CHAPTER 2: THE STRUCTURE OF HANDEDNESS

"To the scientific mind there is no inner difference, no polarity between right and left as there is for instance in the contrast between male and female, or between the front and rear of an animal"

Hermann Weyl (1952)

Summary

The structure of handedness questionnaires is shown to be compatible with a bimodal distribution of handedness. Handedness category correlates with many other items, but degree of handedness within a handedness category does not relate to other variables, and indeed may be artefactual. The existence of a third category of 'Mixed' handedness seems highly dubious and it is suggested that the use of this classification should be discounted.

2:1 Introduction

Common sense suggests that there are two types of handedness i.e. right and left: that is, two qualitatively different categories (see Figure 2.1a). Some might argue that there is a third category of persons, the ambidextrous, who are qualitatively different from both right and left handers (Figure 2.1b). And it is in principle possible to argue that there is a whole range of qualitatively different categories of handedness (Figure 2.1c). A different approach might be to suggest that there is actually a continuum between complete right-handedness and complete left-handedness, and that division of this continuum is purely arbitrary, reflecting only quantitative differences; if so, the particular distribution chosen is clearly of crucial importance, and if it is unimodal we could imagine it being arbitrarily divided into two (Figure 2.1d), three (Figure 2.1e) or more (Figure 2.1f) categories. Alternatively this unimodal normal distribution might be anchored by a significant point, such as zero, so that left handers have $R-L > 0$, and right-handers have $R-L < 0$ (Figure 2.1g). Clearly such a continuum could be yet further divided. An important compromise between the categorical structures (Figure 2.1a-c) and the continuous structures (Figures 2.1d-g) would be a bimodal or multimodal distribution, such as Figures 2.1h and 2.1i, in which, although the distributions are continuous, there are clearly 'natural boundaries' between the portions of the distribution.

This chapter will concern itself with which of the above types of model can best accommodate the various details of handedness, particularly as assessed by questionnaire. To consider such a question is not as sterile or pedantic as it might at first seem. No reasonable genetic model may be constructed without knowing the structure of the phenotypes. Neither is it otherwise possible to answer questions of the form; Are right-handers more right-handed than left-handers are left handed?

Throughout the Chapter I will use a single main principle to decide between models; the best model is that which most simply describes the available data. Occam's razor thus gives an a priori precedence to a model with two categories rather than three. And hence also, data will not be arbitrarily sub-divided unless it is possible to demonstrate significant differences between sub-groups.

The possibility that handedness might be more than just two simple categories was first posited at the end of the last century (although of course there is a classical literature on rare cases of ambidexterity). In the 1860's Broca demonstrated that the speech centre was usually in the left cerebral hemisphere. There were however exceptions to this general rule; Dax's law, that the phenomenon was mirror-imaged in left-handers, accounted for some of the cases, but there were still an uncomfortable number of anomalies. Various explanatory concepts were introduced to help with these difficult cases. It became acceptable to discuss handedness for different tasks as if there were a set of handednesses, each logically independent of the other; and thus it was usually possible to find at least one 'handedness' which was contralateral to the aphasic hemisphere. Similarly it became accepted that there were different degrees of handedness, which could be affected by heredity; thus a right-handed man with left-handed ancestors was felt to be less right-handed than a pure right-hander (i.e. he had left 'stock-brainedness', to use Foster Kennedy's (1916) expression). Similarly it was felt that early brain damage might well either shift dominance from one side to the other ('pathological left-handedness'), or alternatively might shift the degree of dominance without changing its direction. Woo and Pearson (1927) seriously complicated matters, by confusing handedness with asymmetry of grip strength, and eye-dominance, with visual acuity asymmetry, and hence concluding, on the basis of a very sophisticated statistical analysis, that "lateralism, whether ocular or manual, is a continuous variate, and dextrality and sinistrality are not opposed alternatives, but quantities capable of taking values of continuous intensity, and varying one into the other." This may well be true for grip strength asymmetry and visual acuity asymmetry, but it is not necessarily true for handedness and eye dominance.

Early studies of handedness *per se* were those of Jasper (1932), Durost (1934), Hull (1936), and Humphrey (1950). These studies made few theoretical statements, and are thus of less importance for the present purpose than later studies (see Hildreth 1949 for a description of early work). Later studies, in the sixties and seventies were rather more influential, two results being discernable. First, it became a common-place to assume that handedness must be more complex than being simply two categories (e.g. " ... the fact that handedness is not simply a two-valued variable, but must be measured along a continuum" (Shankweiler and Studdert-Kennedy 1975); or, " ... the complexities involved in the classification of handedness" (Satz *et al*, 1967)). Secondly, it also became common for large scale surveys to describe not just right and left-handedness, but right, *mixed* and left-handedness (e.g. Sand and Taylor, 1973; Thompson and Marsch, 1976; Boucher, 1977; Flemminger *et al*, 1977b).

The present work analyses two large scale questionnaires in some detail, in an attempt to provide empirical solutions to the problem of the structure of handedness.

2:2 Method

Survey 1

This questionnaire was distributed in May 1977, and October 1977 to Cambridge undergraduates (mostly in the sciences, hence the male predominance). Thq questionnaires on these two occasions (Survey 1a and 1b) had minor differences in their supplementary questions. Questionnaires were usually distributed at the beginning of a lecture and collected at the end of that lecture, and students were also reminded after the following three lectures to return the questionnaire. A number of questionnaires were also distributed to undergraduates by a postal survey. Response rates were difficult to assess accurately but were of the order of 50%; 948 questionnaires were returned satisfactorily. It is probable that there was a preferential response of left-handers, but this is of no consequence for the purposes of the present study.

Survey 2

This was carried out in June 1977 and consisted of a six page questionnaire distributed to all 1977 graduates of the University of Cambridge. Questionnaires were delivered to individual pigeon-holes on the evening before the graduation ceremony, and asked for the assistance not only of the student but also of his or her parents in completing the questionnaire. Graduation represented the most convenient time at which a large number of students were in the presence of their parents. The questionnaire asked the students, and also the parents, to complete the 12-item handedness questionnaire of Briggs and Nebes (1975). Further questions were also asked about the handedness of other members of the family, and it was thus possible to get reasonably reliable information on the student's aunts, uncles, grand-parents, great-grand-parents and siblings. Once again the response rate was difficult to determine accurately but was of the order of 15-20%. The same questionnaire was also distributed in September 1977 to all freshmen medical students of the University of Birmingham, in the week before their first arrival at medical school. For this questionnaire, a response rate of about 80% was achieved. For the two studies combined 511 questionnaires were completed.

All data from questionnaires were punched on to 80-column punched cards, and analysed by means of the Statistical Package for the Social Sciences (Nie et al, 1975). This statistical package was used also for the multivariate analyses.

In order to simplify the analysis, subjects were asked, in both surveys, if they had ever been forced to change their writing hand. Any subject with a history of forcing (irrespective of whether it was successful) was removed from the analysis. This removed 23 (2.42%) students from Survey 1 and 10 (1.95%) students from Survey 2.

2.3 Results

The questionnaire for Survey 1 was constructed so that it had 28 separate questions on handedness for particular tasks (see Appendix A2:1). By combining some or all of these questions it was possible to replicate other handedness questionnaires in the literature. Thus by using only questions 1 to 12, the handedness scale of Briggs and Nebes (1975) was simulated. Details of the questions themselves, and their inter-combination for forming the other handedness scales, are given in Appendix A2:1.

Annett (1967) used only eight questions, each of which could be answered only with the categories Right, Either or Left. By combining the Usually and Always categories of the present questionnaire it was possible to simulate the Annett handedness scale (AHS). Figure 2.2 shows the number of times that a subject answered that the right-hand was used for a particular task. The J-shaped distribution is similar to that of Annett (1972). The groups are also divided according to Annett's categorisation into Right, Mixed and Left handers. A right-hander is defined as someone who uses the right-hand for all eight tasks; by symmetry, a left-hander is a person who uses the left-hand for all eight tasks, and the remainder of the subjects are classified as Mixed. The proportions of Right, Mixed and Left (0.6936, 0.2664 and 0.0399 respectively) are similar to binomial proportions, although the difference is just significant statistically ($X^2 = 4.46$, 1 df, $p < 0.05$).

Figure 2.3 shows data from the same subjects as Figure 2.2, but the subjects are now classified as if on the Oldfield handedness scale (OHS) (Oldfield, 1971). This scale uses 10 questions, each on a five-point scale (Always Right, Usually Right, Either, Usually Left, Always Left), and the results are calculated simply by adding together all of the individual items (5 for Always Right, 4 for Usually Right, through to 1 for Always Left), and then applying a standardisation such that the maximum possible right-handed score was +100, and the maximum possible left-handed score was -100. Oldfield presented his results divided up into deciles, and this has been done for the present study, both for the OHS, and for all subsequent scales.

Comparison of Figures 2.2 and 2.3 shows little significant difference between the distributions.

Figure 2.4 shows the distribution of the subjects on the Briggs and Nebes (1975) handedness scale (BNHS), in which 12 questions were asked, each of which had five possible answers. The distribution is similar to that of the OHS, but now there is a tendency for extreme categories to be used less (note the change in the ordinate scale); nevertheless the maximima are still at the extremes.

Figure 2.5 shows the results using the Crovitz and Zener (1962) handedness scale (CZHS), which has 14 questions, also on a five-point scale. Notice that now the distribution is changing; the maxima are no longer at the extremes, either for right or for left-handers.

Figure 2.6 shows the scores for the same subjects on a scale composed of all 28 items of the original questionnaire (HS1). Now it is clear that the maxima are well removed from the extremes of the distribution, and indeed the curve appears similar to that of a bimodal normal distribution. The distribution is however asymmetric about the zero line. The dotted lines of Figure 2.6 show the expected distribution if the left-handed categories (i.e. less than zero) were present in the same relative proportions as the right-handed categories; there is a surfeit of weakly left-handed subjects over strongly left-handed subjects. This bears upon the old question of whether left-handers are less extremely lateralised than right-handers, and whether there is a greater variability in their distribution (i.e. taking each half of Figure 2.6 separately, is the absolute mean of the left-handers different from that of the right-handers, and is the variance of the left-handers different from that of the right-handers?).

Before answering this question it must be realised that there are certain possibilities that would render any answer to questions such as this, quite meaningless. Right-handers and left-handers both live in a right-handed world, and thus inevitably left-handers have to confirm in their daily activities by actually using the right hand for tasks for which, all other things being equal, the left hand would be preferable. Cultural pressures alone force most left-handers to use their right-hand for holding a knife at the dinner table; and mechanical constraints produce a tendency for left-handers to use their right-hand for using a screw-driver, or for winding the right-hand thread of a clock (supination being far stronger than pronation of the forearm). To include questions about such activities within the questionnaire is to prejudice any answer to the question as to whether the degree and variance of right-handers is different to that of left-handers. If we were to ask a person to put his right hand in the air, and found that both right and left handers did so, we would not conclude that left-handers were less well lateralised than right-handers. Similarly with handedness questionnaires; the cultural biasses must be removed as far as possible.

Figure 2.7 shows, for each of the individual questions, the mean score of both right and of left-handers, 5 being given for a reply of 'Always Right', through to a 1 for a reply of 'Always Left'. Handedness in this figure is defined in terms of the response to question 1, the hand used for writing (subjects with a history of changing writing hands being excluded). Tasks for which there is no cultural bias should, if lateralisation is equal, lie along the descending diagonal (that is left-handers and right-handers should be mirror-image symmetrical for the task). It may be readily seen that question 17 (holding a knife at table), is grossly non-symmetric, and that questions 3, 7, 22, 23, 25 and 26 all have a strong cultural asymmetry. Of the remaining 20 questions, 11 have a weak degree of cultural bias which is statistically significant, and for one of the questions (number 4), the difference is significant in the opposite direction to the majority.

It is now possible to construct a scale using just the less biassed questions and ask whether there is still a greater variance amongst left-handers. The fact that we have chosen <u>individual</u> questions for which there is no asymmetry does not mean that the combination of these questions will necessarily be symmetrical; the absolute means will necessarily be symmetric, but the question as to the similarity of the variance needs to be examined empirically.

Figure 2.8 shows a modified scale (HS2) constructed by adding together the 21 questions without a strong cultural bias (see Appendix A2:1 for a list of the questions used). The distribution is far more symmetric than the distribution of Figure 2.6, as may be seen by the dotted lines in the left-handed half of the distribution which show the right-handed distribution reflected in proportion to the left-handers total occurrence[1].

Table 2.1 expresses the results more formally, showing the absolute means for right and left-handers, and the

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1. Note also the remarkable similarity of this figure to that of Figure 1 of Goodglass and Quadfasel (1954).

variances, and variance ratio for right and left-handers (i.e. the F-statistic), as well as the kurtosis and skewness. As the number of questions in a questionnaire increases the variance ratio of the distributions decreases until for HS2 it is only 1.36 (which is however significantly different from unity, p = 0.0108 with 114 and 971 dfs). If one constructs a scale of just the nine questions which show <u>no</u> statistical difference in mean value between right and left-handers (HS3) then the resultant absolute mean for right-handers is 62.49, and 62.29 for left-handers, the difference not being significant. For HS3 the variance ratio is 1.258, which is only just significant with P = 0.05. Due to the smaller number of questions in HS3 there is a slightly greater skewness than in the larger HS2.

