

DERMATOGLYPHICS AND THE PROBLEM OF HANDEDNESS

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PART I

INTRODUCTION

The chief problem of handedness is: Are left handers merely individuals who have spontaneously elected, or have been influenced by training, to use the left hand as the preferred functional hand; or is left handedness an inborn trait that may be modified or even reversed by training?

This is a difficult problem to solve for individual cases, but we believe that we can demonstrate that right handers as a group and left handers as a group differ statistically from each other in a great many characters that are not influenced by training.

An ideal criterion for determining whether right handers differ morphologically from left handers would exist if it were found that all true right handers had clockwise hair whorl and left handers counterclockwise hair whorl. It has been found that about 80 per cent of the population have clockwise and 20 per cent counterclockwise hair whorl, which would fit in fairly well with the relative proportions of right and left handers. But alas! Only 21 per cent of our left handers (not appreciably higher than in the general population) have counterclockwise hair whorl. Worse still, 15 per cent of our right handers also have counterclockwise hair whorl. So the direction of hair whorl seems to have no relation to handedness and cannot be used as a criterion thereof.

Measurements of the lengths of the two arms, widths of the two hands, circumferences of the upper and lower arms, show

that in most cases the preferred arm has the larger dimensions, but these differences may be no more than a reflection of the greater functioning of the preferred arm or hand. Hence such data do not help us to decide whether hand dominance is inborn or functionally acquired.

After an extensive search for morphological criteria that might be useful indicators of inborn differences between functional right and left handers, we have been driven by a process of exclusion to use palm, finger and sole papillary patterns as the only available material for this study.

The main advantage for this study of palm, finger and sole patterns lies in the fact that they are determined and fixed for life during the third month of fetal life and are not at all influenced by post-natal functioning of the hands. Bonnevie ('27) and Cummins ('29) have shown that the patterns in the fingers and palms are secondary expressions of morphological differences in the fetal hands and are therefore more important as criteria than they seem. Another advantage of dermatoglyphics for this study is that the present writer (Newman, '30) has already shown for identical twins that there is a strong tendency for the left hander of a twin pair to show a mirror-image relation with the right hander of the pair with respect to palmar configurations, indicating that a reversal in functional dominance is usually correlated with a reversal in palmar configurations. It was this discovery that led us to undertake the present investigation of left-handed single individuals to determine whether or not in them this correlation between functional handedness and dermatoglyphic characters might hold.

In his study of the dermatoglyphics of twins the present writer showed that there is a pronounced statistical bimanual asymmetry of a far-reaching sort involving every element of the palmar complex. Independently, a short time afterward, Cummins, Leche and McClure ('31) published a study of bimanual variations in palmar dermatoglyphics which confirmed our findings almost completely. These studies proved that there is, statistically, a difference between right and left

hands and that this difference involves all of the palmar elements.

More recently, Leche ('32) has published a study of handedness and dermatoglyphics in which she compares the palms of 244 selected left handers with those of 300 unselected persons, consisting of the usual assortment of right handers, left handers and ambidexters. Our present study differs from that of Leche in that we compare our carefully chosen left handers with equally carefully chosen right handers, and we have studied not only palmar dermatoglyphics, as Leche did, but those of fingers and soles. The data on sole dermatoglyphics will, however, be reserved for a separate paper.

What have we found? As a preliminary statement, in advance of the data that support the conclusions expressed, we may say that the group of left handers on the whole differ statistically and consistently from right handers in a great many ways, but that there are many exceptions among both left handers and right handers. When right handers show a statistical predominance of certain pattern units on right hands, left handers frequently show a predominance of these units in left hands, or at least some decrease in dextral predominance. This holds for no less than nine separate items of finger and palm patterns. This was a not unexpected result, but the next result was indeed unexpected. In no less than seventeen items of finger and palm complexes we found that dextral characters (characters that predominate on right hands) were more numerous in the two hands combined in left handers than in right handers. In other words, we find that left handers are in both hands combined more dextral in their dermatoglyphics than right handers. This may be interpreted to mean that the left hands of left handers tend to be dextral, and there is only a slight tendency for the right hands of left handers to be sinistral.

What then are left handers? The data here presented tend to indicate that most left handers are not in general morphologically reversed individuals, but merely individuals in which asymmetry is poorly developed, in which there is no marked

difference between right and left hands. It may also mean that left handers are individuals in whom both hands tend to be dextral and in whom a sinistral hand tends to be absent.

There are only a few cases among left handers where the left hand is more dextral than the right, which would amount to real asymmetry reversal, but there are many more left handers than right handers in which the two hands are almost or quite equally dextral.

The data upon which these statements rest constitute the body of the present paper. For financial aid in accumulating the data for this study the writer wishes to acknowledge his indebtedness to the Rockefeller Biological Research Fund. The data were collected by two assistants, Mrs. Helen Seevers and Mr. Donald Boyer, both of whom also assisted in compiling the data.

