CHAPTER 10: WHAT IS THE ADVANTAGE OF LEFT-HANDEDNESS?

"His left hand is under my head, and his
right hand doth embrace me"

Song of Solomon, ii, 6.

"Birth, and copulation, and death
That's all the facts when you come to brass
tacks"

T.S. Eliot, *Sweeney Agonistes*

10:1 Introduction

In previous chapters I have argued that handedness is determined by a simple genetic system with two alleles at a single locus. There are, I hypothesise, just two phenotypes, right and left-handedness. Given the supposed frequencies of the two phenotypes (about 9.5% and 90.5%), and of the underlying alleles (D = 0.81; C = 0.19) then by necessity we are dealing with a genetically controlled polymorphism. What little evidence there is would suggest that these handedness proportions may well have been constant for fairly long periods of time. Certainly from Ramaley (1913) to the present day, the data may be fitted by an identical genetic model. On a larger time-scale, Coren and Porac (1977) have pointed out that the incidence of left-hand usage in art has remained constant at 7.4% over a five millenia period. Dennis (1958) found a similar proportion of left-hand usage in two Egyptian tombs dated at 2500 BC and 1500 BC. Harrower (1928) and Thomas (1929) discuss similar, although less than reliable, evidence. Prior to the Ancient Egyptian period there is less good evidence of the predominance of right-handedness. Uhrbrock (1973) has reviewed the evidence of Palaeolithic art and concluded that there was an excess of right-handers, although the evidence is far from adequate. Abler (1976) has examined a relatively small number of Palaeolithic skulls and concluded that they show a similar asymmetry to that found by Geschwind and Levitsky (1968) in the planum temporale of modern brains.

Taken together the above evidence suggests that there has been a balanced polymorphism for handedness for at least five millenia, and possibly for five hundred or more millenia.

Genetic theorists (see e.g. Cavalli-Sforza and Bodmer, 1971) have carefully examined the necessary conditions for the maintenance of balanced polymorphisms. "For a polymorphism to be stable there must be at least two opposing forces acting upon it, and they must be balanced in their effects upon it" (Cavalli-Sforza and Bodmer, p 123). Polymorphisms <u>may</u> be maintained by mutation; this however requires far higher mutation rates than are conventionally accepted and this hypothesis will not be considered further in the present case (although local 'hot-spots' might maintain the occasional polymorphism). The usual explanation of polymorphisms is therefore in terms of heterozygote advantage, and this adequately explains such polymorphisms as sickle-cell anaemia in which although the homozygote, SS, dies at an early age, the heterozygote SA is actually <u>more</u> resistant to malaria than the 'normal' individual, AA; in an area for which there is endemic malaria and hence a selective pressure for SA, the S allele will be maintained in the gene-pool. However there are almost no other human polymorphisms for which the maintaining forces are understood. What does however seem to be clear is that the balancing forces need bear no obvious relation to the main phenotypes. Thus it has been suggested that schizophrenia is maintained by an increased fecundity of the grand-parents; and phenylketonuria by an increased IQ of the heterozygote (the homozygote of course having a very low IQ). In at least one genetically inherited asymmetry in man, Kartagener's triad (see Chapter 7), there is a major reproductive disadvantage due to sperm immotility, an anomaly which seems to bear little obvious relation to the side of the heart. It is thus quite possible that the relative advantages of the two forms of handedness may bear no relation at all to brain function.

In trying to explain the balanced polymorphism of handedness we must therefore seek at least two selective forces which together maintain the D and C alleles. This search would be simpler if we could identify the genotypes of individuals; this we cannot do as yet, and we must therefore search for selective advantages for phenotypes. To put it crudely, there must be an advantage to being left-handed and an advantage to being right-handed. To simply have both phenotypes (or particularly, to have all three genotypes)of equal fitness would ultimately result, by genetic drift, in the loss of either allele from the gene-pool (chance determining which of the two it should be).

For alleles to have an increased fitness they must ultimately affect reproductive capacity: that is, the persons concerned must eventually contribute a greater proportion of their genes to the gene-pool than the prior probabilities would suggest. (For a more detailed discussion of quite what is meant by fitness see the Appendix to this chapter).

The literature on handedness is replete with suggestions that right-handers are of greater IQ than left-handers. The issue is however vexed, with several studies failing to find effects (see e.g. Hardyck _et al_ (1976) for a review). I do not wish to go into this "advantage" here, although it may well be that increased intellectual abilities cause the increased fitness of the DD genotype (although such an hypothesis is difficult to reconcile with, for instance, the total lack of social class differences in sinistrality (see Table 3.7 above), for social class has a _prima facie_ correlation with IQ).

Of far greater interest is the potential advantage which must be shown by left-handers (or probably by the DC genotype), which will maintain the C allele . (Note that if the fitness of both DD and CC are greater than that of DC then the polymorphism is _unstable_, and will ultimately result in fixation of either the D or the C allele). Thus the DC genotype should be the fittest of the three genotypes; since the majority of left-handers will be DC rather than CC (see Chapter 7), then there must be an advantage of left-handers over right for some characteristics. These fitnesses need only be very small; Cavalli-Sforza and Bodmer point out that fitnesses of the order of 10^{-5} (i.e. the heterozygote is only 0.001% better at reproducing than the homozygote) will result in balanced polymorphisms after several thousand generations.

Several investigators (e.g. Roux, 1977; MacCluer, 1978; Mayo *et al*, 1978) have pointed out the extreme difficulty, with such potentially small fitness differentials, of actually demonstrating differences in reproductive fitness. Mayo *et al* (1978) have also pointed out that differences in *mean* number of progeny may be of less evolutionary consequence than control of the *variance* of progeny number.

In the rest of this chapter I wish to look directly at data concerning the reproductive fitness of right- and left-handers; the causes of any differences will be left until differences have been demonstrated.