Scrutiny of Table 2.1 shows that almost all the distributions, for both right and left-handers, show significant degrees of skewness and/or kurtosis. These are partly due to ceiling effects, extreme degrees of right or left-handedness not being differentiated within the relatively small numbers of questions asked. Skewness and kurtosis might perhaps also reflect a tendency for a minority of subjects not to read and to consider questions carefully, but instead to simply tick the extreme categories for all questions.

In view of the presence of these significant non-normalities, the validity of parametric tests is somewhat suspect, skewness in particular tending to produce an artefactually high proportion of significant results (false positives) (Snedecor and Cochran, 1967, p 325). In consequence Table 2.1 also shows the significance values of the non-parametric Kolmogorov-Smirnov two-sample test for differences between two distributions (the left-handers' data being mirror-reflected about the abscissa's zero axis before carrying out the test). There are now no significant differences between left and right-handers on the HS3 scale, or even on the HS2 scale.

Table 2.1 also shows the percentage of the questions, for each of the scales, which were counted as 'strongly culturally biassed' and as 'non-culturally biassed' (see Figure 2.7). As the proportion of culturally biassed questions falls, so does the difference between the absolute means of left and right-handers.

To summarise so far, handedness may be regarded as either a J-shaped distribution, or as a bimodal normal distribution, according to the choice of questions asked. Similarly the distribution of responses of left handers and right handers are different or the same according to the particular question asked. On the basis of handedness questionnaires it is therefore not possible to say that left-handers are more variable in their handedness than right-handers; the answer obtained depends upon the questions asked. Parsimony therefore demands that in the first instance we reject the possibility of such a difference.

For convenience of interpretation of work which has used Annett's three categories of right-mixed and left handers, Figure 2.9 shows the scores of subjects on the HS2 divided according to their Annett category. Left and right-handers on the Annett criteria are certainly of their stated handedness. Mixed handers are more problematic; instead of being truly mixed, they are rather a mixture of right and left-handers, the distribution reflecting the bi-modality of Figure 2.8.

So far distributions have been divided into left and right-handers according to whether the score on a scale is greater than or less than zero. This step must be justified; also, a far simpler criterion will be used, if possible.

For each of the 28 questions the number of usages of 'either' responses was found. For question 1 (hand used for writing) nobody answered 'Either', and for question 13 (hand used for drawing a picture) only 2 (0.21%) persons answered 'Either'. For all other questions there were far higher proportions of 'Either' responses. Since writing hand is the most lateralised of the questions, it is the most profitable to examine it as a single criterion for dividing the distribution of Figure 2.8 into two parts.

The strength of lateralisation is also shown in the fact that only 13 subjects (1.37%) answered 'Usually Right', and 5 (0.52%) answered 'Usually Left', the remaining 98.10% answering in the 'Always' category.

For HS1 (Figure 2.6) only two right hand writers (0.25%) had scores of less than zero, and 18 (13.36%) left-hand writers had scores of greater then zero; an overall inconsistency of classification of 2.16%. For HS2 (Figure 2.8) we find that 1 right hand writer (0.12%) and 10 left-hand writers (7.57%) were mis-categorised, an overall error rate of 1.18%. If the criterion is made +10 instead of zero, then 3 right-handers (0.41%) and 7 left hand writers (5.3%) are mis-classified, an overall error-rate of 1.08%. Whilst a criterion of 10 is slightly better at dividing the distribution, a criterion of zero has been retained for convenience (the criterion of 10 is presumably slightly better due to its taking account of the small cultural bias remaining in the HS2 scale.)

For the rest of this ~~paper~~ chapter a right-hander is defined as a person who both writes with his right hand and has a score of greater than zero on the HS2, and a left-hander is defined as both writing with his left-hand and having a score of less than zero on HS2. 10 subjects have therefore been excluded from the analysis. Scrutiny of the individual results of these 10 subjects revealed nothing unusual except perhaps a greater tendency than usual to use the 'either' column.

Since all persons who had been forced to change their writing hand had been eliminated from the analysis at an earlier stage, we may conclude that in the first instance, and in the absence of evidence of forcing to change hands, a person's handedness is best assessed by means of the hand uses for writing. This agrees with the conclusion reached by Annett (1970).

In the rest of the present study all degrees of handedness will be measured in terms of the 21-item scale (HS2).

Having discussed the overall distribution of HS2 we must look at the details of its structure. A normal distribution is necessarily produced if a character is influenced by a large number of statistically independent events. If therefore many of the items used for constructing the handedness scale were correlated then a normal distribution would result. Hand-clasping and arm-folding are good examples of items which might be thought to correlate with handedness, and hence have been included in handedness inventories (e.g. Berman, 1971) but neither hand-clasping nor arm-folding actually correlates with handedness at all (see Chapter 9).

The structure of a scale may be best assessed by inter-correlating all of the individual test-scores, and then factoranalysing the resultant inter-correlation matrix. When this is done for the entire data of HS2 all of the items positively inter-correlate with each other, and the resultant factor analysis produces a large first factor accounting for 55.2% of the total variance (Principal Axis Analysis, Nie et al, 1975). Other factors are not significant (see Figure 2.10 for a plot of eigen-values against factor number). This result is similar to that of White and Ashton (1976), and of Bryden (1977). However it is inevitable that this particular form of factor analysis will produce such a result. The problem is that, in the same way as the overall distribution of scores is bimodal (Figure 2.8), so the distribution of the scores on each individual test is also bimodal. The correlation coefficient of such scores will thus only reflect the large variance due to the distance between the two peaks, and will hardly be influenced at all by the smaller variance within each handedness peak; hence a large common factor is almost inevitable. The question of far greater importance concerns the factor structure when one considers only one half of the distribution of Figure 2.8, for then it is not necessarily true that there will be a common factor.

I have therefore factor-analysed all of the items of the HS2 distribution, separately for each handedness group. The question on hand-writing was excluded from this analysis because almost all of the subjects answered in the same category. For the right-handers all of the 190 possible inter-correlations between items were positive; for the left-handers, with a rather smaller sample size, 166 (7.3%) of the 190 inter-correlations were positive. Figure 2.10 shows that, in each case, the first factor is highly significant, accounting for 24.5% of the total variance in the right-handers, and 22.4% of the total variance in the left-handers. Using a 'scree-slope criterion' (Child, 1970) only the first factor is significant for the right-handers, and only the first two factors are significant for the left-handers. The first factor in each case loaded strongly on each of the component tests. The second factor in left-handers seemed to relate to those questions which were reversed (i.e. the correct answer for a pure left-hander would be the right hand), and is thus similar to the second factors found by White and Ashton (1976), and Bryden (1977).

The factor analyses are therefore justification for thinking not only that there is an overall dimension called handedness, but that within each handedness sub-group there is also a dimension called degree of handedness, and that, on the basis of evidence from questionnaires, there is only one dimension within each handedness category.

It might seem inefficient , in view of the uni-dimensionality of each handedness group, to use a 21-item questionnaire in order to quantify degrees of handedness. Appendix A2:2 describes an attempt to produce a shorter, more efficient scale which retains most of the variance of the larger questionnaire.

So far in the analysis of the 28-item handedness questionnaire, I have only considered the differences between total scores of individuals, or else differences between individual items across all subjects. It is however possible that within subject variance is also of importance. Thus it would be possible to produce a score of exactly zero on, say, HS1, by ticking 'Either' for all of the questions, or alternatively by ticking 'Always Right' and 'Always Left' for alternate questions. Each strategy results in the same total score, but has very different implications. It is possible that left-handers may produce similar scores to right-handers overall, but that this may be a result of a greater variability within their responding. This may be assessed by calculating, for each individual's responses, the mean response, and the standard deviation of that subject's responses. Table 2.2 shows, for HS1, HS2 and HS3 the mean and standard deviation of the individual standard deviations. For HS3, the most interesting test of the hypothesis, left-handers show no more variability in their responding to the questions than do right-handers. This may be seen graphically in Figure 2.11.

Our justifications for regarding the major groupings of left and right handers as separate categories, are several fold. The first thing is that individuals are consistent. If a laterality is not statistically consistent within individuals it is of little interest; one example of an inconsistent asymmetry is wing-folding in *Drosphila melanogaster* (see Appendix A9:1). We know from simple observation that gross handedness category is highly consistent within individuals. A second reason for regarding handedness categories as different is that they behave differently. Thus the incidence of a family history of sinistrality is different in the left-handers and the right-handers (77.5% versus 35.8% in the present sample, $X^2 = 73.3$, 1 df, $p < 0.001$). Similarly, cerebral dominance for speech is different in the two handedness categories (e.g. Zangwill, 1960).

The question thus arises as to whether the differences in the *degree* of handedness *within* each handedness category are also meaningful. Without directly testing the possibility we may presume, from the work of Raczkowski *et al* (1974), that since all of their questions showed at least a 74% test-retest agreement, and that half of them showed a more than 93% agreement, that the differences in degrees of handedness are also consistent within individuals. This possibility is also being tested directly at the present.

The next question is whether degree of handedness correlates with any other behaviours. The most important aspect of this question concerns genetic correlates. If degrees of handedness is related to genetic factors then it must be taken into account by any adequate genetic model. Hecaen and Sauguet (1971) have suggested that left-handers without a family history of sinistrality are more strongly left-handed than those with a family history. Conversely it has been suggested, e.g. Briggs et al (1976) that both left and right handers might be sub-divided into two separate groups, weak handers being the result of early brain damage, whilst strong handers are genetically determined.

Consider the question of family sinistrality. In survey 1 subjects were asked to give the handedness of their parents, grand-parents and siblings; they were also cautioned not to guess, but only to answer if they were certain. The mean number of relatives reported by left and right-handers did not differ significantly (right-handers, mean = 4.93; left-handers, mean = 4.84, $F(1,885) = 0.0208$, NS); neither did number of relatives reported relate to degree of handedness within either of the handedness categories. (right-handers, $r = 0.028$, NS; left-handers, $r = 0.018$, NS). A positive family history of sinistrality was defined as any relative being described as either left-handed or ambidextrous. As mentioned earlier there was a highly significant difference between left and right-handed categories. Figure 2.12 shows the percentage of individuals within portions of each handedness category, with a positive family history. Within left-handers there is no difference between weak and strong left-handers, and within right-handers there is no difference between weak and strong right-handers (Left-handers, $X^2 = 3.88$, 3 df, NS; right-handers, $X^2 = 7.43$, 7 df, NS). To exoress this same result in a different way, the mean degree of handedness within a handedness category is not related to a family history of sinistrality (Table 2.2); this result also shows the lack of significance of the apparent trend in Figure 2.11). This is evidence against the degree of sinistrality or dextrality being genetically determined.

The degree of propositus handedness as a function of maternal and paternal handedness is also shown in Table 2.3. In right-handers there is a significant effect of maternal handedness, and an almost significant effect for paternal handedness. However given that these significance levels are small, and that a large number of tests have been carried out in Table 2.3, they are probably not truly significant; combined with the fact that the results are in opposite directions to one another, and that the trends in the left-handers data are in the opposite direction, this probably means that the results may be disregarded.

A more direct test of the inheritance of degree of handedness is possible using the data of Survey 2, in which there are measures of degree of handedness in parents and their children. Figure 2.13 shows the mean and median degree of right-handedness of the right-handed children of two right-handed parents, parental handedness being expressed as mid-parental handedness. There is no evidence of a correlation (F (7,300) = 0.69, NS). This same result may be expressed in a different fashion by saying that in the same cases the multiple correlation of student handedness upon maternal and paternal handedness is not significant. Table 2.4 shows, for each handedness combination of propositus and parents, the multiple correlations of children upon parents; none are significant. The simple correlation between each parent and child is also shown; none are significant. Neither is there evidence of assortative mating, inter-parental correlations being non-significant. There were insufficient families with two left-handed parents to allow analysis.

In summary it would appear that there is no evidence for degree of handedness being inherited, only direction of handedness.

Cerebral trauma has been proposed to account for differences in direction and degree of handedness. Effects upon direction will be discussed later. Table 2.2 shows that persons who report a history of either head trauma or of neurological disease do not show differences in degree of handedness from those without such a history.

Bakan (1971) has proposed that acute cerebral anoxia of the infant during childbirth results in left-handedness, and hence, since birth complications are related to birth order, left-handedness should be more common in the first-born, and also in the fourth-born and later than in second and third-born children. Table 2.3 shows that degree of handedness does not relate to birth-rank, and that those reporting a history of birth complications or difficulties do not have a lesser degree of lateralisation.

In combination with the genetic data these results provide no evidence for the suggestion that weak and strong handers have different aetiologies.

Table 2.3 also shows several other factors which have been considered to be related to degree of handedness. There is no significant difference between the sexes; nor is degree of handedness related to hand-clasping type. A history of reading or writing difficulties is not related to degree of lateralisation, although it must be remembered that the parents sample is of well above average intelligence. Hair-parting side correlates with the direction of whorl of the head hair, another lateral asymmetry which has on occasion been claimed to relate to handedness; Table 2.3 shows there to be no relation with degree of handedness. It may also be added, without providing detailed evidence, that degree of handedness does not relate to ABO or Rhesus blood groups, eye-colour, or colour-blindness.