MATERIALS AND METHODS

Extensive data were collected for 100 left handers, half of them women and half men, chosen mainly from the student body of The University of Chicago. Our thanks are here tendered to those who, at considerable inconvenience, allowed themselves to be subjects of this investigation. Notices were posted on bulletin boards and were published in the Daily Maroon requesting all persons who were left handers to communicate with our assistants, and if willing to be examined, to make appointments. A large percentage of the left handers on the campus were thus made available for study, though there should be about two or three times as many as those found, if previous statistical studies are at all valid.

The following data were obtained for most of the cases studied:

1. The preferred hand used in writing, throwing, catching, holding a hammer or other one-handed instruments.
2. The foot used in kicking a football or other object.
3. The foot put forward in high jumping.
4. The preferred eye in sighting, as in aiming a gun or similar action.

5. The arm held outward in arm folding.
6. The arm removed first in taking off a coat and the arm first put into the sleeve when putting on a coat.
7. Anthropometric measurements:
 - a. Alecranon to finger tip of both arms.
 - b. Length of both feet.
 - c. Width of both feet.
 - d. Width of both hands.
8. The position, right or left of the median line, of the crown whorl of the head hair.
9. Whether the crown whorl was single or double.
10. The direction of whorl of hair in the crown, whether clockwise or counterclockwise.
11. What close relatives are left handers, if any.
12. Complete palm prints.
13. Complete finger prints.
14. Complete sole prints.

Much of the effort involved in collecting anthropometric data was probably wasted, for accurate measurements on the living require a skill of technique possessed by only a few experts. Our data showed some suggestions of a correlation between arm, hand and foot dimensions and functional manual dominance, but the differences are too small for accurate comparison, for they usually do not seem to exceed the methodological error. At some later date we hope to continue these anthropometric studies of handedness.

THE DIAGNOSIS OF HANDEDNESS BY BEHAVIOR TESTS

The degree of consistency of left-handed performance varies greatly in the several tests used for diagnosing left handers. The throwing test was the most constant. Among left-handed males, forty-nine out of fifty throw left-handed; among females forty-five throw left-handed, four throw right-handed and one throws with either hand. Males are more likely to be skilled in throwing and the fact that 98 per cent of our group of left-handed males throw left-handed indicates that the throwing test is the best single criterion of left handed-

ness. The next best criterion is the holding test, involving holding hammer, tennis racquet, or other single-handed implement. Of the fifty males forty-six hold with left hand, three with right hand and one was doubtful. Of the fifty females forty-one hold with left hand, six with right hand, and three with either hand. The males, being more accustomed to handling implements, show a more consistent left-handed preformance. The preference in one-handed catching differed greatly in the two sexes. In females forty-one out of fifty catch with the left hand, four with the right hand, and three with either hand. In males, however, only eight out of fifty prefer the left hand for catching, two prefer the right hand, while thirty-eight have no preference for either hand. The probable explanation for this great discrepancy between the two sexes lies in the fact that males more commonly play baseball and wear the catching glove on the non-throwing or less skilled hand, thus training that hand, the right hand, to be skilled in catching. Women, however, seldom play hard-ball baseball, requiring the use of the catching glove, and therefore prefer to catch with the more skilled hand. In males the training of the right hand for catching seems to bring that hand, in most cases at least, up to an equality with the left hand, the result being that 76 per cent of males catch equally well with either hand. Consequently, the catching test is not a good criterion of left handedness in males, but is one of the best for females.

The writing test is far from being diagnostic for left handedness. Among fifty female left handers, twenty-seven write with the left hand, nineteen with the right, and four with either hand. Among fifty male left handers, twenty-five write with the left hand and twenty-five with the right. The explanation for this large percentage of right-handed writers is, of course, that a large majority of left handers are forcibly trained to write with the right hand, and only the most refractory ones persist in left-handed writing. Left-handed writing, as is well known, is ill adapted to its function for reasons too obvious to need repetition. Hence any one per-

sisting in left-handed writing is likely to be more strongly reversed in handedness than one who becomes a right-handed writer. One who writes left-handed, unless because of some defect in the right hand, is pretty sure to be a true left hander.