The stimulus to the present study was the close scrutiny of a paper by Hicks and Kinsbourne (1976). In a somewhat confused [redacted] attempt to discriminate between genetic and environmental hypotheses for the origin of left-handedness, they examined the handedness of a large number of their students, dividing the students (mean age 20.18 years) into those who had two biological parents, those with only one biological parent (due to death, etc.) and those with one or more step-parents. Handedness correlated better with biological parents handedness than with step-parental handedness. The result is however of little worth since:

a. the ANOVA used was invalidated by the gross bimodality of the Oldfield handedness questionnaire (see Figure 2.3).

b. the students had, on average, lived with their step-parents for only 7.24 years, i.e. they were on average 12.94 years old at the time of the re-marriage; one may presume that adult handedness is fixed by the age of 12, and probably many years before that.

Of far greater interest in the Hicks and Kinsbourne study are the incidences of sinistrality in the parents of various groups. The table below summarises the data:

Parental type	Mothers				Fathers			
	Right	Left	N	% Left	Right	Left	N	% Left
Two biological parents	998	103	1101	9.35%	998	103	1101	9.35%
One biological parent and no step-parent	11	5	16	31.25%	23	4	27	14.81%

Parental type	Mothers				Fathers			
	Right	Left	N	% Left	Right	Left	N	% Left
Step-parent and a biological parent:-								
a. Biological parent	16	11	27	40.74%	56	25	81	30.80%
b. Step-parent	15	12	27	44.44%	60	21	81	25.92%

There is an increased incidence of sinistrality in both mothers and fathers who do not come from a family with two biological parents (Mothers, $X^2 = 62.21$, 1 df, $p < 0.001$; Fathers, $X^2 = 45.11$, $p < 0.001$).

Whilst such data is indirect evidence, I would like to suggest, on the strength of this rather surprising result, that there might be an improved reproductive efficiency in left-handers. This could, perhaps, manifest in many ways: for instance, in terms of a tendency to have more sexual partners, and hence to divorce and re-marry more often; to have more children, and perhaps less miscarriages; (but possibly more therapeutic abortions); to have children at an earlier age, to reach puberty earlier, or to have more diseases associated with sexual activity. The rest of this chapter will critically assess some of the above notions in view of the evidence from data in several surveys. To my knowledge there is almost no relevant data in the literature; although there is a limited suggestion that left-handers tend to be illegitimate rather more often than might be expected (Pringle 1961).

The little that is known about hand usage in sexual behaviour (Oldfield, 1970) seems to further our knowledge little beyond that of the Song of Songs.

10:2 The number of children in left-handed families

If there is a reproductive advantage in being left-handed then we might well expect to find that left-handers come from larger families than do right-handers; alternatively left-handed matings (i.e. in which one or both parents are left-handed) might have more children than non-left-handed matings. Data to test both of these hypotheses can be obtained from Surveys I and II, and the first hypothesis can be tested using the NCDS data.

Table 10.1 shows the results of two-way analyses of variance of the data of surveys I and II. For the NCDS data it is necessary, in view of the heterogeneity of the sample, to include social class as a controlling variable. Also, since the relevant dependent variable is the household size when the propositus is seven years odl, it is necessary to include propositus parity as an independent variable since many families may not be complete by that stage. Finally, in view of the different incidences of left-handedness in the two sexes in the NCDS study, sex of propositus is included as a further independent variable. Table 10.2 shows the results of this fourway analysis of variance.

Table 10.3 shows a summary of the relevant analyses of Tables 10.1 and 10.2; the significance levels of the main effects, and the size and variation of the fitted constants for the analysis of variance equation (Multiple Classification Analysis - see Nie et al, 1975). From this latter table it is clear that in Surveys I and II there is no significant tendency for left-handers to come from larger families. The NCDS data does not show a significant effect; however if a one-tailed test is used (since the direction of the effect was specified in advance) then left-handed propositi have a tendency ($p = 0.078$) to come from larger families (an average of 0.05 children greater). Whether this latter effect is truly significant is a moot point. Figure 10.1 shows the NCDS data plotted as a function of social class, parity, and sex. Not surprisingly there is a massive parity effect, and also a social class effect, and a parity and social class interaction, none of which are unexpected.

Examination of the data of Table 10.3 in terms of parental handedness shows a rather different result. In five of the six studies families with at least one left-handed parent have a significantly greater family size, there being a simple unweighted mean effect size of 0.37

children more in left-handed matings, the combined one-tailed probability being 0.0016.

In summary, the NCDS provides limited support for the possibility of left-handed propositi coming from larger families. The data from surveys I and II provides good support for the possibility that left-handed parents have slightly larger families than do non-right-handed parents. Regrettably this latter hypothesis cannot be further tested on the large NCDS data.

10:3 Parental age and handedness

A reproductive advantage may be manifested in several ways other than a simple excess of progeny; if maternal age is relatively less then the generation time will be reduced, and hence relatively more progeny will be produced per unit of time.

Table 10.4 summarises data from the NCDS and survey II on maternal age at the birth of the child. Once more analysis of the NCDS development variable (maternal age) must be in terms of the independent variables social class, parity, and sex of propositus (Table 10.5). There are massive effects of social class and parity, and possibly a small interaction between them, none of which are unexpected. The effect of handedness is not quite significant (two-tailed probability = 0.116), but is in the expected direction, and thus the one-tailed probability = 0.058. Figure 10.2 shows a graph of the NCDS data as a function of class, parity and sex.

Table 10.6 shows the analyses of variance for Survey II, the mother's age at the birth of the first four children being analysed separately (note that in this analysis, each mother may re-appear in each of the four tables, whereas in the NCDS analysis each mother can only appear once, at a single parity).

Table 10.4 summarises the data of Tables 10.5 and 10.6. It is clear that there is probably no effect of parental type, although the data is only from survey II, and hence relatively small. For both survey II,and II combined with NCDS, there is a highly significant effect of propositus handedness on maternal age; on average the mother of a left-handed propositus will have a child some 0.309 years earlier than the mother of a right-handed properitus (weighted mean of effect sizes).