Levy and Reid (1976, 1978) claimed that there were significant differences within handedness groups according to the posture of the hand during writing. A number of each handedness group write with the pen pointing towards the writer, rather than the more common way with the nib of the pen pointing away from the writer. An attempt was made to measure the posture of the hand during writing, by asking the questionnaire respondents to tick one of four figures, to indicate which best illustrated their own hand-writing position. These figures were taken from Levy and Reid (1976) as illustrating "typical writing postures". This question was not included in Survey 1a.

On the basis of tachistoscopic evidence, Levy and Reid said that right handers with a normal writing position, and left-handers with an inverted (or 'hooked') writing position were left hemisphere dominant for language, and that the remaining groups were right hemisphere dominant for language. Table 2.5 shows the proportions of the inverted and normal types in right and left handers in Survey 1b and 2. The inverted position is apparently more common in right-handers than Levy and Reid would suggest, at about 12%. The 'inverted' position in left-handers is far less common than would be expected if indeed it related to left hemisphere language dominance, for we now believe that the majority of left-handers have language in the left hemisphere. From the present data it would seem far more likely that the inverted writing position corresponds to right-hemisphere language, and indeed the relative proportions, about 13% and 30%, (which are similar to those of Lawson (1978)) ~~bare~~ bear a remarkable similarity to the estimated proportions of right cerebral dominance obtained from dichotic listening tests (e.g. Lishman and McMeeken, 1977), unilateral ECT studies (e.g. Geffen _et al_, 1978), and clinical studies (Annett, 1975). Table 2.3 shows that within handedness groups the degree of handedness is unrelated to writing posture.

For the above data on hand writing position it must be emphasised that the data have not been verified by direct observation, and hence the results must be regarded as only tentative.

2:4 Discussion and Performance Asymmetries

Degree of handedness, as assessed by questionnaire, is an internally consistent concept. However it cannot be shown to relate to any genetic factors, nor to be related to a number of other independent variables. The question therefore arises as to whether it is perhaps just an artefact of the method of measurement. One possibility is that the extremity of responses used by a subject is less a function of his actual hand behaviour but more a result of personality differences between subjects. This possibility would be supported by the finding of Hicks and Pellegrini (1978) that right and left handers showed no difference on Rotter's 'locus of control' scale, but that 'mixed' handers showed a significant difference from either right or left handers. The possibility of a personality difference is being directly tested at the present. The finding of a curvilinear relation between degree of handedness and a perceptual task (Thomas and Campos, 1978) may perhaps also be explained in such terms.

Our initial question, of the structure of handedness, therefore receives two possible answers. Handedness may have a bimodal normal distribution, with an anchoring point at the anti-mode of zero between the two halves of the distribution; alternatively the degree of handedness within each half of the distribution may yet be shown to be artefactual, in which case handedness may most economically be described as being two categories, left and right, the single best criterion for distinguishing them being the writing hand (assuming that the person has not been forced to change writing hand). The latter position would be consistent with that suggested by Colbourn (1978).

In either case, bimodal or bicategorial distribution, responses to handedness questionnaires must be reconciled with the unimodal distribution found in certain motor tasks such as finger-tapping. The discrepancy cannot be explained away by saying that handedness questionnaire items are unreliable, since they seem to correlate moderately well with observation of the actual behaviours (Raczkowski et al, 1974; Coren and Porac, 1978). Annett (1970; 1972) has pointed out that for many tasks, e.g. peg-moving and grip-strength (Woo and Pearson, 1927; Woo, 1928), the difference between right and left hand proficiency is distributed normally, with a mean displaced towards the right-hand side (i.e. the majority are better with the right hand). On the basis of this observation Annett claims that the underlying structure of handedness is a continuous unimodal normal distribution, and that hand performance categories are derived from it in an almost arbitrary fashion, the criterion varying, and differences in criteria accounting for differences in handedness incidence found in different studies (Annett, 1975). In later studies Annett (1978) suggests that the distribution of manual skill asymmetry also shows a significant degree of negative skewness, although she presents no evidence for this, and indeed, the skewness is notably absent in the data of Woo and Pearson (1927).

It is tempting to assume, ~~that~~ since tasks such as grip-strength, peg-moving and finger-tapping are objective, whilst questionnaires are subjective (and perhaps are ultimately only measuring some form of preference), that the results of the motor test must be superior. This however need not be the case. Provins and Cunliffe (1972) measured test-retest correlations over a period of 3 days, for seven different unimanual skilled tasks and for only two of the tasks, one of which was writing ability, was the right-left difference significantly correlated between the two occasions. Annett <u>et al</u> (1974) found that right-left differences on a peg-moving task showed a statistically significant test-retest correlation over a period of 7 weeks to 18 months; nevertheless the coefficient of determination showed that only 47% of the variance was retained between the two occasions. Within a group of right-handers, Shankweiler and Studdert-Kennedy (1975) found that only one of five unimanual tasks showed a significant test-retest correlation over a period of a week or two. In contrast to such results, handedness <u>category</u> is almost certainly highly consistent between occasions, and one might expect almost 100% of the variance to be retained. Thus in data derived from the National Child Development Study (see Chapter 3:2 for further details) 99.6% of 9153 children described by their mothers as right-handed at age 7, wrote with their right hand at age 11, and 94.4% of 1119 children described by their mothers as left handed at age 7 wrote with their left hand at age 11; the tetrachoric correlation coefficient is 0.947, indicating that 89.8% of the variance has been retained over a 4 year period, despite cultural and other pressures, and the possibility of developmental changes in degree of laterality. In adults the correlation would probably be even higher.

For peg-moving and finger-tapping there is at least some evidence that the tasks are correlated, albeit not very well, with handedness category. But for many tasks for which one might expect a correlation with handedness, there is simply no correlation. Arm-folding and hand-clasping have already been mentioned as examples of this. Kimura and Vanderwolfe (1970) found that accuracy of fine movements of the fingers was unrelated to handedness, and was actually superior in the left hand of both left and right-handers. Wolff et al (1977) found that rhythmic tapping on a key (without a metronome as a guide) was better in the right hand in both right and left-handed subjects, there being no difference between the two handedness categories. Similarly, hand differences need not be in favour of the right hand; Ingram (1975) found that two out of five manual tasks in young children showed a significant overall left hand superiority.

Far from being typical or necessary, peg-moving and finger-tapping would seem unusual in correlating with handedness. Since even in these cases the correlation with handedness is poor, one may speculate as to the underlying handedness structure. If indeed the real structure of handedness is a bimodal normal distribution then if a test were perfectly correlated with handedness both in degree and direction then we would expect that test to have a bimodal normal distribution. As, however, the correlation between handedness and a motor test became less, so we would expect that, assuming the variance of each half of the distribution stayed similar, ~~then~~ the means of the two distributions would come closer together. The increased height of the right-handed distribution would mean that when the tests reached a certain low degree of correlation that the mode of the left-hand distribution would be lost in the left-hand tail of the right-hand distribution. The resulting distribution would thus appear to approximate that of a unimodal normal distribution, with its mean shifted to the right. It would however be significantly skewed, in the manner pointed out for skull asymmetry by Annett (1975).

This process may be seen occurring in two sets of data from the National Child Development Study. Figure 2.14 shows the overall population distribution of over 12,000 11-year old children on a task in which they were asked to mark as many squares as possible on a piece of graph paper, using either the right or the left hand. The distribution just shows a bimodality. Figure 2.15 shows the same data broken down by handedness (as defined in Chapter 3.3). It is now clear that each hump on the curve is a result of one handedness category. As the symmetry of a task becomes greater (and the learned skill becomes relatively less) so the two modes merge into one. The same children in the NCDS were also asked to pick up 20 match-sticks as quickly as possible, one hand at a time. Figure 2.16 shows the distribution for this task, broken down by hand. Although statistically different these distributions are clearly very similar in absolute terms, and it must be clear that the overall population distribution is unimodal. (The clear kurtosis is probably a function of number preferences, and of recording the times in integer numbers of seconds)

The overall argument is of course similar if handedness is regarded as bicategorical rather than bimodal.

2:5 Conclusions

The structure of handedness questionnaires implies a bimodal normal distribution within an anchoring point at zero. Whilst subjects appear to show internal consistency in their degree of handedness within either handedness category, degree of handedness has not been shown to correlate in any useful way with any of a number of other variables. Handedness might therefore actually be bi-categorical, the variations in degree being artefactually a function of personality variables. For genetic purposes handedness may almost certainly be regarded as bi-categorical, left and right, the single best criterion for distinguishing the two categories being the writing hand. There is no evidence that left-handers are more variable or less extreme in their handedness than are right-handers.

APPENDIX A2:1 THE HANDEDNESS QUESTIONS USED IN SURVEY 1.

Which hand do you use for the following tasks:-

1. To write a letter legibly.
2. To throw a ball to hit a target
3. To play a game requiring the use of a racket
4. At the <u>top</u> of a broom to sweep dust from the floor
5. At the <u>top</u> of a shovel to move sand
6. To hold a match when striking it
7. To hold scissors when cutting paper
8. To hold thread to guide through the eye of a needle

*9. To hold the <u>pack</u> whilst dealing cards.

*10. To hold the <u>nail</u> whilst hammering it into wood

11. To hold a toothbrush whilst cleaning one's teeth

*12. To hold the <u>jar</u> whilst unscrewing the lid

13. To draw a picture

*14. To hold potatoes whilst peeling

15. To hold a jug when pouring water from it

16. To hold a knife when cutting a slice of bread

17. To hold a knife when also eating with a fork

18. To hold a glass for drinking

*19. To hold a dish whilst drying it

20. To hold a comb to combone's hair

*21. To hold a deck of cards whilst sorting them

*22. To hold the body of a penknife whilst opening the blade

*23. To hold a clock whilst winding it

24. To reach for a book on a high shelf

25. To strum the strings of a guitar

26. To pull the trigger of a rifle

27. To hold a scrubbing brush to the floor

28. To rub writing off a blackboard with an eraser

*Indicates questions for which the correct answer for a pure right hander would be the left, hand: the data for all such questions has been reversed before any further analysis has taken place.

The above questions have been used to simulate other handedness scales (see Chapter 2:3). (Note that substitutions are not always exact, particularly in the details of the wording).

APPENDIX A2:1

Scale	Reference	Questions used
AHS	Annett (1967)	1,2,3,4,5,6,7,8.
OHS	Oldfield (1971)	1,2,4,6,7,10*,11,13,16 x 2**
BHNS	Briggs and Nebes (1975)	1,2,3,4,5,6,7,8,9,10,11,12.
CZHS	Crovitz and Zener (1962)	1,2,3,7,8,10,11,12,13,14,15, 16,18,19.
HS1	This study	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20,21, 22,23,24,25,26,27,28.
HS2	This study	1,2,4,5,6,8,9,10,11,12,13, 14,15,16,18,19,20,21,24, 27,28.
HS3	This study	1,5,8,9,12,13,19,21,27,28.
HS4	This study	1,5,8,9,12,21.

Notes

* Amongst my own set of questions there was no adequate substitute for Oldfield's question 10, and therefore question 10 of my own study has been arbitrarily substituted.

** Question 16 has been used twice in constructing the OHS, once as a substitute for question 6, and once as a substitute for question 7 of Oldfield's study.

APPENDIX A2:2 THE CONSTRUCTION OF AN OPTIMAL HANDEDNESS QUESTIONNAIRE

A questionnaire with 28 items is cumbersome and tedious for subjects to complete; particularly in lower intelligence subjects it is probable that the magnitude of the task prevents each question being considered as deeply as it requires. A shorter questionnaire is therefore desirable.

Ideally a shorter questionnaire should retain as much of the variance of a larger questionnaire as is possible. The ideal that has been taken is the 21 item handedness scale, HS2. The variance to be retained is that within each handedness category, and the two halves of the distribution must therefore be assessed separately. Table A2:1 shows the rank ordering of each of the 20 constituent items (excluding hand-writing) in a hierarchial multiple regression of the individual questions upon HS2, the individual question with the highest partial correlation being entered at each step. The two handedness categories are shown separately. Table A2:1 also shows the proportion of accounted variance (i.e. the square of the multiple correlation coefficient) after the introduction of each new question. Thus, for right-handers question 28 alone will account for 34.9% of the variance of HS2, whilst adding question 12 will then account for 51.9% of the variance of HS2.

It will be noted that the order of questions is different in the two handedness categories; this does not mean that the structure of handedness is necessarily different within right and left-handers, but rather reflects the particular order of correlations with each particular data, an order which chance factors can make moderately idiosynchratic. Note that the simple correlations of each question with HS2, are in 82% of cases, greater than 0.4 and all are positive.

One way of producing a shorter questionnaire would be to take the top N questions of Table A2:1 and to then use them in association with their appropriate regression coefficients, to produce a scale. This however has two inconveniences. Firstly, it requires a complex regression; and secondly, the coefficients of that regression equation would differ for right and left handers. Nevertheless if, say, a 3 item questionnaire was required for just left-handers, this would be the optimal approach.

