Handedness: A Family Study

ARTHUR FALEK

Department of Medical Genetics of the New York State Psychiatric Institute, Columbia University, New York 32, N. Y.

INVESTIGATIONS into the determination of hand preference have been directed either toward the biological or the environmental aspects of human personality development. Of potentially related phenomena, other functional asymmetries, speech, intelligence, vocational aptitude and some very specific behavior patterns have been subjected to scrutiny. Procedurally, hand preference has been measured by the questionnaire method, demonstration tests, or psychomotor tests.

Twins have received particular attention, since they are supposed to have a significantly higher frequency of left-handedness than do single-born individuals. There is disagreement on the type of zygosity group (one-egg or two-egg) showing an increased proportion of left-handers (Dahlberg, 1926; Rife, 1940; Husèn, 1955).

The theory of a cramped fetal position as the most plausible cause of this increase in twins has been questioned (Overstreet, 1938). With the fetus being in constant rotation throughout its development, neither the apparent prenatal position nor a certain kind of birth presentation can really be expected to be indicative of subsequent laterality. Moreover, left-handedness and twinning seem to be independent phenomena (Torgersen, 1950).

Four major family studies on hand dominance have been conducted in the last 50 years, all of them by means of questionnaires. The probands were university students who provided information on their own hand preference and by correspondence on the hand preference of their parents and siblings. In this manner, the distribution of right- and left-handedness in the offspring was determined in relation to the handedness of the parents. The genetic mechanism controlling hand preference was classified as simple recessive by Ramaley (1913), as undetermined by Chamberlain (1928) and as a graded quantitative (polygenic) trait by Rife (1940). In Trankell's (1955) statistical reevaluation of these first three studies, attention was called to the agreement in the data obtained by these investigators. Merrell (1957) doubted that the genesis of handedness can be accounted for independently by either hereditary or environmental factors.

The main objectives of the present study of hand preference variations in families of New York City school children were (a) to determine the cause or causes and total expressivity range of hand preference and (b) to establish, if possible, a family pattern of hand dominance which would explain the distribution of right- and left-handedness in children of all four types of parental combination.

The following questionnaire, based partly on the work of Hull (1936), was approved by The Board of Education of the City of New York for circulation among

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the parents of the students:

Please answer each question with one of the following: right (R), either (E), left (L).

a. With which hand do you write?
b. With which hand do you distribute cards when dealing them?
c. With which hand do you draw or sketch a picture?
d. With which hand do you hold the top of the broom handle when sweeping?
e. With which hand do you put your house key in the keyhole when both hands are free?

Have you ever found it necessary to change your activities from one hand to the other due to illness, injury or social pressure? Yes.... No.... If the answer is yes, please give details on the other side of this questionnaire.

An introductory statement by the school authorities served to inform the parents that the study was limited to families in which both of the child's natural parents were in the home. The six schools selected as representative of the metropolitan school population distributed a total of 10,900 questionnaires. A more detailed account was presented in an earlier report (Falek, 1957).

Of the 5,652 questionnaires returned, 5,118 were acceptable for the purposes of the study. The main reasons for rejection were lack of identification, refusal to be interviewed, unavailability of the natural parent or parents because of death, failure to answer more than two questions, and impairment in the use of one hand (permanent injury or loss). School regulations precluded follow-up letters or visits to those persons who did not respond to the questionnaire.

The accepted questionnaires of each school were keyed and tabulated as to the handedness of every parent. The scoring technique for measuring an individual's hand preference on the basis of his replies to the five test items was patterned after the method used by Durost (1934). Accordingly, a person's manual dominance was determined by the difference between the number of his right (R) and left (L) responses, divided by the total number of responses. "Either" answers were counted only in the total score. Positive scores were taken to indicate various degrees of right-handedness, with negative scores denoting gradations in left-handedness.

The parent population was divided into four classes of handedness matings, the right-to-left-handed matings being subdivided according to which parent was left-handed. Since the smallest group (17 matings) was that with two left-handed parents, it was used in toto for further study. Of those matings where both parents were classified as right-handed, 20 cases were selected by random number from families where both parents scored relatively high right on the original questionnaire. From 47 families with a markedly left-handed father and 45 with a markedly left-handed mother, 20 matings were randomly selected from each group for detailed evaluation, making a total of 77 families.