In summary, there seems to be moderately good evidence that left-handed propositi come from families in which the mother is relatively younger.

Table 10.7 examines, for the NCDS only, the paternal age as a function of properitus handedness. However since normally maternal and paternal age are highly correlated (r = 0.873 in the NCDS data) is is not surprising that in a simple four-way analysis of variance there is a similar effect as to maternal age. The more interesting question is whether when the relative contribution of the maternal-paternal correlation is partialled out, there is still a paternal age effect. Table 10.7 shows an analysis of variance with maternal age as a co-variate. Now there is not a hint of a paternal age effect; and indeed the class effect is much-reduced and appears to be quadratic in form, a surprising effect. The parity effect remains similar although much reduced in size.

10:4 Interval between marriage and first birth and between successive births

A reproductive advantage might also manifest as a decreased interval either between marriage and the first birth, or between successive births. The NCDS data allows one to examine this question as a function of the propositus handedness (but regrettably, not as a function of parental handedness). Once more, it is the large sample size of the NCDS which justifies this rather oblique approach to the problem.

Table 10.8 shows an analysis of variance in which the interval between marriage and the first birth is the dependent variable, and social class, parity of the present birth, sex of propositus and handedness of propositus are the independent variables. There is a large class effect. There is also a parity effect, which may probably be interpreted partly as a maternal cohort effect, and partly as an interaction with social class. There is however not a hint of a main effect due to parity, and the fitted constant is actually in the wrong direction. The highly significant H x C x P interaction is probably an artefact of non-normality coupled with a large sample size.

Table 10.9 shows an analysis of variance in which the interval between the previous birth and the present birth is the dependent variable, and class, parity, handedness and sex are the independent variables. Once more there is a highly significant effect of social class, although this seems to be quadratic in form; there is also a parity effect which has a quadratic component (and may well be interpretable in part as a maternal cohort effect). The handedness effect is rather near significance, and, although in the expected direction, is very small.

In summary, neither of these studies show any convincing link with handedness.

10:5 The incidence of miscarriages/abortions/ectopics by handedness

This question may be examined in survey II, and in the NCDS data. Table 10.10 shows a four-way analysis of variance in which the dependent variable is the number of abortions, miscarriages or ectopics suffered by the mother (a square-root transformation has been used to stabilise variance) and the independent variables are social class, propositus handedness, parity and sex. The parity effect is highly significant (as would be expected). There are no class or sex effects. Handedness shows no significant main effect. The highly significant four-way interaction is almost certainly an artefact of non-normality and may be ignored.

In survey II the mothers were asked to report how many miscarriages they had had. Mothers of right handed propositi reported a mean of 0.458 miscarriages (N = 417, SD = 0.957), whilst mothers of left-handed propositi reported a mean of 0.5020 miscarriages (N = 81, SD = 1.127), an effect in the opposite direction to that predicted, and for which the probability is non-significant.

The data of survey II (but not the NCDS) may be re-analysed in terms of maternal handedness. Right-handed mothers had a mean of 0.504 miscarriages (N = 428, SD = 1.050) whilst left-handed mothers had a mean of 0.428 miscarriages (N = 49, SD = 0.677). The difference, although in the expected direction, is not significant. 28.03% of the right-handed mothers, and 32.65% of the left-handed mothers had had no miscarriages, a non-significant difference.

In summary there is no evidence for a difference in history of miscarriages as a function of handedness.

10:6 Onset of puberty as a function of handedness

A reproductive advantage could also manifest itself as an earlier onset of puberty, and hence an increased (or at least earlier) reproductive span. This may be investigated in several ways in the NCDS data. In all cases it is necessary to analyse by social class, parity (or strictly maternal cohort in some cases) and propositus handedness.

Table 10.11 shows the age of the mother's menarche. There are massive class effects (probably a function of nutritional status) and parity effects (probably a cohort effect, the age of menarche having fallen successively this century). There is not a hint of a handedness effect.

Table 10.12 to 10.15 shows the assessment of the developmental stage of the secondary sexual characteristics of boys and girls as a function of their own handedness. Note that since the survey was carried out at the age of 11, most children are not far into puberty, if at all. Consequently, the distributions are rather skewed, and hence non-normalities may produce spurious interactions in the analysis of variance.

Table 10.12 shows the stage of development of the boys' genitalia. There is a highly significant effect of handedness, although it is in the opposite direction to that predicted. I suspect that this result is spurious.

Table 10.13 shows the stage of development of the boys' pubic hair. None of the main effects are significant although there may be a significant trend in the class data. In particular, in contra-distinction to Table 10.12 there is no effect of handedness (hence my suggestion that the effect in Table 10.12 is spurious).

Table 10.14 shows the stage of development of the girls' breasts. There is a significant parity effect, which is probably not spurious (see below). There is not a hint of a handedness effect.

Table 10.15 shows the stage of development of the girls' pubic hair. As in Table 10.14 there is a significant effect of parity. Whether this main effect is <u>truly</u> one of parity is an interesting question. Do high parity girls really reach puberty earlier? A possible artefact is that these high parity girls inevitably come from older mothers, and since parental income and hence child nutrition, correlate with parental age, these girls might receive substantially better diets. Alternatively there might be interaction effects between children (pheromonal perhaps?). Nevertheless the effect is small. Of more relevance in the present study is that there are no effects of handedness of girl's sexual development.

In summary, pubertal development does not relate to handedness.

10:7 Summary

There is evidence that left-handers have relatively younger mothers, and that left-handed matings produce more progeny. There is also some evidence that left-handers are more likely to divorce. These differences represent possible advantages for left-handers which may help to maintain the existence of the phenotype.