More desirable would be a questionnaire in which the scale was produced by simple addition of the individual items, and for which the items were the same for right and for left handers. There is no simple statistical approach to such a problem, with the exception of a combinatorial multiple regression. This has not been carried out due to its unwieldiness. Instead an approach was adopted in which firstly the nine questions were taken for which there was no cultural bias (i.e. those of HS3), thus ensuring a reasonable degree of symmetry for the final scale. These nine questions were then run in a hierarchial multiple regression against HS2, separately for each handedness category. Of the top six questions in the analysis, five were the same for each handedness group. A scale (HS4) was therefore constructed by simple addition of these five questions (and also of question 1, writing hand). Table 2.1 shows that the left and right-handed means of HS4 are not significantly different, and that the variances are only just significantly different with p less than 0.05. It must be pointed out however that the small number of questions means that there is a small degree of skewness, although this is not as great for right-handers as on the AHS, OHS or BNHS, or for left-handers on the AHS or OHS. Kurtosis is negligible for right-handers, and smaller for left handers than on the AHS or OHS.

Table A2.2 shows, separately for right and left-handers, the correlations between the HS2, HS3 and HS4 scales. The correlation for right-handers between the 6 item HS4, and the 21 item HS2 is 0.811, indicating that HS4 retains 65.7% of the variance of HS2; for left-handers the variance retention is 42.83%.

The selection of an appropriate questionnaire for different purposes is not easy. For detailed research the maximum number of questions is desirable, and HS1 or or HS2 would be recommended. For larger scale surveys of both right and left-handers, HS3 or HS4 would be appropriate, depending upon the desired number of questions. For research on just one handedness category, an optimal n-category questionnaire may be constructed by asking the top n questions shown in Table A2.1.

It must be remembered that the analysis given in this appendix assumes that individuals will make the same response to a single question on its own, or in the context of another 4, 8, 20 or 27 questions. This is of course not necessarily true and should be investigated empirically. Nevertheless it is hoped that the approach of this appendix provides a more rational approach to questionnaire construction.

TABLE 2.1 Mean and Variance of Left and Right handers on each of the scales

Scale	Number of questions	Percent strongly biassed q.s.	Percent unbiassed questions	Absolute Means Right	Absolute Means Left	R - L	P	Standard deviation Right	Standard deviation Left	Variance Ratio	
AHS	8	25%	37.5%	93.67	68.07	25.60	$<10^{-5}$	16.31	35.18	4.65	
OHS	10	10%	20%	85.57	74.94	10.63	$<10^{-5}$	13.60	25.02	3.38	
BNHS	2	16.6%	41.6%	76.32	66.92	9.40	$<10^{-5}$	19.70	26.04	1.74	
CZHS	14	14.2%	35.7%	74.92	63.33	11.59	$<10^{-5}$	16.64	26.77	2.58	<
HS1	28	25%	35.7%	70.09	49.19	20.90	$<10^{-5}$	17.36	22.86	1.73	<
HS2	21	0	47.6%	66.45	60.71	5.74	0.0036	19.24	22.47	1.36	(
HS3	9	0	100%	62.49	62.29	0.19	NS	23.48	26.33	1.258	(
HS4	6	0	100%	61.88	62.63	-0.75	NS	29.76	33.53	1.269	(

Note: Significance of variance ratios is calculated with (114,791) degrees of freedom

	Skewness Right	sig	Skewness Left	sig	Kurtosis Right	sig	Kurtosis Left	sig	Kolomogorov-Smirnov two-sample test for difference between Right and Left distributions
AHS	-3.45	< 0.01	1.07	< 0.01	15.69	< 0.01	1.04	< 0.05	P < 0.0001
OHS	-1.58	< 0.01	1.22	< 0.01	3.14	< 0.01	1.19	< 0.05	P < 0.0001
BNHS	-1.06	< 0.01	0.66	< 0.01	1.88	< 0.01	-0.26	NS	P = 0.003
CZHS	-0.73	< 0.01	0.85	< 0.01	0.71	< 0.01	0.50	NS	P < 0.0001
HS1	-0.65	< 0.01	0.24	NS	0.34	< 0.05	-0.91	< 0.05	P < 0.0001
HS2	-0.53	< 0.01	0.34	NS	0.14	NS	-0.69	NS	P = 0.056
HS3	-0.47	< 0.01	0.81	< 0.01	-0.14	NS	0.35	NS	P = 0.977
HS4	-0.75	< 0.01	0.98	< 0.01	0.06	NS	0.57	NS	P = 0.980

TABLE 2.2 Shows the mean and standard deviation of the individual subject's standard deviation on the items comprising the three scales HS1, HS2 and HS3.

Scale	Handedness	$\overline{SD}$	σ_{SD}	$\overline{SD}_R$ vs $\overline{SD}_L$	σ_{SD_R} vs σ_{SD_L}	Kelmogrovov-Smirnov test SD_R vs SD_L
HS1	R	0.821	0.292	$F(1,793) = 186.5$ $P \ll 0.001$	NS	K-Sz = 5.53 $P \ll 0.001$
	L	1.246	0.284			
HS2	R	0.824	0.296	$F(1,835) = 13.51$ $P = 0.083$	$P < 0.05$	K-Sz = 2.02
	L	0.943	0.380			
HS3	R	0.876	0.394	$F(1,850) = 0.004$ NS	NS	K-Sz = 0.88 NS
	L	0.878	0.457			

TABLE 2.3

	Group	Right-handers Mean	Right-handers N	Right-handers Sig	Left-handers Mean	Left-handers N	Left-handers Sig
Family History	-	66.49	503	F(1,772) = 0.206 NS	55.92	26	F(1,111) = 1.591 NS
	+	65.83	271		66.26	87	
Number of Left-handed relatives	0	66.75	520	F(3,787) = 0.966 NS; linear trend P = 0.1951	55.70	27	F(3,110) = 2.375 P = 0.074; linear trend P = 0.685
	1	66.90	201		65.17	46	
	2	63.14	55		64.24	25	
	3+	61.40	15		50.81	16	
Maternal Handedness	R	66.74	700	F(1,1748) = 4.769 P = 0.0293	59.11	85	F(1,106) = 2.60 P = 0.1092
	L	60.66	50		67.69	23	
Paternal Handedness	R	65.94	676	F(1,746) = 3.026 P = 0.823	61.14	88	F(1,106) = 0.215 NS
	L	70.08	72		58.50	20	
Sex	Male	66.14	541	F(1,707) = 0.172 NS	58.96	84	F(1,98) = 2.634 NS
	Female	66.85	168		68.75	16	
Birth Rank	1	65.80	390	F(4,736) = 0.252 NS	59.96	60	F(3,99) = 1.297 NS
	2	66.79	229		66.44	27	
	3	66.32	80		52.00	13	
	4	68.85	28		58.33	3	
	5+	64.71	14		-	0	
Birth Complications	-	66.44	591	F(1,779) = 0.126 NS	59.92	102	F(1,111) = 1.618 NS
	+	65.67	90		69.00	11	
Head Trauma or Neurological disease	-	66.60	735	F(1,777) = 1.523 NS	61.39	109	F(1,111) = 2.12 NS
	+	61.88	26		44.75	4	

Complicat...

Head Trauma or Neurological disease	- +	66.60 61.88	735 26	F(1,777) = 1.523 NS	61.39 44.75	109 4	F(1,111) = 2.12 NS
Hand position whilst writing	Normal Inverted	65.80 66.04	334 61	F(1,393) - 0.008 NS	60.04 62.41	41 12	F(1,51) = 0.089 NS
Hand-clasping	Right Left	67.55 64.89	179 221	F(1,398) = 2.84 P = 0.0594	57.16 63.10	25 29	F(1,52) = 0.830 NS
Reading or Writing difficulty	No Yes	66.47 64.96	721 62	F(1,781) = 0.353 NS	61.43 55.00	102 11	F(1,111) = 0.806 NS
Hair parting	Right Left Middle or 'Others'	67.77 66.60 63.54	167 485 96	F(2,745) = 1.510 NS	62.63 59.88 65.63	19 77 11	F(2,104) = 0.375 NS

TABLE 2.4

Handedness Propositus	Mother	Father	N	Multiple correlation on propositus	Sig of multiple correlation	Simple corr's on propositus Mother	Father	Simple correlation of maternal and paternal handedness
R	R	R	308	0.0743	$F(2,305) = 0.847$ NS	0.0182	0.0718	-0.0142
L	R	R	43	0.2144	$F(2,40) = 0.963$ NS	-0.166	0.132	0.0159
R	R	L	26	0.1979	$F(2,23) = 0.469$ NS	0.0232	0.1979	0.0994
L	R	L	10	0.2944	$F(2,7) = 0.332$ NS	0.1386	-0.1366	0.562
R	L	R	28	0.228	$F(2,25)_{NS} = 0.691$	-0.1198	-0.1859	-0.142
L	L	R	15	0.2696	$F(2,12)_{NS} = 0.470$	0.1718	-0.1940	0.0763

Table 2.5

Survey 1b		Hand posture whilst writing: Normal	Inverted	N	% Inverted
Handedness	Right	348	632	410	15.12%
	Left	57	19	76	24.99%

$$X^2 = 4.50,\ 1df,\ P < 0.05$$

Survey 2		Hand posture whilst writing: Normal	Inverted	N	% Inverted
Handedness	Right	380	48	428	11.21%
	Left	53	25	78	32.05%

$$X^2 = 27.70,\ 1\ df,\ P < 0.001$$

TABLE A2:1

Shows, for left and right-handers separately, the order of entering each of the component items of HS2 into the regression equation, and the cumulative percentage of the variance accounted for.

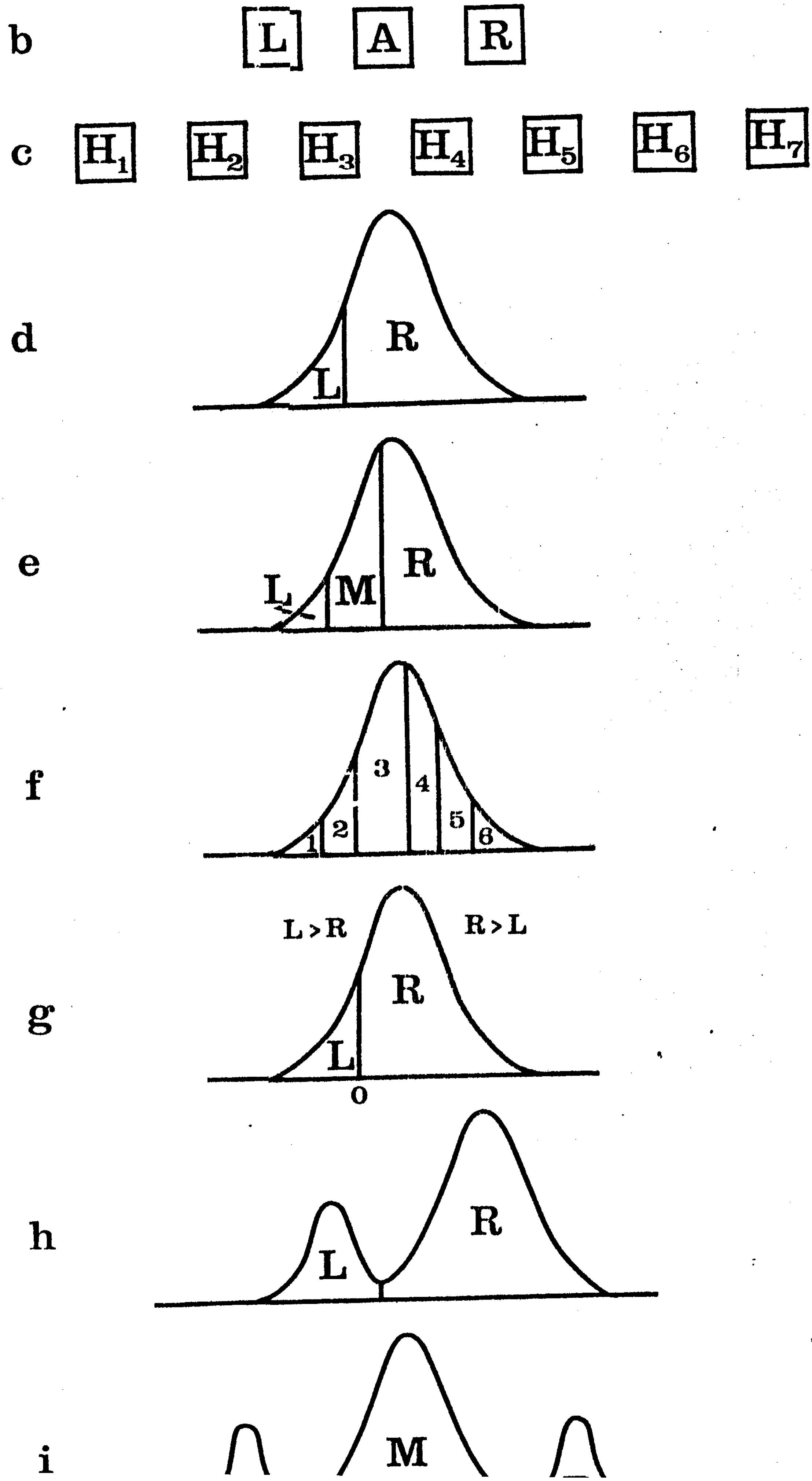
	Right-handers		Left-handers	
Order of entry	Question	Variance	Question	Variance
1	28	34.8	27	31.7
2	12	51.9	19	53.7
3	8	61.9	11	67.2
4	21	70.0	9	74.4
5	4	76.3	18	79.4
6	14	81.7	12	83.2
7	15	85.4	8	85.8
8	9	88.8	20	87.9
9	19	91.1	5	90.3
10	20	92.8	14	92.3
11	10	94.2	2	94.2
12	24	95.5	24	95.7
13	5	96.6	21	96.6
14	11	97.7	10	97.7
15	18	98.3	6	98.5
16	6	98.9	4	99.0
17	27	99.4	15	99.3
18	2	99.6	16	99.6
19	16	99.8	28	99.9
20	13	99.9	13	99.9

TABLE A2:2

Correlations, for right and left-handers separately, between HS2, HS3 and HS4. Right-handers are placed in the triangle above the diagonal, and left-handers in the triangle below the diagonal.