Each home was visited and all family members over five years of age were tested for their hand preference by a battery of tests and personal interviews. Although all of the 77 sets of parents had previously agreed to home interview, it was only possible to complete this study on 44 of these families. On direct contact at least one of the parents in the other families refused or was unavailable for home testing.

In order to replenish the most crucial group, left-to-left matings, an additional survey was organized in another high school and in a city college. The procedure of ascertainment was simplified in such a way that instead of a questionnaire distributed among the parents, statements were read before all classes. The only item asked for was the name of any pupil both of whose parents either wrote with the left hand or both worked and ate with it. Of the 5,721 students questioned, 14 reported that both parents were left-handed. However, only nine families of this group were available for further study. Of the 53 families tested, 49 were white and 4 nonwhite. Altogether, there were 248 individuals, ranging in age from 6 to 59 years: 53 fathers, 53 mothers, 59 sons, and 83 daughters. Only the results from the home visits were used for further analysis. For the home interview all subjects were asked to demonstrate the five activities listed in the original questionnaire as well as the following four activities:

f. Hold the spoon as you do when you eat with it.
g. Strike a match.
h. Hold the knife as you do when cutting bread.
i. Thread the needle.

The family distribution for the original questionnaire and the home demonstration test is given in Table 1.

In addition to the demonstration test, a motor test battery was developed to evaluate hand preference. Previously used laterality indicators either consisted of tests of eye-hand coordination or were so designed as not to be readily transportable. There had been so much disagreement on the relation between eye and hand dominance that quantitative measures of eye-hand coordination were not used in the present study. The five tests of the motor battery to be given in the home were chosen for assessing the strength and speed of each hand, as well as index finger rapidity in wrist-arm movements, and dexterity in thumb-forefinger manipulation.

In measuring hand strength, a Kny-Scheerer dynamometer was employed in such a way that the highest score obtained in three trials by each hand was the value recorded. Because of its dimensions and ovoid shape, this test instrument proved to be difficult to manage for younger children and other persons whose fingers were too short to curl around the outer ridge.

For the remaining four tests, each hand was recorded in three intervals of five seconds each, separated by a five-second intermission. The preferred hand, as given

TABLE 1. FAMILIES CLASSIFIED AS TO HANDEDNESS OF PARENTS BY ORIGINAL QUESTIONNAIRE AND BY HOME DEMONSTRATION

Parental Mating Types			Originally Selected Population			Originally Selected Population Plus Supplementary Population	
Father		Mother	Original Quest.	Home* Q5	Home† Q9	Home* Q5	Home† Q9
R	×	R	11	15	13	16	14
R	×	L	6	4	6	8	9
L	×	R	15	19	17	21	17
L	×	L	12	6	8	8	13
Total			44	44	44	53	53

* Home retest with 5 original questions.
† With 4 additional questions.

on the questionnaire, was never tested first. The speed of the index finger was assessed by means of a tapping board, a familiar device in psychological laboratories. A Veeder-Root counter automatically recorded the number of taps produced by the right and left forefingers.

Arm-wrist movement was appraised by a "Turnbuckle Test", using a remodeled Veeder-Root counter which added each time the screw-knob was made to complete one revolution in either direction. At the signal, the knob was turned in one direction by outward wrist-arm movements with no independent activity by the fingers.

The same counter was employed in a "Watch-Winding Test". In this measure of finger dexterity, however, thumb and forefinger turned the screw-knob in an outward direction.

Wrist-hand movement was evaluated by means of a "Pencil Tapping Test". The number of pencil dots made on uniform blank sections of paper in the specified time intervals were scored at a later date.