APPENDIX 10:1 FITNESS AND HANDEDNESS

Lest it is not quite clear what advantages are being proposed, let us consider a formal model, using the notation of Cavalli-Sforza and Bodmer (1971; p 125 *et seq*).

Let the fitnesses of the three genotypes, DD, DC and CC be 1-s, 1 and 1-t respectively. For a balanced polymorphism s and t must both be greater than zero. If s = 0, and t = 0, then drift alone will eliminate one or other allele: if s and t are $>$ 1, then an unstable equilibrium will eventually result in either one or other allele being lost. If s $>$ 0 and t $<$ 0, then D will rapidly become fixed; and vice-versa for s $<$ 0 and t $>$ 0.

Let the frequency of the C allele at equilibrium be 0.19 (i.e. 9.5% true sinistrality). We may then write:

	DD	DC	CC
Fitness:	1-s	1	1-t
p(Genotype|right-handed)	0.724972	0.255083	0.019945
p(Genotype|left-handed)	0.	0.81	0.19

Weighting the genotype frequencies by their fitnesses we obtain:

$$\text{Fitness}_{\text{Right-handers}} = F_r = 1. - 0.7249s - 0.0199t$$

$$\text{Fitness}_{\text{Left-handers}} = F_l = 1. - 0.19t$$

Relative fitness of right-handers with respect to left-handers

$$= RF = \frac{F_r}{F_l} = \frac{1. - 0.7249s - 0.0199t}{1 - 0.19t}$$

It may readily be shown (Cavalli-Sforza and Bodmer, 1971, Eq'n 4.5) that in a stable polymorphism at equilibrium:-

$$\frac{t}{s} = \frac{p(D)}{p(C)}$$

If this equation is substituted into the previous equation then it rapidly becomes clear that RF is 1.0. This is not surprising however, and indeed it is the reason that there is a polymorphism. However this overall fitness is comprised of two components, s and t. From one generation to the next, RF = 1.0. But this does not mean that at particular stages of each generation that RF = 1.0. Only the net effect must be 1.0. If, for instance, we consider a pair of alleles in which, say, AA produces a doubling of the fertility of an organism, but a produces a doubling of the probability of the progeny surviving to reproductive age, then if there were only two phenotypes, these would have an identical net RF; but at particular stages of the reproductive cycle their RF's would vary dramatically.

If we consider the situation when s = 0, i.e. there is a disadvantage to being CC, then it becomes clear that:-

$$\frac{F_r}{F_l} = \frac{1. - 0.0199t}{1. - 0.19t} > 1$$

conversely for t = 0, i.e. a disadvantage to being DD, then:

$$\frac{F_r}{F_l} = 1.\ 0.7249s > 1$$

Thus by isolating components of the reproductive process from one generation to the next, we might possibly find differences between the two phenotypes. But it must be remembered that overall such differences will be statistically difficult to discern.

TABLE 10.1 Shows, for the 6 groups of surveys I and II, the analysis of variance of total family size upon handedness of 'propositus' (i.e. student in propositus generation, or students mother in the maternal generation, or student's father in the paternal generation).

Main Effects	I:propositus (student) generation df	F	p	I:maternal generation df	F	p	I:paternal generation df	F	p	II:propositus (student) generation df	F	p	II:maternal generation df	F	p	II:paternal generation df	F	p
Propositus handedness (right vs left)	1	0.091	0.763	1	1.393	0.241	1	0.885	0.349	1	0.075	0.784	1	0.061	0.805	1	0.091	0.7
Family type (RxR vs 'RxL,LxR & LxL)	'1	0.165	0.685	1	1.106	0.296	1	4.951	0.028	1	6.764	0.010	1	0.291	0.590	1	0.651	0.420
Interaction	1	0.576	0.448	1	0.002	0.966	1	0.580	0.448	1	4.799	0.029	1	0.003	0.954	1	0.097	0.756
Residual	815			97			111			432			419			405		
Total	818			100			114			425			422			408		

Breakdown by sub-groups

Propositus	Family	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
R	RxR	2.827	1.231	601	2.802	1.769	71	2.847	1.789	85	2.596	1.028	307	2.822	1.601	344	2.853	1.718	342
R	RxL,LxR,LxL	2.741	1.112	116	2.315	2.001	19	3.692	1.974	13	3.114	1.279	61	2.970	1.731	34	3.069	1.907	29
L	RxR	2.718	1.147	64	3.555	3.045	9	2.000	0.925	8	2.860	1.059	43	2.891	1.173	37	2.735	1.399	34
L	RxL,LxR,LxL	2.842	1.127	38	4.000	2.828	2	3.667	3.082	9	2.680	1.600	25	3.000	2.563	8	3.250	1.893	4

Table 10.2 Analysis of variance of total children in household when propositus aged 7 (NCDS I), as a function of father's social class (C), and propositus parity (P), sex (S) and handedness (H).

	df	F	P
Main Effects			
H	1	2.004	0.157
C	4	43.518	≪ 0.001
P	3	1158.427	≪ 0.001
S	1	0.042	0.837
Interactions			
H x C	4	1.077	0.366
H x P	3	1.086	0.354
H x S	1	0.066	0.797
C x P	12	2.531	0.003
C x S	4	0.727	0.573
P x S	3	1.711	0.162
H x C x P	12	0.769	0.683
H x C x S	4	1.656	0.157
H x P x S	3	3.656	0.012
C x P x S	12	0.846	0.603
H x C x P x S	11	0.913	0.527
Residual	10241		
Total	10319		

Multiple Classification Analysis   Grand Mean = 2.80

H		C		P		S	
Right	- 0.01	I	- 0.09	0	- 0.53	Male	- 0.001
Left	0.04	II	- 0.12	1	- 0.09	Female	0.001
		III	- 0.03	2	0.69		
		IV	0.11	3	1.47		
		V	0.50				

Multiple R = 0.519

TABLE 10.3 Shows, for surveys I and II and NCDS, the results of a multiple classification analysis of family size as a function of propositus handedness (right or left) and of parental type (R x R or 'R x L, L x R or L x L"). Exact two and one-way probabilities are given for these main effects. The full ANOVA tables are given in Table 10,1 . For the NCDS data, only the p value and MCA result is given for propositus handedness, although a complete 4-way ANOVA table is given in Table 10.2 . (Note that in the NCDS, parental handedness was not known). Combined probabilities have been calculated using the method of Kendall (1951). All MCA results have been adjusted for independents.