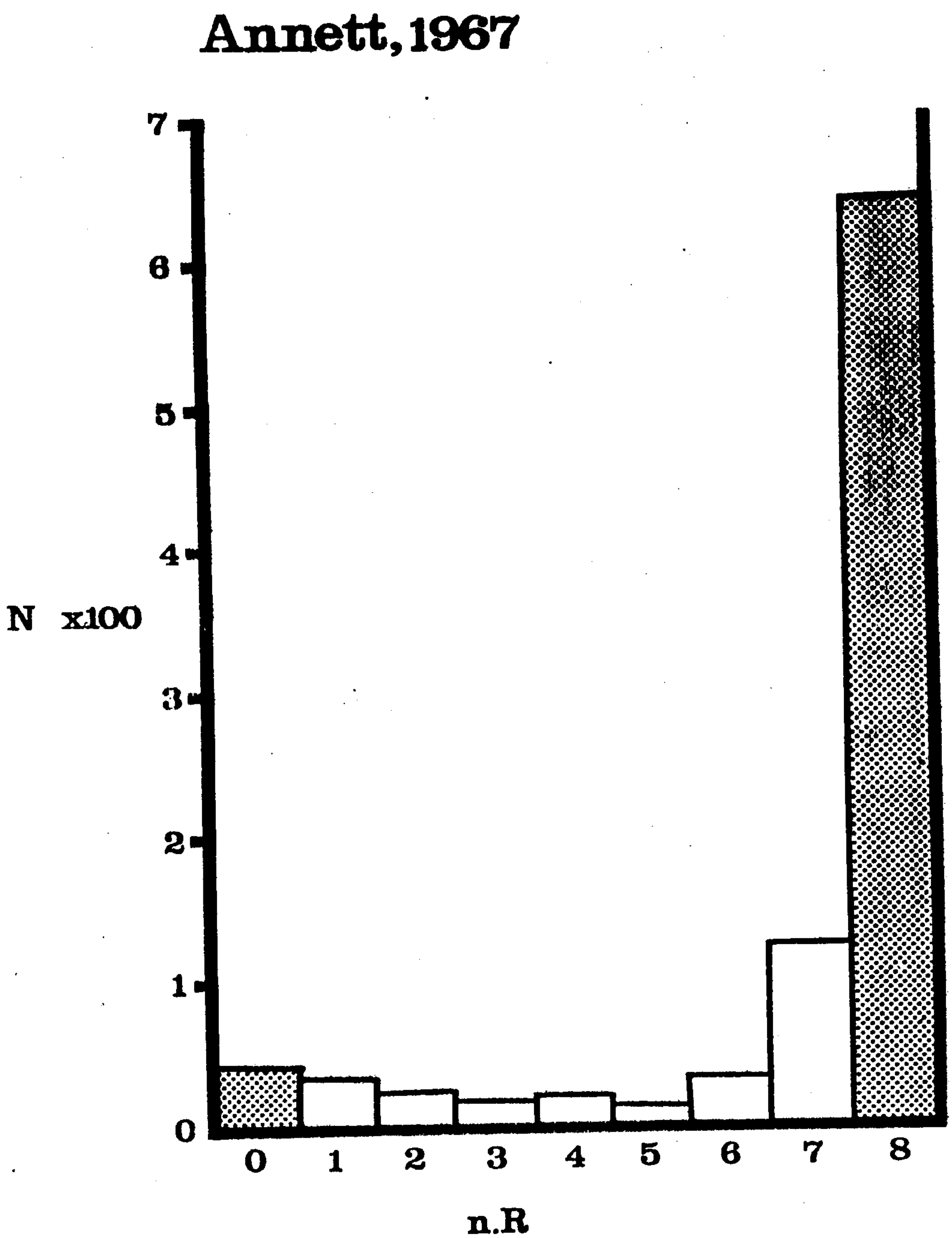
	HS2	HS3	HS4
HS2	-	0.918	0.811
HS3	0.793	-	0.925
HS4	0.654	0.946	-

Figure 2.1 Shows, schematically, various possible models of the structure of handedness.



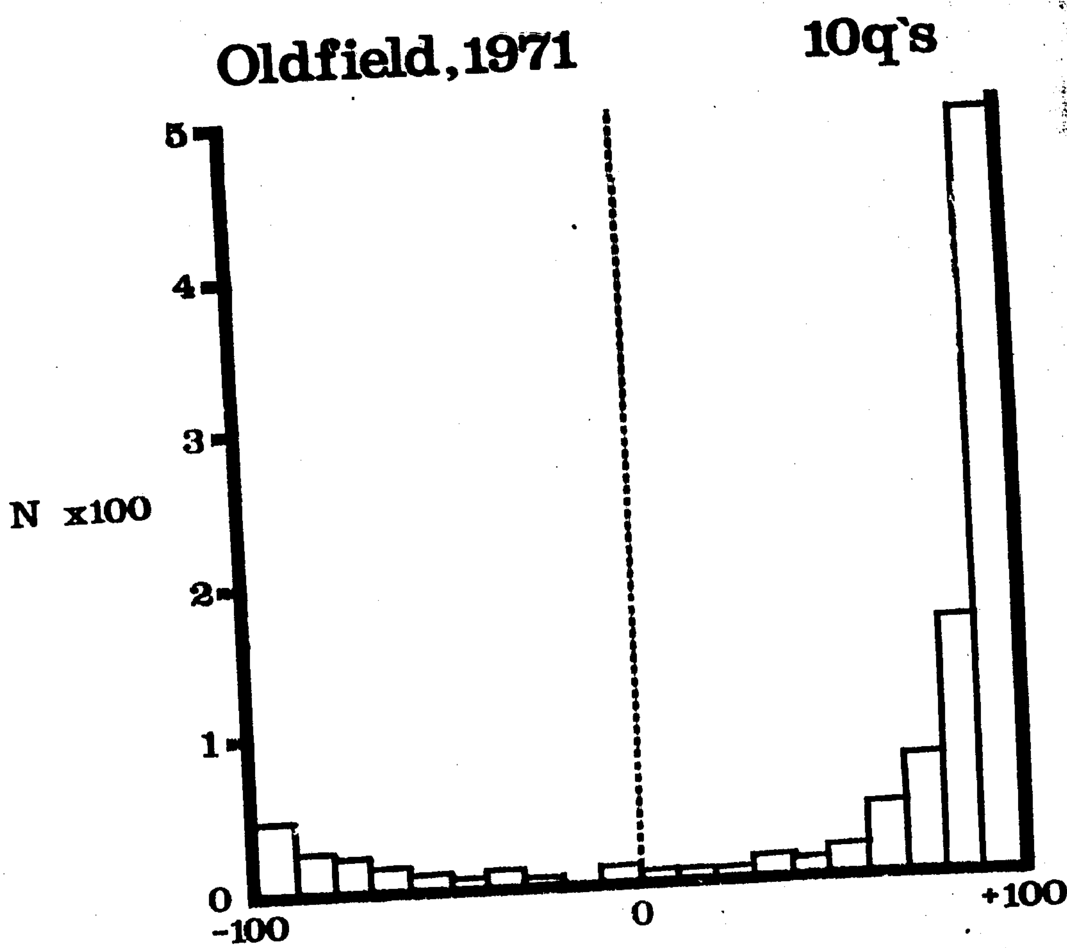
b
L
A
R
c
H_1
H_2
H_3
H_4
H_5
H_6
H_7
d
L
R
e
L
M
R
f
1
2
3
4
5
6
g
L > R
R > L
L
R
0
h
L
R
i
M

__Figure 2.2__ Shows the distribution of scores of the subjects of Survey 1 on the eight-item handedness scale of Annett (1967). Abscissa shows the number of questions for which the subject indicated that the right hand was used.



Annett, 1967
7
6
5
4
N x100
3
2
1
0
0
1
2
3
4
5
6
7
8
n.R

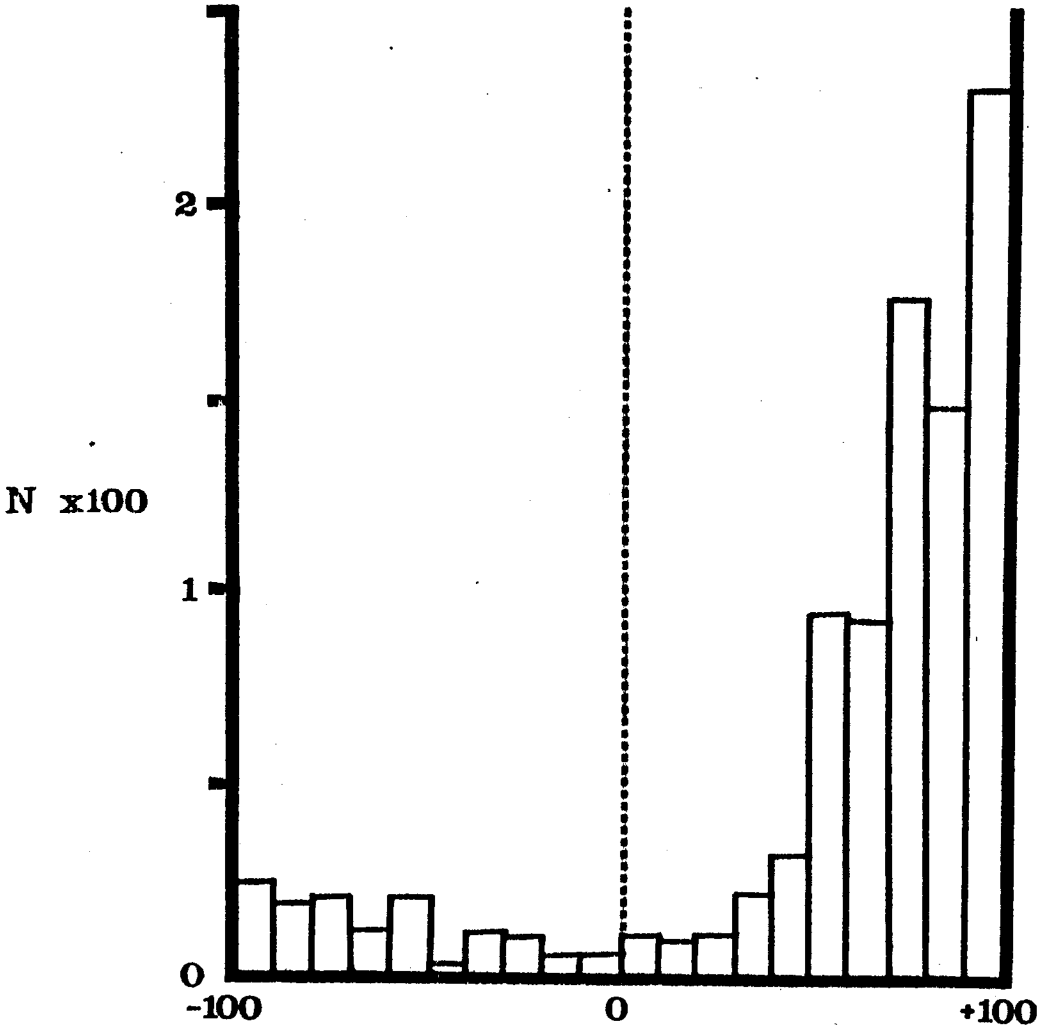
Figure 2.3 Shows the scores of the subjects of Survey 1 on the Oldfield handedness scale (OHS). Abscissa shows scores standardised as described in text. Each half of the distribution (left and right) is divided into deciles. A score of +100 indicates complete right-handedness and a score of -100 indicates complete left-handedness



Oldfield, 1971
10q's
N x100
5
4
3
2
1
0
-100
0
+100

Figure 2.4 Shows the scores of the subjects on the Briggs-Nebes handedness scale (BNHS). Otherwise as for Figure 2.3

Briggs & Nebes, 1975 12q's



<u>Figure 2.5</u> Shows the scores of subjects on the Crovitz and Zener Handedness scale (CZHS).