The position of hands in holding a gun is somewhat like writing, since many left handers have been trained by fathers or other teachers to brace the gun against the right shoulder and to steady the barrel with the left hand. This test, however, seems to be applicable only to males, for few females have had any experience in aiming a gun. Of the fifty males tested for the arm forward in aiming a gun, twenty-nine held the left arm forward, as right handers always do, nineteen held the right arm forward, one had no preference, and one was uncertain. This test is not a good one for diagnosing handedness, but those holding the right arm forward are likely to be as real left handers as are persistent left-handed writers. As a substitute for the gun-holding test a sighting test was used for females which consisted of sighting along a stick with one eye. Of the fifty left-handed females, thirty-five sighted with the left eye, thirteen with the right, and two were variable. It is probable that gun holding also is largely determined by the master eye and that the arm forward in gun holding is determined, unless reverse training intervenes, by the master eye. Eye sighting in fifty right-handed women shows just the reverse of the condition in left-handed women. Thirty right handers sight with the right eye, ten with the left and ten were uncertain. The conclusion seems to be warranted, then, that there is a close correlation between handedness and eye sighting, but there are two possible alternative explanations: either preferred eye functioning is determined through preferred hand functioning, or there is a deep-seated biological correlation between two very different body parts, hand and eye. At present there are no data available for making a decision between these alternatives.

The arm-folding test gave rather unexpected and unsatisfactory results, indicating that this reaction has very little

value as a test of handedness. Among fifty female left handers twenty-seven folded the left arm outward, thirteen the right arm outward, three varied from one arm to the other, and seven were uncertain. Among fifty male left handers, twenty-eight folded the left arm out, twenty the right arm out, and two varied from arm to arm. All told, 55 per cent of the left handers folded the left arm out and 33 per cent the right arm out, and 12 per cent were variable. We expected to find that right handers would show an equal preference for folding the right arm out, but that did not prove to be the case. Data were taken on only fifty right-handed females of which thirty-three (66 per cent) folded the left arm out, sixteen (or 32 per cent) the right arm out, and one was uncertain. There are thus more individuals folding left arms out among right handers than among left handers. The most striking difference between the two groups is the relatively large number of individuals who were indefinite as to which arm is folded outward, 12 per cent for left handers and only 2 per cent for right handers. This uncertainty among left handers may be a criterion of left-handed behavior, indicating a tendency toward equality, ambidexterity, of the two arms.

The test for arm first taken out of or put into the sleeve in removing and putting on coat was intended to be a novelty test for handedness, as no previous data seem to have been obtained for these behavior items. Of the fifty female left handers, twenty take off right sleeve first, twenty-three left sleeve first, and seven are uncertain; and twenty-six put on right sleeve first, seventeen put on left sleeve first and seven were uncertain. There is certainly no marked or consistent asymmetry of habit to be noted in these data, but let us compare them with fifty right-handed women. Among these, twelve take off right sleeve first, thirty-three left sleeve first and five are uncertain; seventeen put on right sleeve first, twenty-eight left sleeve first and five are uncertain. In the two operations combined, left handers take off or put on coat right hand first 46 per cent of the time, while right handers

do it only 29 per cent of the time. Again left handers prefer left hand first 40 per cent of the time and right handers 60 per cent of the time. In other words, left handers show a preponderance of preference for right hand first and right handers for left hand first operations. There is evidently some real basis for this reversal in the asymmetry of coat donning and doffing, and the tests though not diagnostic for handedness, add to the data showing a reversal in behavior among left handers.

Right and left footedness

Tests were also made to discover the more skilled foot or the stronger leg. In the test for the preferred foot in kicking a football, the results showed that women apparently have no tendency to kick or no definite preference for either foot. Hence the test was given throughout only to men. Of fifty left-handed men, thirty-four kicked with left foot, twelve with right foot, two with either foot, and two were uncertain. Since nearly all right handers are also right footers in kicking, the preponderance of left-footed kickers among left handers is very striking.

The high jumping test was given to both sexes. This consists of determining which foot goes over the bar first and also which foot gives the chief spring in jumping. Of fifty females, thirty put left foot forward, six put right foot forward, two were variable, and twelve uncertain. Of the fifty left-handed men, twenty-four put left foot forward, twenty-one right foot forward, and two were uncertain. The data for women are probably unreliable since most women do little if any high jumping and it was difficult for them to decide which foot they preferred to put forward. For males this test has some value, though it is partly vitiated by the fact that the foot forward is determined for most jumpers by the side from which the bar is approached, which seems quite variable even among right handers. The latter, however, have a strong preference for jumping off the right foot and sending the left foot over the bar, while our left handers showed almost equal preference for the two feet.

Summary of all tests of behavior

There was great variation among the 100 left handers studied in the total of left-handed activities exhibited by the different individuals. Of the five best tests (writing, throwing, catching, holding and kicking) preference among male left handers for left hand, or equality of two hands, was shown in all five, in four, in three, in two or in one, in the following percentages:

Left-handed in 5 tests, 36 per cent
Left-handed in 4 tests, 40 per cent
Left-handed in 3 tests, 16 per cent
Left-handed in 2 tests, 6 per cent
Left-handed in 1 test, 2 per cent

For females the kicking test was omitted for reasons explained above, but the distribution for the other four best tests was as follows:

Left-handed in all 4 tests, 50 per cent
Left-handed in all 3 tests, 42 per cent
Left-handed in all 2 tests, 6 per cent
Left-handed in all 1 test, 2 per cent

Thus 92 per cent of both sexes combined were left-handed in at least three of the four or five best test items.