Survey	Propositus handedness					Parental handedness				
	Right	Left	Direction	p_{two}	p_{one}	R x R	RxL,LxR,LxL	Direction	p_{one}	p_{two}
I-propositus family	0.001	-0.03	-	0.763	0.618	0.01	-0.04	-	0.683	0.658
I-maternal family	-0.08	0.66	+	0.241	0.121	-0,11	0.40	+	0.296	0.148
I-paternal family	0.07	-0.43	-	0.349	0.825	-0.20	0.86	+	0.028	0.014
II-propositus family	-0.01	0.03	+	0.784	0.392	-0.07	0.28	+	0.010	0.050
II-maternal family	-0.01	0.06	+	0.805	0.402	-0.01	0.13	+	0.590	0.295
II-paternal family	0.01	-0.08	-	0.763	0.618	-0.02	0.23	+	0.420	0.210
NCDS	-0.01	0.04	+	0.157	0.0785					

Combined one-tailed probabilities

Surveys I and II $x^2 = 10.22$, 10 df $p = 0.421$ $x^2 = 24.75$, 10 df, $p = 0.00584$

Surveys I, II and NCDS $x^2 = 15.31$, 12 df $p = 0.224$

TABLE 10.4 Shows, for surveys II and NCDS, the results of an analysis of variance of maternal age at the birth of a child. Results are expressed as a multiple classification analysis, and for surveys II there are in terms of propositus handedness, and family type (RxR vs RxL, LxR, LxL) whilst for the NCDS just the effect in terms of propositus handedness is given; the full analysis of variance is given in Table 10.5 (for the NCDS) and Table 10.6 for survey II. All MCA results are adjusted for all other independents.

Survey	Propositus handedness					Parental handedness				
	Right	Left	Direction	p_{two}	p_{one}	R x R	RxL, LxR, LxL	Direction	p_{two}	p_{one}
II- Child 1	0.08	-0.42	+	0.404	0.202	0.11	-0.46	+	0.364	0.182
II - Child 2	-0.02	0.09	-	0.853	0.573	0.07	-0.29	+	0.626	0.313
II -Child 3	0.46	-3.62	+	0.020	0.010	-0.05	0.16	-	0.095	0 952
II - Child 4	0.49	-2.37	+	0.172	0.086	-0.11	0.22	-	0.289	0.855
NCDS	0.02	-0.20	+	0.116	0.051					

Combined one-tailed probabilities

Survey II	$x^2 = 18.42$, 8 df,	p =0.0182	$x^2 = 6.142$, 8 df,	p = 0.631
Survey II & NCDS	$x^2 = 24.37$, 10 df,	p =0.00667		

TABLE 10.6 Shows, for the four parities of survey II, the analysis of variance of maternal age upon handedness of propositus and family type.

Main Effects	II: Child 1 df	F	p	II: Child 2 df	F	p	II: Child 3 df	F	p	II: Child 4 df	F	p
Propositus handedness (right vs left)	1	0.697	0.404	1	0.034	0.853	1	5.497	0.020	1	1.894	0.172
Family type (RxR vs RxL, LxR & LxL)	1	0.824	0.364	1	0.238	0.626	1	2.807	0.095	1	1.137	0.282
Interaction	1	0.779	0.378	1	0.113	0.737	0	-	-	0	-	-
Residual	420			383			228			84		
Total	423			386			230			86		

Breakdown by sub-groups

Propositus	Family	Child 1 Mean	SD	N	Child 2 Mean	SD	N	Child 3 Mean	SD	N	Child 4 Mean	SD	N
R	RxR	28.23	4.53	299	31.07	5.99	270	33.26	5.87	148	34.06	3.73	46
R	RxL,LxR,LxL	27.47	3.55	59	30.82	6.50	57	33.56	7.52	41	35.86	6.96	23
L	RxR	27.38	3.96	42	31.41	5.95	41	34.16	6.97	25	8.11	9.99	9
L	RxL,LxR,LxL	27.75	4.87	24	30.52	6.80	19	33.83	8.53	12	31.66	4.03	6

Table 10.5 Analysis of variance of mother's age at birth of child as a function of child's parity (P), handedness (H) and sex (S), and of husband's social class (C).

	df	F	P
Main Effects			
H	1	2.473	0.116
C	4	75.917	≪ 0.001
P	3	973.932	≪ 0.001
S	1	0.001	0.989
Interactions			
H x C	44	1.127	0.342
H x P	3	1.864	0.133
H x S	1	1.970	0.160
C x P	12	1.180	0.291
C x S	4	2.922	0.020
P x S	3	0.395	0.757
H x C x P	11	1.499	0.124
H x C x S	4	0.941	0.439
H x P x S	3	4.713	0.003
C x P x S	12	1.336	0.190
H x C x P x S	12	0.995	0.450
Residual	11190		
Total	11268		

Multiple Classification Analysis   Grand Mean = 26.87

H		C		P		S	
Right	0.02	I	1.52	0	-2.52	Male	0.0
Left	- 0.20	II	1.20	1	0.35	Female	0.0
		III	-0.33	2	2.92		
		IV	-0.41	3	4.65		
		V	-1.47				

Multiple R = 0.465

TABLE 10.7 Analysis of variance of father's age at birth of child as a function of his own social class (C), and of propositus handedness (H), sex (S) and parity (p). Analysis of covariance is also given, taking maternal age into account.