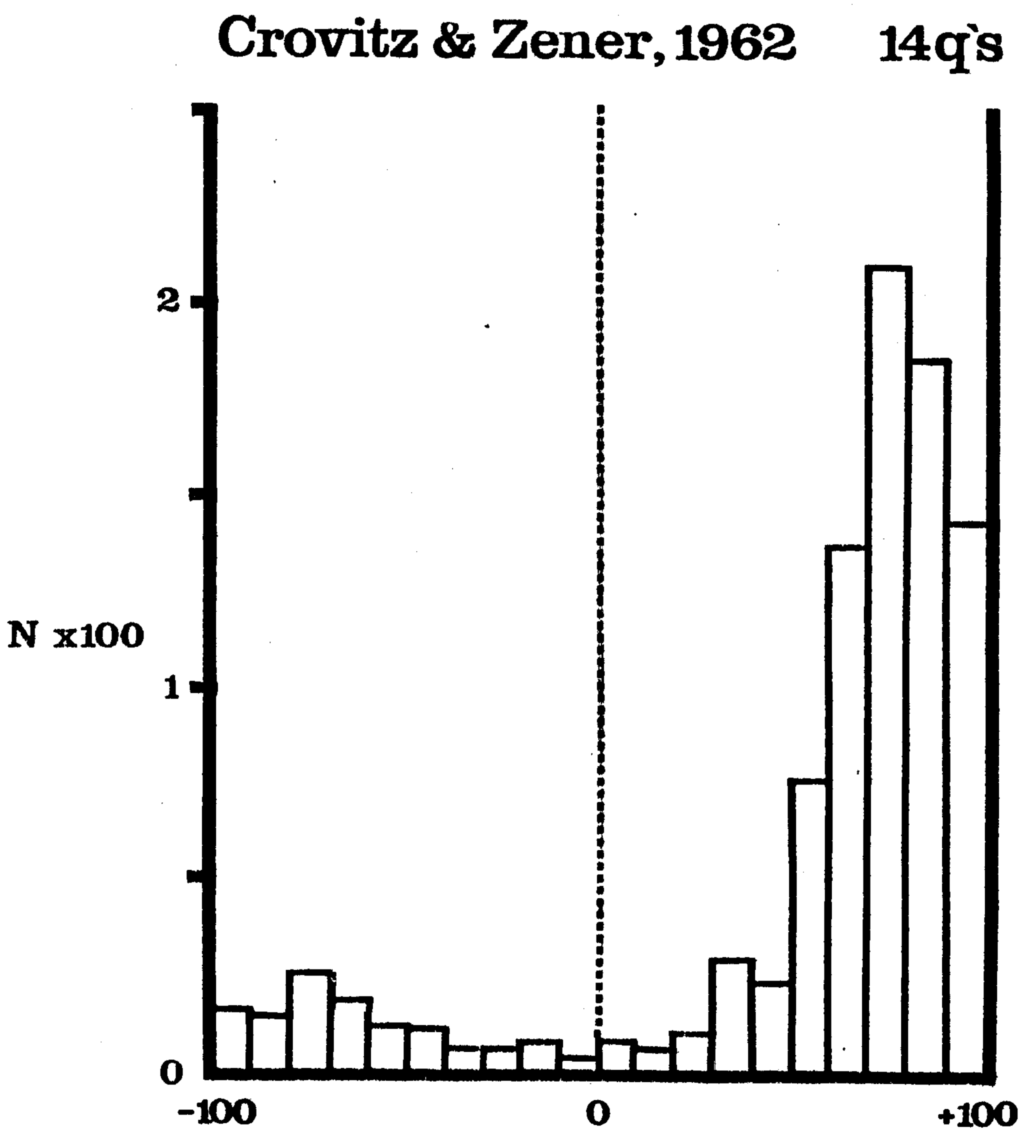

Crovitz & Zener, 1962
14q's
N x100
2
1
0
-100
0
+100

Figure 2.6 Shows the distribution of scores on the 28 item HS1. The dotted line in the left half of the distribution represents the reflection of the right half of the distribution around the mid-line, and in proportion to the total number of left-handers.

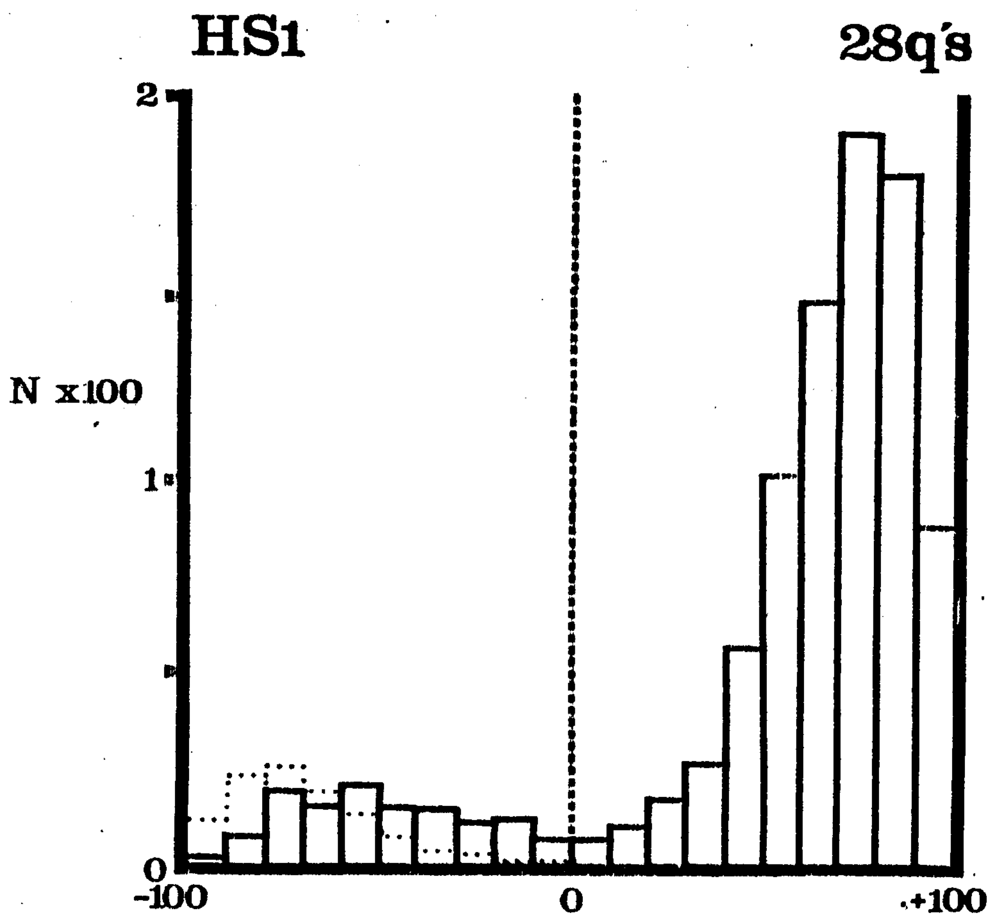
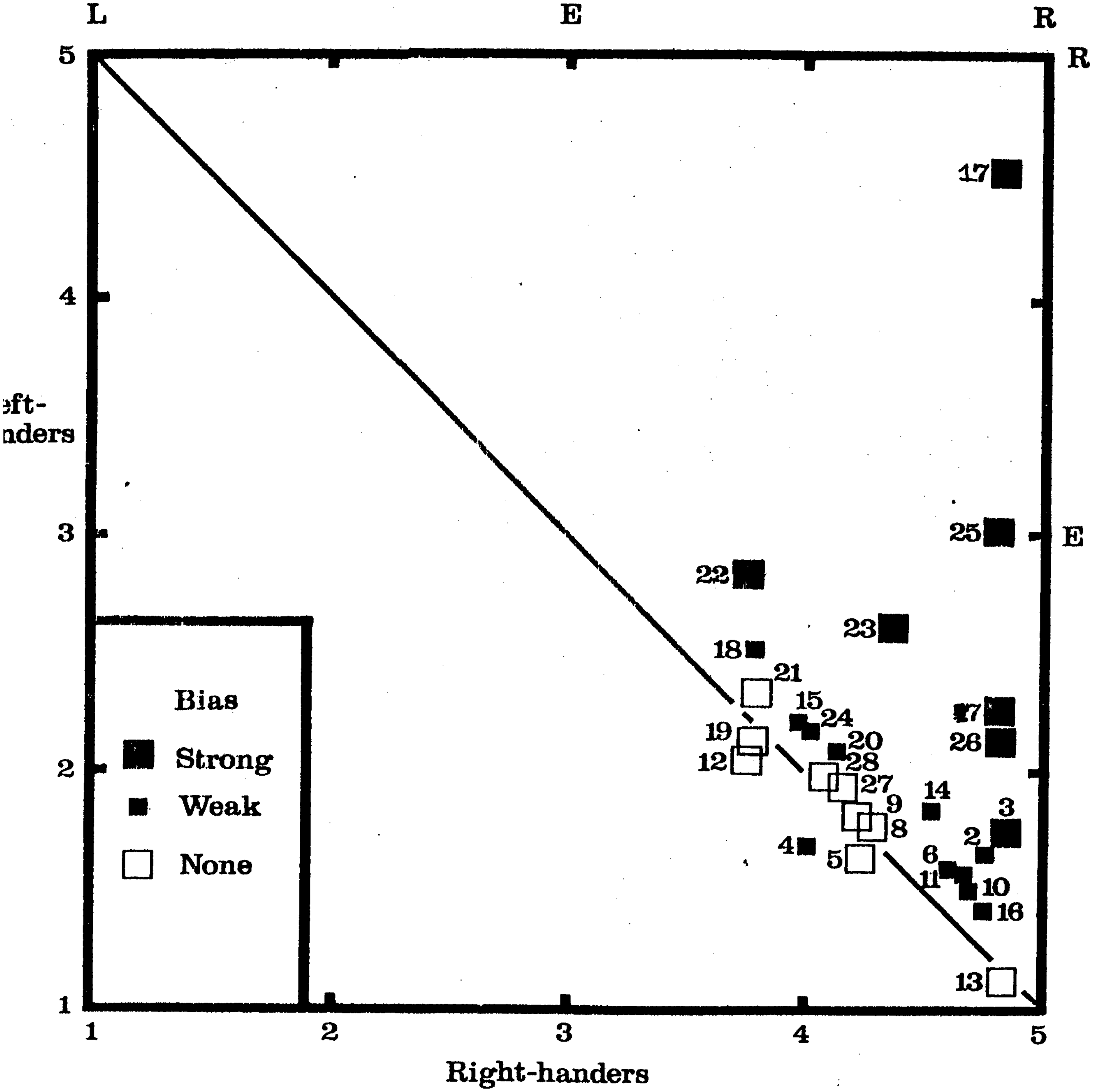

HS1
28q's
N x100
2
1
0
-100
0
+100

Figure 2.7 Shows, for each of the 28 individual questions, the mean scores of right and left-handers. Differences between right and left handers were tested by means of a t-test; points shown as open squares are not significantly different in right or left handers with $P > 0.05$. Solid squares show a significant difference; these have been arbitrarily divided into large differences (large squares), and small differences (small squares). Numbers alongside points represent question numbers. Question 1 has been omitted due to almost all subjects answering in extreme categories (see text).

Handedness Questions



<u>Figure 2.8</u> Shows the distribution of scores on a 21-item handedness scale (HS2), as described in the text, and in Apoendix A2:1. Dotted line in left-hand half is as in Figure 2.6