The difference in score between the right and left hands for each of the tests of the motor battery was the raw hand preference score. A plus score indicated right-hand preference and a minus score signified left-hand preference. In the first group of families examined, retests were made after an interval of two hours. The retests were consistent and failed to reveal raw score hand preference changes in cases where the difference in score between the right and left hands was 8 or more. Subsequently, therefore, retests were made only where the difference was less than 8. Since the number of dots in the "Pencil Tapping Test" could not be counted during home visits, the size of the difference between hands was not known, and no retests were conducted.

The mean and variance of the raw hand preference scores for each of the motor tests in the six age-sex groups (fathers, sons over age 14, sons ages 6–14, mothers, daughters over age 14, daughters ages 6–14) were calculated. For the first four tests of the motor battery, the change in raw score for each hand from test to retest was used to provide data for the determination of the variance in score for each hand on retest.

Group differences in the number of tested subjects were caused by the inability of some persons, mostly youngsters, to manipulate the dynamometer or Veeder-Root counter, or sit through the Pencil Tapping Test. According to the results of an analysis of variance for the first four tests, all differences between right and left hands in the given motor measures significantly exceeded the variance for each hand upon retesting (Table 2), thus providing statistical evidence for the fact that these tests measure a characteristic which may be defined as handedness.

For the four tests administered in three parts, the relationship among these parts was studied to elicit possible effects of learning and fatigue. No significant effects were found. In the absence of such effects and in view of the agreement of test and retest, it was concluded that the motor tests were reliable.

To measure the common elements in the test battery, intercorrelations were run on the scores of the total family population, with most of them proving significant for both parents and children. In none of the six groups investigated were significantly negative correlations found for any of the tests in the battery. To the extent that the

TABLE 2. SIGNIFICANCE OF THE RATIOS OF THE VARIANCE BETWEEN HANDS TO THE VARIANCE BETWEEN TEST AND RETEST FOR ONE HAND

Motor Tests	F Values		Critical Values	
	Left Hand	Right Hand	.01	.05
Dynamometer	3.70	4.15	1.66	1.44
Finger Tap	2.47	1.82	1.45	1.32
Turnbuckle	1.78	1.43	1.43	1.29
Watch	2.39	2.07	1.39	1.26

correlations were positive, the different tests of the battery could be said to be measuring a common function.

The next step in the analysis was to combine all test scores (standard scores). For one method, the individual difference scores for each of the six tests, the five motor tests and the home demonstration, were divided by the standard deviation obtained in each test for the group under analysis: $(R - L)/s$. In another procedure, the mean score for each test in each of the six groups was subtracted from the difference scores, and then divided by the standard deviation: $[(R - L) - (\bar{R} - \bar{L})]/s$.

While the mean for the parents was close to zero, because of nearly equalized numbers in the four mating groups, that for the children was intermediate between the means for the parents and for a randomly selected group. In other words, parents and children were not directly comparable on the basis of the scores provided by the second technique. However, a difference in sign between the two sum standard scores of the motor tests for an individual proved useful as an indicator of ambidexterity. Statistically, this use of the two methods was based on the following considerations:

For the motor tests, most distributions of R—L scores were bimodal, with a mode at large positive values, more right than left, an antimode for small positive values and a second, less well-defined mode for negative values. The mean usually fell in the region of the antimode. It was assumed, then, that the antimode might be a more reasonable division point between right-hand scores and left-hand scores than would zero. Since the antimode was difficult to determine objectively, and the mean usually roughly coincided with it, it seemed that the mean might be a suitable objective, if arbitrary, cut-off point. Further, since social pressure tends toward right-handedness, individuals who were inherently right-handed were expected to have right-handed scores, while some individuals who were inherently left-handed would be shifted towards the right-hand end of the scale and have only small left-hand scores, and ambidexters would tend to be found in the group with low right-hand scores. Hence it seemed reasonable to classify all individuals with negative R — L scores as left-handed, all those with scores above the mean as right-handed, and those falling between as ambidextrous or of doubtful hand preference. While 43 of 142 children were classified as ambidextrous, only three mothers and no fathers were so classified. It should be remembered that many of the parents were selected because of their high scores.