	Without co-variate			With co-variate		
Main Effects	df	F	p	df	F	p
H	1	0.401	0.526	1	0.328	0.567
C	4	48.298	0.001	4	4.995	0.001
P	3	724.232	0.001	3	45.927	0.001
S	1	1.557	0.212	1	1.503	0.220
Co-Variate	-	-	-	1	1.59 x 10^5	0.001
Interactions						
H x C	4	2.260	0.060	4	2.237	0.063
H x P	3	2.893	0.034	3	1.460	0.223
H x S	1	4.734	0.030	1	1.949	0.163
C x P	12	1.255	0.238	12	1.679	0.065
C x S	4	1.629	0.164	4	0.560	0.692
P x S	3	0.602	0.614	3	0.621	0.602
H x C x P	11	1.535	0.112	11	1.762	0.055
H x C x S	4	0.934	0.443	4	0.890	0.469
H x P x C	3	4.014	0.007	3	1.286	0.277
C x P x S	12	1.837	0.037	12	1.594	0.086
H x C x P x S	11	1.433	0.151	11	1.049	0.399
Residual	10855			10853		
Total	10932			10931		

Multiple Classification Analyses (adjusted for independents and for co-variate) Grand Mean = 29.94

H		C		P		S	
Right	- 0.01	I	0.19	0	-0.48	Male	-0.04
Left	+ 0.06	II	0.16	1	-0.001	Female	0.05
		III	-0.14	2	0.61		
		IV	0.08	3	0.97		
		V	0.40				

Multiple R = 0.772

Table 10.8 Analysis of variance of interval between marriage and the birth of the mother's first child, as a function of parity of present child (P), social class (C), the sex of the child (S), and the writing hand of the child (H).

	df	F	P
Main Effects			
H	1	0.235	0.628
C	4	27.350	≪ 0.001
P	3	126.247	≪0.001
S	1	1.474	0.225
Interactions			
H x C	4	0.419	0.795
H x P	3	1.364	0.252
H x S	1	0.037	0.848
C x P	12	0.856	0.583
C x S	4	1.207	0.306
P x S	3	2.027	0.108
H x C x P	12	7.535	<0.0001
H x C x S	4	1.417	0.228
H x P x S	3	0.118	0.949
C x P x S	12	0.887	0.560
H x C x P x S	11	0.641	0.795
Residual	10079		
Total	10157		

Multiple Classification Analysis   Grand Mean = 2.20 years

H		C		P		S	
Right	-0.001	I	0.30	0	0.42	Male	-0.03
Left	0.03	II	0.38	1	-0.09	Female	0.03
		III	-0.08	2	-0.53		
		IV	-0.21	3	-0.83		
		V	-0.35				

Multiple R = 0.220

Table 10.9 Analysis of variance of interval between birth of pre child and present child, as a function of husband's social class (C), and propositus parity (P) and sex (S) and handedness (H).

	df	F	p
Main Effects			
H	1	0.187	0.665
C	4	8.306	<0.001
P	3	13.871	≪0.001
S	1	0.554	0.457
Interactions			
H x C	4	0.806	0.521
H x P	3	0.801	0.493
H x S	1	0.514	0.474
C x P	12	0.598	0.846
C x S	4	0.656	0.622
P x S	3	0.707	0.548
H x C x P	11	1.056	0.398
H x C x S	4	2.077	0.081
H x P x S	3	1.026	0.380
C x P x S	12	1.047	0.402
H x C x P x S	10	0.874	0.557
Residual	7123		
Total	7199		

Multiple Classification Analysis   Grand Mean = 3.53 years

H		C		P		S	
Right	0.001	I	-0.30	1	0.11	Male	-0.01
Left	-0.03	II	0.01	2	0.15	Female	0.01
		III	0.07	3	0.15		
		IV	-0.04	4	-0.04		
		V	-0.26				

Multiple R = 0.103

Table 10.10 Analysis of variance of number of abortions /miscarriages/ectopics (after square-root transformation to stabilise variance) as a function of husband's social class (C), parity (P), and propositus handedness (H).

	df	F	p
Main Effects			
H	1	0.001	0.981
C	4	1.847	0.100
P	3	33.571	$\ll 0.0001$
S	1	0.001	0.978
Interactions			
H x C	4	1.652	0.158
H x P	3	0.365	0.778
H x S	1	1.749	0.186
C x P	12	0.748	0.705
C x S	4	0.087	0.987
P x S	3	0.164	0.921
H x C x P	11	1.520	0.117
H x C x S	4	1.009	0.401
H x P x S	3	3.032	0.028
C x P x S	12	0.901	0.545
H x C x P x S	12	2.808	0.001
Residuals	11195		
Total	11273		

Multiple Classification Analysis

Grand Mean = 1.05
(NB. All variables are expressed as square-roots)

H		C		P		S	
Right	0.001	I	0.01	0	-0.02	Male	0.001
Left	- 0.001	II	0.00	1	0.00	Female	-0.001
		III	-0.001	2	0.02		
		IV	0.01	3	0.03		
		V	-0.01				

Table 10.11 Analysis of variance of age at mother's menarche by social class of husband (C), parity of present child (P), handedness of present child (H) and sex of present child (S)

	df	F	p
Main Effects			
H	1	0.018	0.893
C	4	5.588	$\ll$0.001
P	3	9.121	$\ll$0.001
S	1	0.062	0.803
Interactions			
H x C	4	1.541	0.187
H x P	3	0.666	0.573
H x S	1	0.379	0.538
C x P	12	1.067	0.384
C x S	4	0.378	0.825
P x S	3	1.582	0.192
H xC x P	12	0.848	0.600
H x C x S	4	0.543	0.704
H x P x S	3	0.405	0.749
C x P x S	12	0.981	0.465
H x C x P x S	11	1.706	0.066
Residual	7667		
Total	7745		