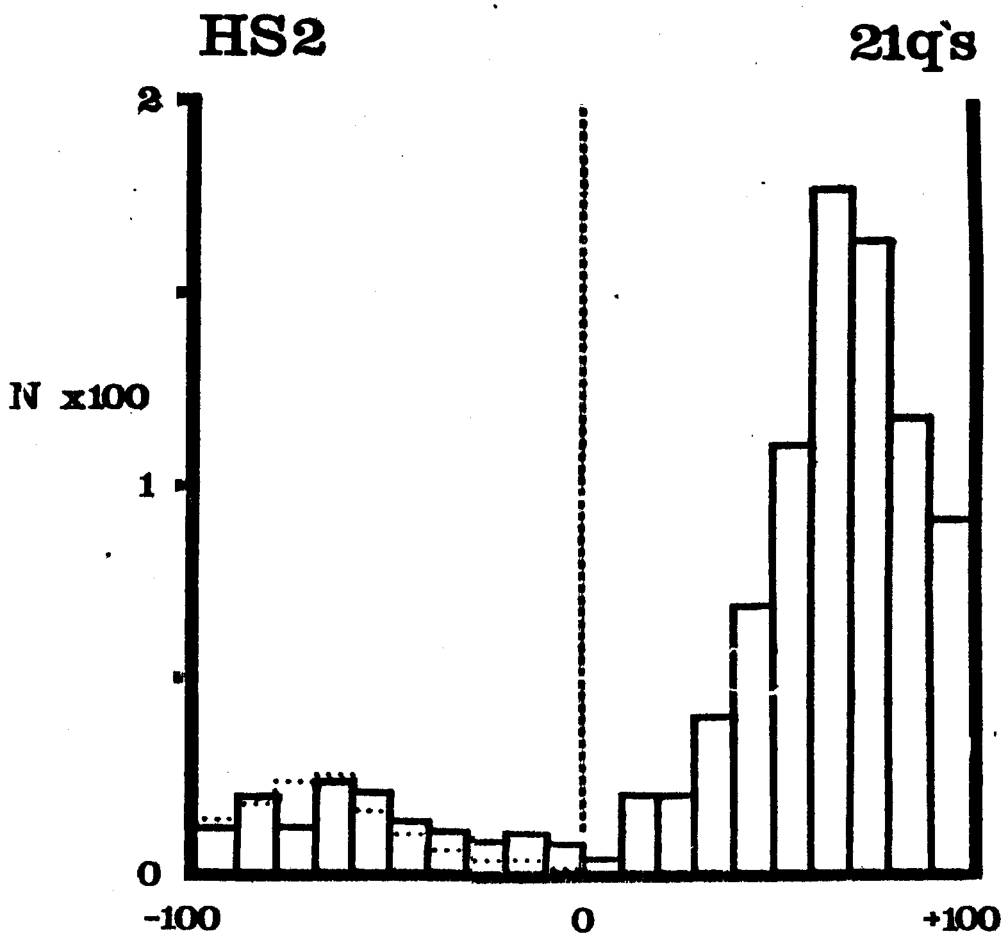
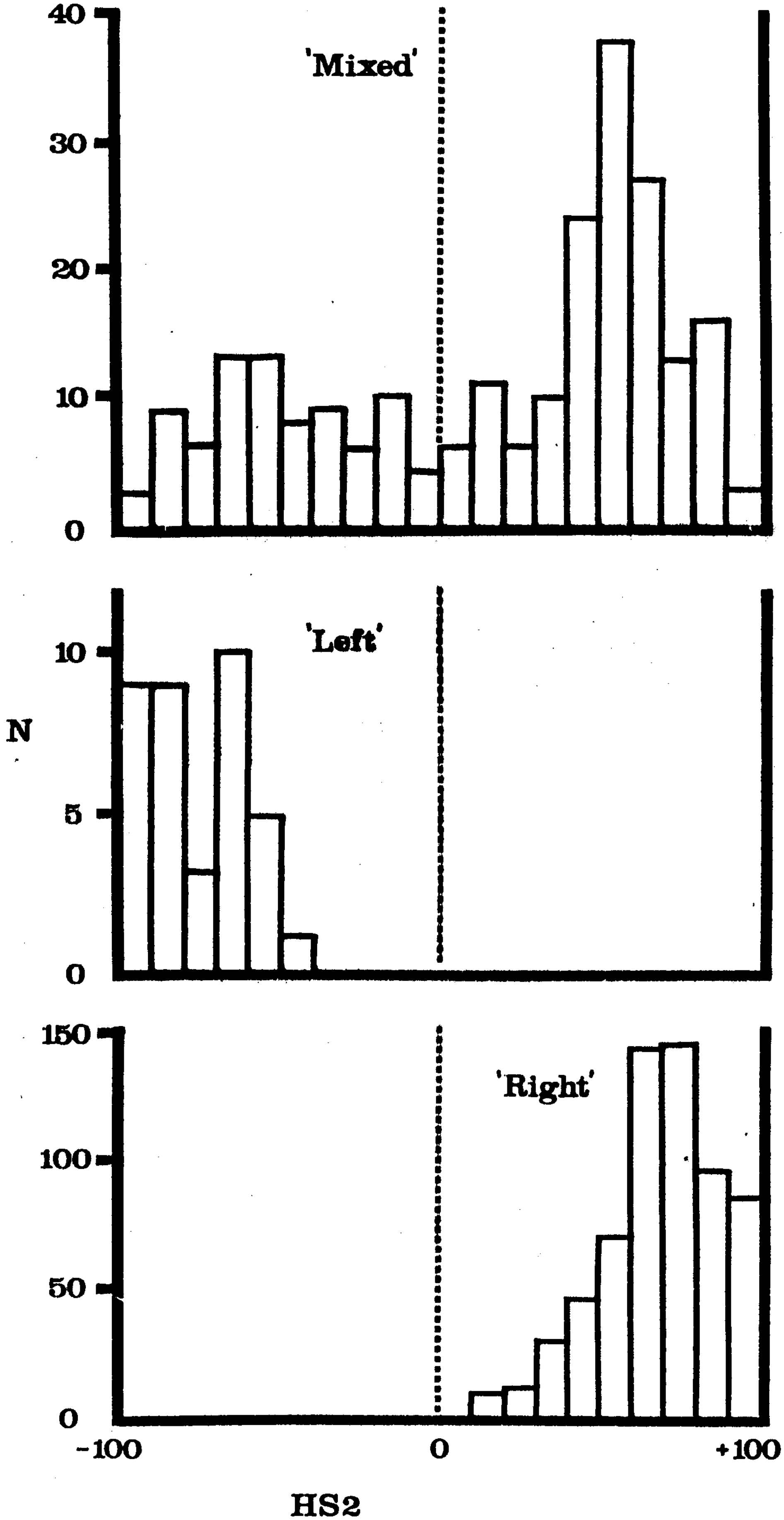
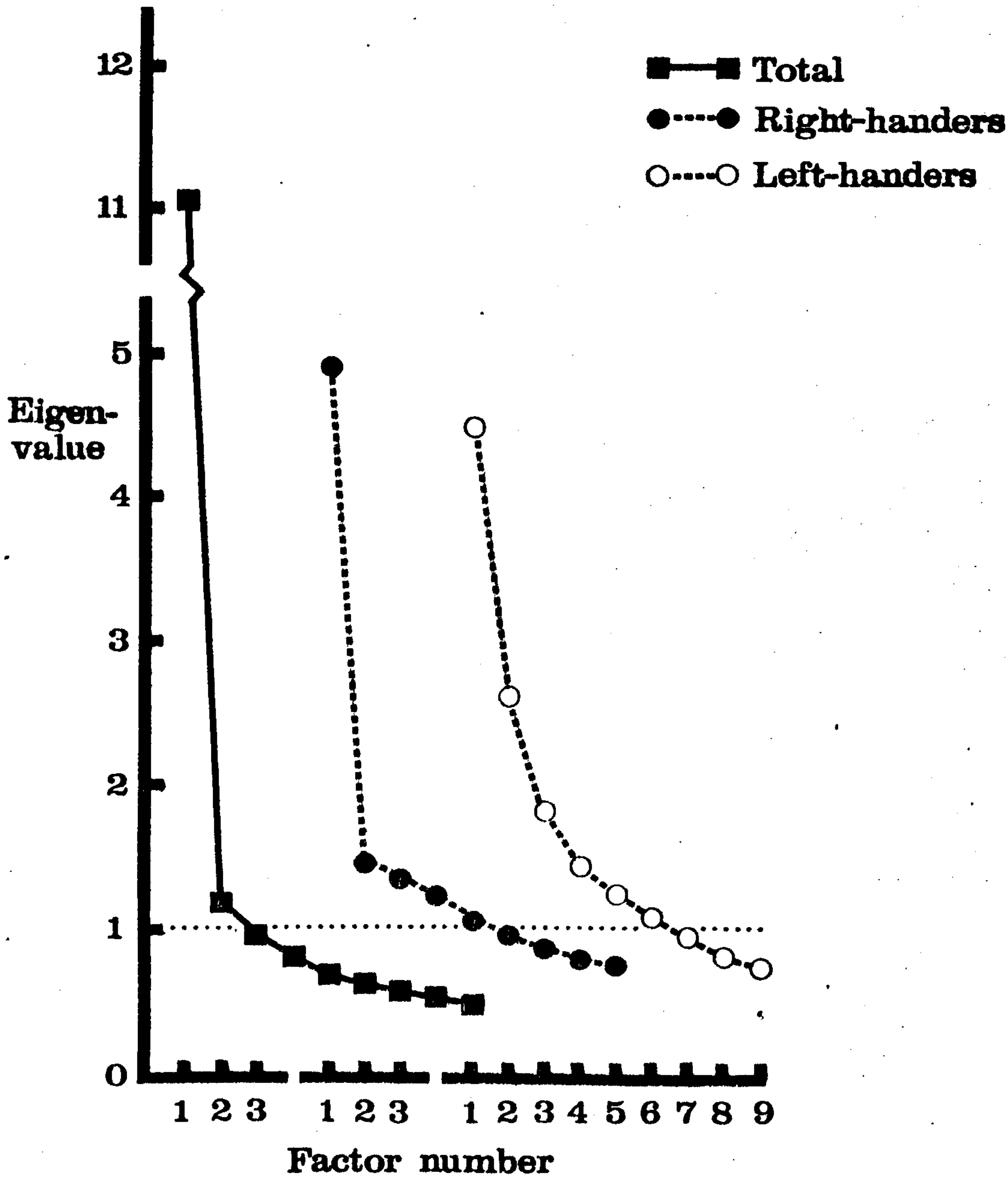

HS2
21q's
2
N x100
1
0
-100
0
+100

Figure 2.9 Shows the distribution of subjects divided into their classification of Right, Mixed and Left (Annett, 1967), as a function of their scores on the HS2. Note differences in scale of ordinates.

(1987) categories



<u>Figure 2.10</u> Shows a plot of eigen-value against factor number for factor analysis of questions in HS2. Solid squares indicate factor analysis of left and right-handers combined; solid circles indicate factor analysis of just right-handers, and open circles indicate factor analysis of just left-handers. Note that each curve has been staggered along the abscissa to avoid confusing overlap.

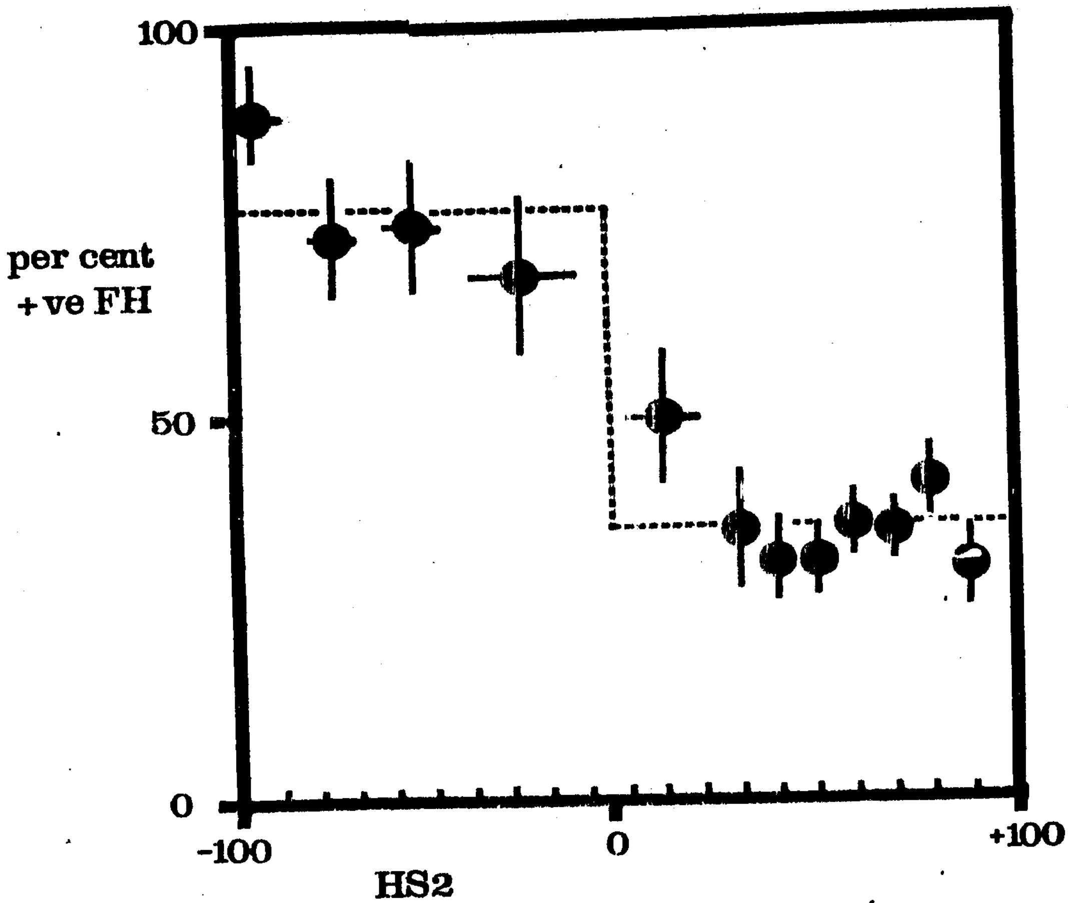


Total
Right-handers
Left-handers
12
11
5
4
3
2
1
0
Eigen-
value
1 2 3 1 2 3 1 2 3 4 5 6 7 8 9
Factor number

Figure 2.11 Shows the mean (abscissa) and standard deviation (ordinate) of the responses of individual subjects on the HS3.

<u>Figure 2.12</u> Shows, for different groupings within each handedness category, the percentage with a positive family history of left-handedness (see text for definition). Subjects are grouped into deciles on the HS2 scale. For the top seven right-handed categories each solid circle indicates one handedness decile. For the remaining points adjacent groups have had to be concatenated to produce adequate sample size; horizontal lines through each point indicate range of that particular point. Vertical bars through points indicate ± one standard error.

Dotted line represents expected distribution if there is no relation between degree of handedness and family history



100
per cent
+ve FH
50
0
-100
0
+100
HS2

<u>Figure 2.13</u> The degree of handedness (ordinate) of right-handed children of two right-handed parents in Survey 2 is shown as a function of the mid-parental handedness score (abscissa). Solid circles indicate mean, vertical bars representing ± one standard error. In view of skewness of overall distribution, dotted lines indicate medians. Figures along the top indicate sample size for each point.