The original questionnaire scores were used for estimating the frequency of left-handedness in the parental population (10,236 parents). In this population 3.10 per cent of the mothers and 3.88 per cent of the fathers were classified as left-handed. The difference between the sexes was not statistically significant ($.007 \pm .0037$).

In the 53 families subjected to further analysis, the 142 children have similar percentages of left-hand responses to eight of the nine questions on the home demonstration test. The only exception is the bimanual broom sweeping item, where there is a higher percentage of left responses. In the parental sample, however, left-hand scores are less frequent in response to the writing and drawing questions than to the others, apparently as a reflection of previous school pressures on the determination of hand preference.

A next step in the study is the analysis of the data by family groups. In comparing the handedness of the children of the four mating types on the demonstration test, a significant inter-group difference is found at the five per cent level ($\chi^2_{(3)} = 8.82$). Relatively low frequencies of left-handed offspring are seen in all mating categories except for that between left-handed mothers and right-handed fathers, which produces a significant increase in left-handed children (Table 3). There is no significant difference in the proportions of left-handed children when the offspring of left-handed mothers are compared with those of right-handed mothers. What is more, the frequency of left-handedness in the children of two left-handed parents does not differ statistically from that found in the children of either two right-handed parents or a left-handed father and a right-handed mother.

The motor test results present a somewhat different picture. Using the $(R - L)/s$ or $[(R - L) - (\bar{R} - \bar{L})]/s$ scores discussed above, no significant hand preference differences are obtained among the children of the four mating groups, apparently due to the fact that some individuals yielded $R - L$ difference scores close to zero. In other words, they did equally well with both hands. Such ambidextrous persons may have been easily shifted in hand preference classification by relatively small error variations in the scores.

It seemed advisable, therefore, to reanalyze the data without those individuals for whom the sum of the standardized scores calculated in the two ways given above differed in sign, indicating ambidexterity. When one of the parents was found to be ambidextrous, the entire family was omitted. There then remain 45 families with 92 children (Table 4).

Significant differences ($P < .05$) are now seen among the children of the four mating groups. In order to examine the combined results of the motor and demonstration tests in this population, the demonstration test data have been recalculated for those families and children accepted for the motor test analysis. The results again show significant inter-group differences ($P < .025$) for the offspring of the four mating groups (Table 5).

TABLE 3. COMPARISON OF HANDEDNESS OF CHILDREN ACCORDING TO PARENTAL MATINGS (DEMONSTRATION TEST)

	R. ♂ × R. ♀	R. ♂ × L. ♀	L. ♂ × R. ♀	L. ♂ × L. ♀	Total
Number of Matings	14	9	17	13	53
Right-Handed Children	36	15	41	26	118
Left-Handed Children	4	9	6	5	24
Total	40	24	47	31	142

$\chi^2_{(3)} = 8.82$, $P < .05$

TABLE 4. COMPARISON OF HANDEDNESS OF CHILDREN ACCORDING TO PARENTAL MATINGS (MOTOR TESTS: EXCLUSIVE OF AMBIDEXTERS)

	R. ♂ × R. ♀	R. ♂ × L. ♀	L. ♂ × R. ♀	L. ♂ × L. ♀	Total
Number of Matings	9	8	16	12	45
Right-Handed Children	17	8	28	18	71
Left-Handed Children	3	8	6	4	21
Total	20	16	34	22	92

$\chi^2_{(3)} = 8.18, P < .05$

TABLE 5. COMPARISON OF HANDEDNESS OF CHILDREN ACCORDING TO PARENTAL MATINGS (DEMONSTRATION TEST: EXCLUSIVE OF AMBIDEXTERS)

	R. ♂ × R. ♀	R. ♂ × L. ♀	L. ♂ × R. ♀	L. ♂ × L. ♀	Total
Number of Matings	11	7	16	11	45
Right-Handed Children	21	8	30	18	77
Left-Handed Children	3	6	5	1	15
Total	24	14	35	19	92

$\chi^2_{(3)} = 9.41, P < .025$

From Tables 3, 4 and 5 it is clear that there is a significant relationship between the handedness of the parents and the frequency of left-handed children. Interclass correlations between parental scores and those of their children, however, do not show any degree of association. The nonlinear relationship between the number of left-handed parents (0, 1, or 2) and the frequency of left-handed offspring accounts for the absence of a significant correlation between the average scores of parents and children. Furthermore, the similar frequencies of left-handed children when both parents are right-handed or left-handed indicate that hand preference is not readily explained on the basis of classical Mendelian segregation.