Multiple Classification Analysis Grand Mean = 13.26 years

H	
Right	-0.001
Left	0.01

C	
I	-0.16
II	-0.11
III	0.00
IV	0.15
V	0.06

P	
0	-0.11
1	0.05
2	0.05
3	0.21

P	
Male	0.01
Female	-0.001

Multiple R = 0.083

Table 10.12 Analysis of variance of developmental stage of boys' genitalia by social class of father (C), parity (P) and own handedness (H).

	df	F	p
Main Effects			
H	1	8.702	0.003
C	4	0.236	0.918
P	3	1.044	0.372
Interactions			
H x C	4	1.191	0.313
H x P	3	0.467	0.705
C x P	12	1.309	0.205
H x C x P	12	0.810	0.641
Residual	5311		
Total	5350		

Multiple Classification Analysis   Grand Mean = 1.80

H		C		P	
Right	0.01	I	0.01	0	0.01
Left	-0.08	II	0.02	1	-0.001
		III	-0.01	2	-0.04
		IV	-0.01	3	0.02
		V	-0.00		

Multiple R = 0.050

Table 10.13 Analysis of variance of stage of development of boys' pubic hair, as a function of father's social class (C), own parity (p) and own handedness (H).

	df	F	p
Main Effect			
H	1	0.369	0.543
C	4	1.659	0.157
P	3	1.097	0.349
Interactions			
H x C	4	0.539	0.707
H x P	3	1.921	0.124
C x P	12	0.406	0.962
H x C x P	12	0.429	0.953
Residual	5279		
Total	5318		

Multiple Classification Analysis   Grand Mean = 1.41

H		C		p	
Right	0.001	I	0.00	0	0.01
Left	-0.01	II	0.01	1	0.00
		III	0.00	2	-0.03
		IV	-0.001	3	-0.00
		V	-0.09		

Multiple R = 0.045

Table 10.14 Analysis of Variance of developmental stage of girls' breasts as a function of father's social class (C), own parity (p) and own handedness (H).

	df	F	p
Main Effects			
H	1	0.085	0.770
C	4	0.351	0.844
P	3	4.043	0.007
Interactions			
H x C	4	0.918	0.452
H x P	3	1.531	0.204
C x P	12	1.363	0.176
H x C x P	12	0.643	0.806
Residual	5041		
Total	5080		

Multiple Classification Analysis   Grand Mean = 2.01

H		C		p	
Right	0.001	I	-0.02	0	0.03
Left	-0.01	II	0.03	1	0.02
		III	-0.01	2	-0.06
		IV	-0.01	3	-0.11
		V	0.02		

Multiple R = 0.052

Table 10.15 Analysis of variance of developmental stage of girls' pubic hair as a function of father's social class (C), own parity (p) and own handedness (H).

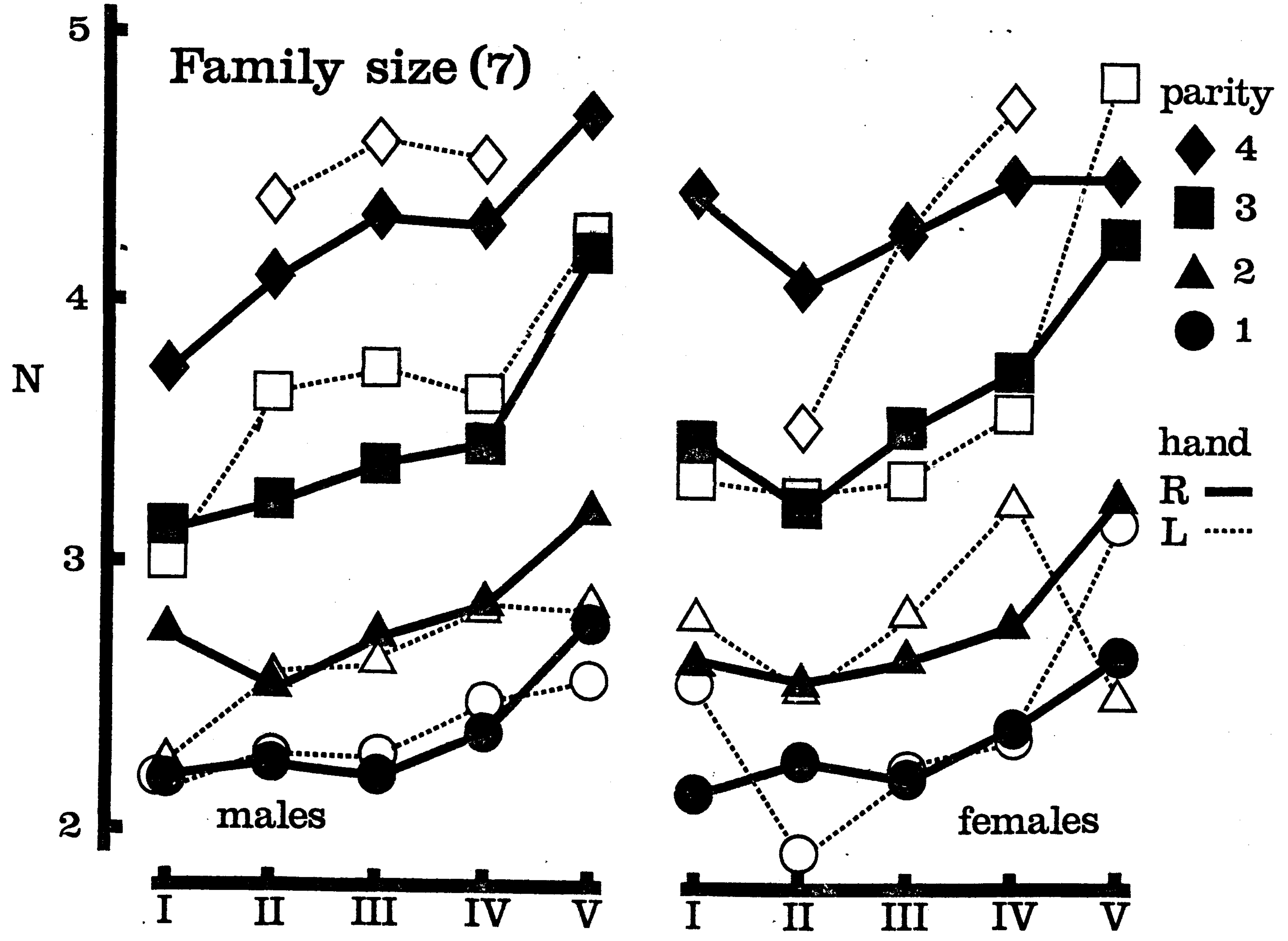
	df	F	p
Main Effects			
H	1	0.734	0.392
C	4	0.223	0.926
P	3	4.000	0.007
Interactions			
H x C	4	0.742	0.563
H x P	3	3.346	0.018
C x P	12	0.618	0.829
H x C x P	12	0.951	0.494
Residual	5006		
Total	5045		