R,R parents: R children

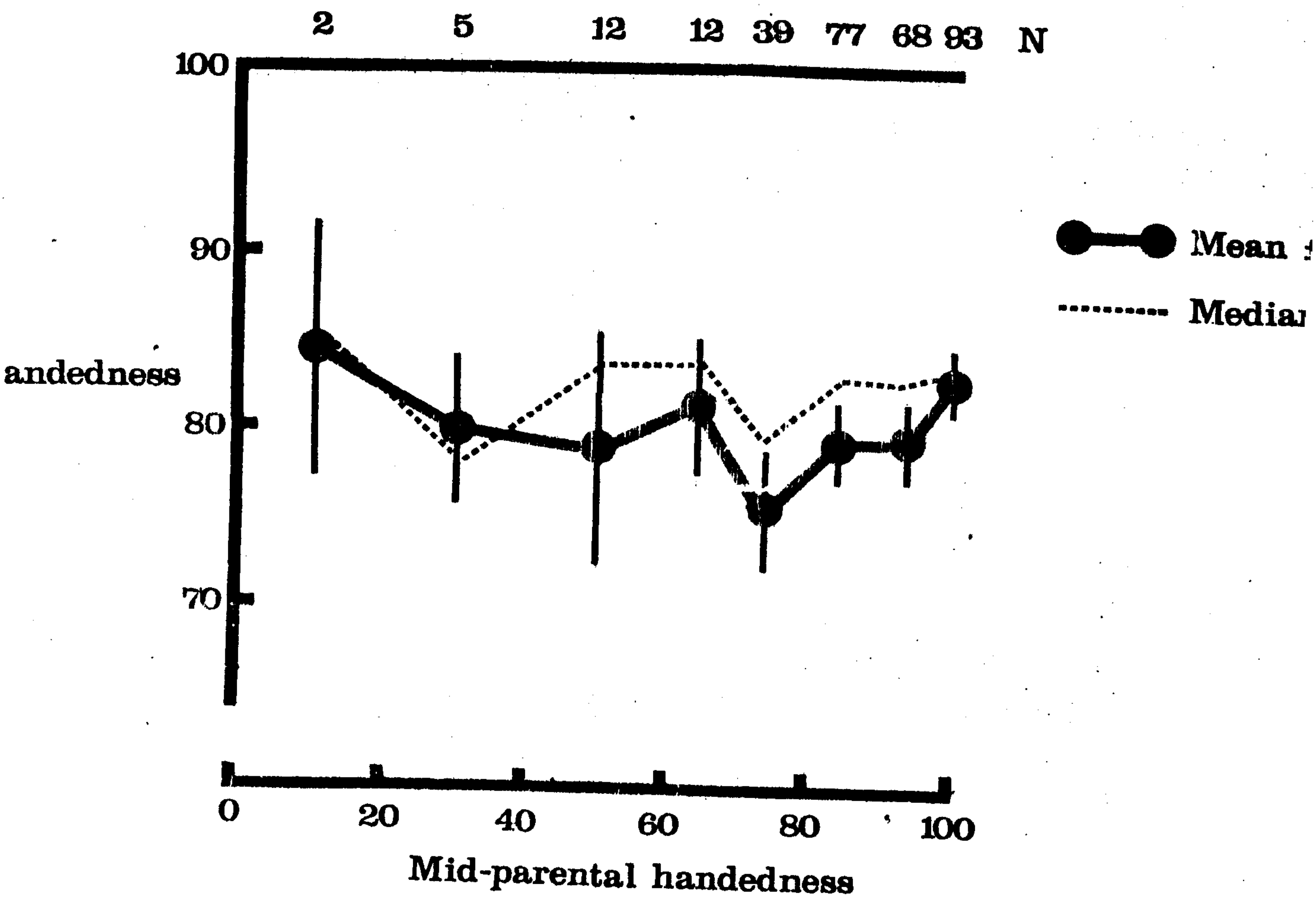
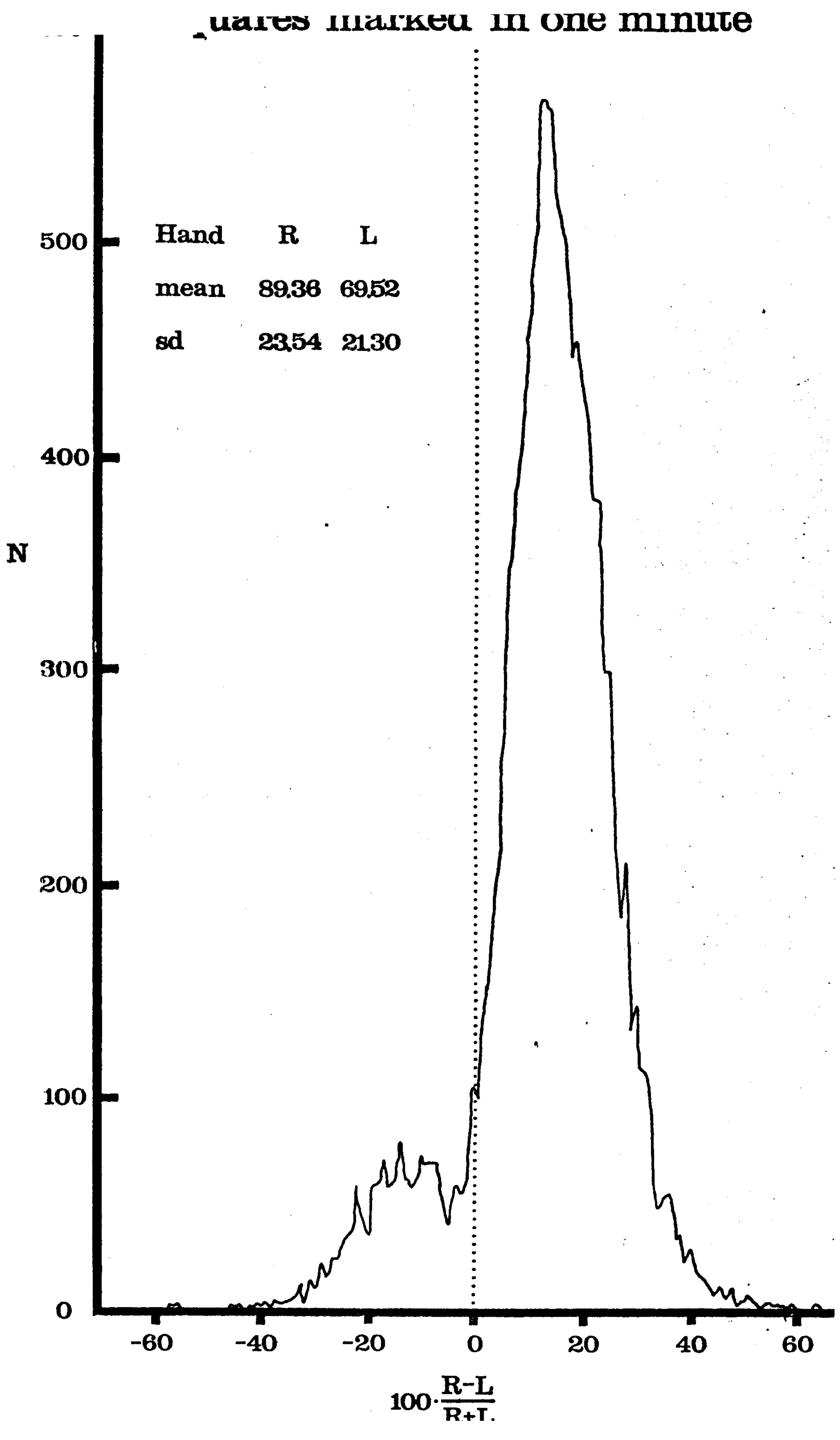


Figure 2.14 Shows the population distribution of an asymmetry score (100 x (R-L)/(R+L)) on a unimanual task, marking as many squares as possible on a piece of graph paper in one minute, as ascertained in 12777 11-year old children in the National Child Development Study. Overall Mean = 12.84; SD = 13.46; Skewness = -0.852; Kurtosis = 2.687.



_uares marked in one minute
Hand R L
mean 89.36 69.52
sd 23.54 21.30
N
500
400
300
200
100
0
-60
-40
-20
0
20
40
60
100·(R−L)/(R+L)

Figure 2.15 Shows the same data as Figure 2.14 but broken down by handedness (see Chapter 3.3 for details). For right-handers the mean score = 16.225, whilst for left-handers the mean score is -13.805; the respective SD's are 8.348 and 11.207 whilst skewnesses are 0.480 and -0.031. Kurtoses are 3.337 and 6.812, and sample sizes are 11208 and 1416 respectively.

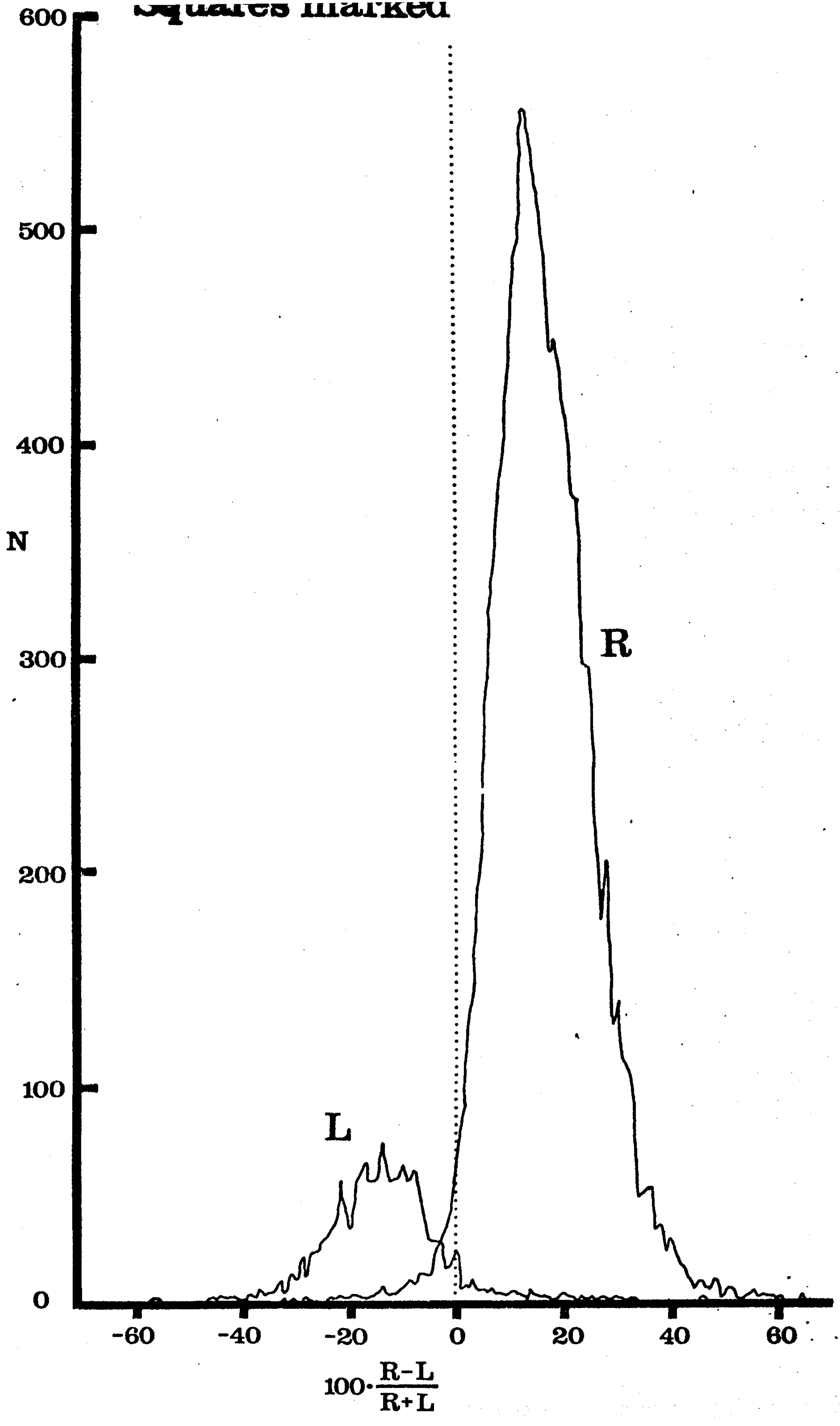

600
500
400
300
200
100
0
N
R
L
-60
-40
-20
0
20
40
60
100·(R−L)/(R+L)

Figure 2.16 Shows the distribution of an asymmetry score (-100 x (R-L)/(R+L)) for a task in which 11-year old children were timed at picking up 20 matches unimanually. For the entire population (N = 12747), the mean = 0.485, SD = 8.98, skewness = 0.262, and Kurtoses = 4.985. For right- and left-handers the respective distribution parameters are means = 0.982 and -3.408; SD's = 8.747 and 9.882; skewnesses = 0.331 and -0.351; Kurtoses = 4.319 and 10.467; and sample sizes = 11184 and 1419 respectively.

Time to pick up 20 matches