A plausible working hypothesis might be that hand dominance results from the interaction of the genetic potentialities of the child and various parental attitudes. The effectiveness of the guidance provided by the parents in changing any inborn preference would seem to depend on the degree of coercion used, on the age of the child at the time of parental intervention, and on the consistency with which such pressure is brought to bear on the child. This hypothesis is supported by data obtained in re-interviews with 19 cooperative families in the four parental combinations (three sets of right-handed parents, four with a left-handed father, three with a left-handed mother, and nine where both parents are left-handed).

The attitudes of the parents towards handedness may largely be the result of their own social, vocational and economic experiences. Social problems are reported by left-handed subjects of either sex. Aside from the embarrassing need for special seating arrangements at the table, many left-handed persons find their unusual hand preference used by others as the butt of unpleasant jokes. Nevertheless, social drawbacks seem to be less important as a motivating force than the vocational and economic problems faced by the left-hander.

For example, local vocational agencies report that in semi-skilled and factory employment the left-handed male has a considerable disadvantage in job placement, mainly because machines are designed for the right-hander. It is not surprising, therefore, that left-handed fathers interested in improved economic opportunities

for their children should be particularly set on having the home training directed toward right-handedness. The majority of fathers in the family study are in non-professional occupations. Of interest is the fact that children of the left-handed fathers tend to be right-handed.

The majority of mothers in our sample were employed either in secretarial or in unskilled capacities and only worked for a short time prior to marriage. Hence the left-handed mother, while experiencing social pressures similar to the left-handed father, encounters only a fraction of the economic and vocational stresses associated with hand preference. It may be for this reason that left-handed females tend to be more permissive in regard to left-handedness in their children than are their husbands. Only when they are married to left-handed husbands do they apply themselves most diligently to the task of turning their children into right-handers.

Right-handed parents are rarely familiar with the problems faced by left-handers in a right-handed world and are therefore not concerned with the hand preference of their children. With little or no parental guidance in this respect, the large majority of their children tend to become right-handed anyway. A higher frequency of left-handed children occurs only in the mating group where the father is right-handed and the mother left-handed. Without reinforcement from her husband's bias, a left-handed mother does not seem to exert much pressure on her own account in the determination of her children's hand preference.

In the group of matings where the father is left-handed and the mother right-handed, the father's bias against left-handedness is sufficiently strong to result in as low a frequency of left-handed offspring as is found in right-to-right matings. Right-handed mothers in this group become acquainted with the disadvantages of left-handedness through some of the problems encountered by their husbands. They cannot be expected, however, to be so strongly or so consistently motivated to direct the development of hand preference in their children as left-handed mothers married

TABLE 6. HANDEDNESS OF CHILDREN IN REINTERVIEWED FAMILIES

Parental Mating Types			Occupation of Father	Children					
				Little Home Pressure		Moderate Home Pressure		Constant Home Pressure	
Father		Mother		R	L	R	L	R	L
R	×	R (3)	Laborer	2	—	—	—	—	—
			Semi Prof.	—	1	—	—	—	—
			Professional	1	1	—	—	—	—
R	×	L (3)	Laborer	5	1	—	—	—	—
			Semi Prof.	1	2	—	—	—	—
			Professional	—	—	—	—	—	—
L	×	R (4)	Laborer	—	—	—	—	8	—
			Semi Prof.	—	—	3	—	—	—
			Professional	2	1	—	—	—	—
L	×	L (9)	Laborer	—	—	—	—	7	1
			Semi Prof.	1	—	—	—	5	—
			Professional	1	1	—	—	2	2

to left-handed fathers. In fact, there is evidence from the re-interviews that they do not exert as much pressure (Table 6).