Multiple Classification Analysis Grand Mean = 1.91

H		C		p	
Right	0.001	I	0.02	0	0.03
Left	-0.03	II	0.01	1	0.02
		III	-0.001	2	-0.06
		IV	0.00	3	-0.10
		V	-0.04		

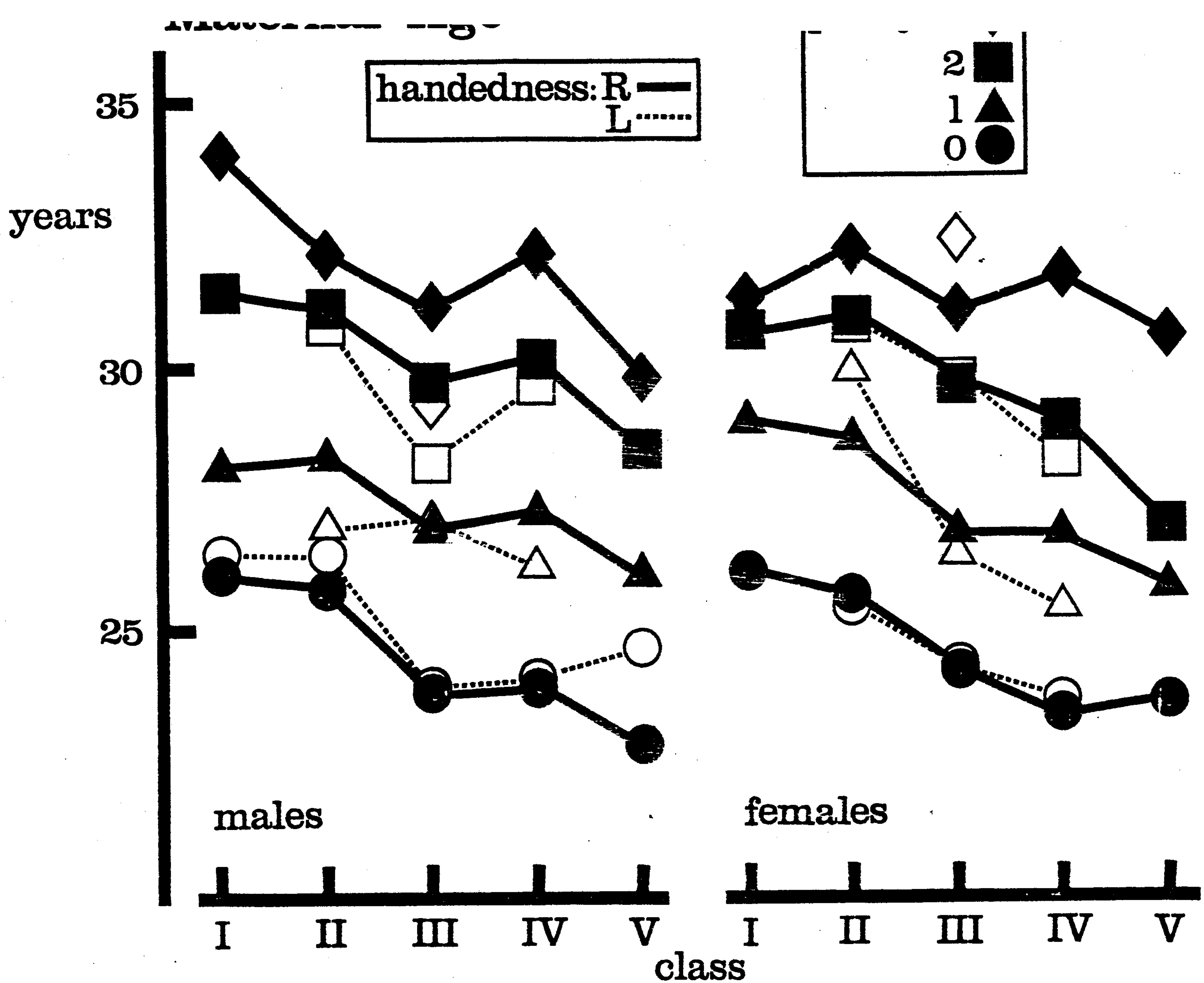
Multiple R = 0.053

Figure 10.1 Shows the family size (at propositus age 7, i.e. NCDS I) as a function of social class, sex of propositus and parity of propositus.



Family size (7)
N
5
4
3
2
parity
4
3
2
1
hand
R
L
males
females
I
II
III
IV
V
I
II
III
IV
V

Figure 10.2 Shows the mother's age at birth of the propositus as a function of social class, parity, and sex of propositus.


handedness: R
L
2
1
0
35
30
25
years
males
females
I
II
III
IV
V
class