricular enlargement in schizophrenia: a meta-analysis of studies of the ventricle-brain ratio", *British Journal of Psychiatry*, **160**, 687-697.

Wade, N. J. 1998a, "Early studies of eye dominances", *Laterality*, **3**, 97-108.

Warner, R. t. 1972, *Thucydides: History of the Peloponnesian War,* Revised edn, Harmondsworth: Penguin.

Williams, H. 1994, "Freelance", *Times Literary Supplement* 14-14.

Zhou, W. & King, W. M. 1998, "Premotor commands encode monocular eye movements", *Nature*, **393**, 692-695.