On this basis, it may be hypothesized that dissimilar degrees of parental influence mask the original difference between the innate potentialities of children of left-handed fathers and right-handed mothers and of children of two left-handed parents. As a result, equal frequencies of left-handed children are found in these two mating groups.

Tentative support for a hereditary component in the causation of a particular hand preference comes from a combination of findings, each of which in itself would seem to carry relatively little weight. Taken together, however, these findings present a picture which supports a hypothesized genetic component of handedness. One such finding is that there are left-handed children, reported as being well-adjusted by both home and school, who remain left-handed despite the efforts of their left-handed parents to render them right-handed. It would seem, therefore, that handedness depends in part on some basic characteristic of the individual.

Another important point can be seen when one compares the frequencies of left-handed children from the two mating types where relatively little parental pressure is exerted (namely, both parents right-handed and left-handed mothers married to right-handed fathers). In the latter instance, there is a significantly higher frequency of left-handed children. The two mating groups with little parental pressure lend some indirect support to the hypothesis of a hereditary component operating in the determination of hand preference.

Finally, the parents were asked about the occurrence of left-handedness in their parents and sibs. In families with a left-handed child, the proportion of families with at least one left-handed relative was found to be significantly greater ($P < .001$) than in families with no left-handed child. The excess of families with left-handers, in the presence of a left-handed child, was so pronounced that it did not seem possible to ascribe it entirely to differences in the degree of familiarity with the handedness patterns of relatives. (Table 7).

The failure of families with a left-handed child to show a significant increase in left-handed parents does not invalidate the explanation. The results of this analysis

TABLE 7. HANDEDNESS OF RELATIVES OF PARENTS IN LEFT- AND RIGHT- CHILD FAMILIES

	Families with at least one left-handed relative	Families with no left-handed relative
Families with at least one left-handed child	15	7
Families with no left-handed child	6	25

$\chi^2_{(1)} = 10.86$, $P < .001$

TABLE 8. HANDEDNESS OF PARENTS IN LEFT- AND RIGHT- CHILD FAMILIES

	Families with a left-handed parent	Families with no left-handed parent
Families with a left-handed child	18	4
Families with no left-handed child	21	10

$\chi^2_{(1)} = 0.682$, $P < .30$

giving a P between .3 and .5 are in part explained by the fact that the left-handed fathers may have been particularly anxious to direct their children toward right-handness (Table 8).

SUMMARY AND CONCLUSIONS

In this study of the families of a representative series of New York City school children, the main objectives were to determine the mechanisms involved in the development of a hand preference in individuals, and to establish, if possible, a family pattern of hand dominance which would explain the distribution of right- and left-handedness in the children of four types of parental combination. A battery of motor and demonstration tests was used for measuring hand preference, and a sample of parents from the four mating groups was interviewed concerning the degree to which they tried to make their children right-handed.

The following conclusions were reached:

1. A consistent and statistically significant increase in the proportion of left-handed children is found only in matings of right-handed fathers and left-handed mothers. In all other mating groups (two right-handed parents, left-handed father and right-handed mother, and two left-handed parents), the observed left-handedness rates of the children vary only from 11 to 18 per cent.

2. Families differ in whether and to what extent the children are guided towards right-handedness. Left-handed fathers are particularly cognizant of the economic as well as the social drawbacks of left-handedness, and tend to be most concerned with making their children right-handed. Mothers generally cooperate with the efforts of their left-handed husbands to make their children right-handed. Compared with right-handed mothers, however, left-handed mothers are more consistent in their determination to direct their children toward right-handedness. Left-handed wives of right-handed men apparently exert little influence on the hand preference of their children. Right-handed parents are usually least aware of the problems associated with left-handedness.

3. A possible genetic effect is demonstrated by the following observations: (a) inability of some left-handed parents to change the hand preference of their children, (b) differences in the frequency of left-handed children in the two mating groups revealing no evidence of marked parental pressure, and (c) increased frequency of a left-handed relative in families with a left-handed child.

4. The hand preference of an individual is the result of both his genetic endowment and his early training in the home.

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