Among the fifty left-handed women, there were no cases where the subject was right handed in both writing and throwing, while among the fifty left-handed men there were two such cases. In both of these cases there is some question as to their being left handers. In one of these cases the man is right-handed in writing and throwing, ambidextrous in holding and catching and has a slight preference for the left foot in kicking. He should probably not be included as a real left hander, but is kept on the list because he considers himself as such. In the other of these cases the man is right-handed in writing, throwing, holding and kicking, but ambidextrous in catching. He claims to be a left hander trained to be right-handed and is therefore included, though with some reservation.

We feel that we have collected a representative group of persons commonly classed as left handers, but we also suspect that the group is far from homogeneous biologically—a suspicion that will be discussed at length after the presentation of further data.

PART II

PALMAR DERMATOGLYPHICS AND HANDEDNESS

Two studies in this field have been carried on independently and simultaneously, one by Stella M. Leche in Cummins' laboratory at Tulane University, and the other by the present writer and assistants. Our work has been almost ready for publication since the autumn of 1931. Publication was delayed by difficulty in filling in certain gaps in the anthropometric data. As there seems to be no immediate prospect of filling these gaps it seems best to publish the results of the dermatoglyphic analysis without further delay. Leche's paper deals exclusively with palmar dermatoglyphics while our study attempts to survey the whole field of dermatoglyphics. One main difference between these two studies lies in the fact that Leche's control group (unselected group) consists of right and left handers and ambidexters in their normal proportions in the population, while our control group consists of carefully selected right handers only. Leche had 244 left handers while we had only 100. The two methods of diagnosing functional left handedness are different in detail but seem to be about equal in adequacy, for the results of the two studies of so-called left handers are quite similar. These few discrepancies will be dealt with in the appropriate places. On the whole the two studies are confirmatory.

The technique of palmar dermatoglyphic study explained

The subject of palmar dermatoglyphics has come within recent years to be of very considerable biological importance. The main lines and patterns of the palms have been shown to have a strong hereditary basis and various human races

have been shown to be characterized by rather marked differences. Newman, in 1930, made extensive use of palmar patterns as a means of diagnosing identical twins and showed that there were numerous instances of asymmetry reversal, or mirror imaging, in palmar patterns between the two members of a pair in identical twins.

For the purposes of this study we may confine ourselves to data that have to do with the bimanual asymmetry of palmar main lines and patterns. Independently of each other Newman, first, and a little later Cummins and Leche showed that there is a pronounced statistical difference between the patterns of right and left hands, the difference being evident in each of the four main lines and in each of the five patterns. For those who are unfamiliar with the subject of palmar dermatoglyphics, it may be said that there are four 'main lines,' A, B, C and D, in each palm. Each main line is a friction ridge that starts at one of the triradii at the bases of digits II, III, IV and V. The course of a main line runs from the point of a triradius that leads away from a finger base out to some point on the palmar margin. Definite rules are formulated for tracing these lines. The terminations on palmar margins of these main lines are numbered from 1 to 13, the lowest numbers, 1 and 2, being on the proximal border at the junction of the wrist; 3, 4, 5' and 5'', being positions on the ulnar border of the palm, 5'' being the most distal; 7, 9, 11 and 13 being spaces between the finger bases, 7 being that between digits IV and V, 13 that between I and II, etc. It will be seen that terminations with lower numbers are more proximal or more ulnar and that those with higher numbers are more distal or more radial.

Now we have found that right hands tend to have the various main lines placed more transversely across the palm, with their terminations in more distal and more radial positions; while left hands tend to have their main lines placed more diagonally across the palm, with their terminations more proximal and more ulnar. It was found that each of the four main lines showed independently of the others a tendency

for right hands to have more distal or more radial terminations and hence to be represented by higher numbers on right hands than on left hands.

The palmar asymmetry index. A convenient measure of the extent of bimanual asymmetry of a palm is what might be called the palmar asymmetry index. This index is made up of the sum of the four numbers designating the terminations of the four main lines of the higher hand minus the sum of the lower hand. Without burdening the reader with a statement of all the rules for numbering main line terminations, we may merely state that in rare instances where a main line is short or wanting, it is given a value intermediate between the two adjacent points of termination. This reasonable procedure was first suggested by Valsik, and, although it has some weaknesses as an expression of palmar configurations, it seems well adapted for comparing relative degrees of dextrality or sinistrality in palmar main lines.

Whether or not this summary concerning bimanual asymmetry in palmar patterns is clear, I think a brief statement about the numerical differences between right and left palms will be intelligible.

The commonest formula for the four main lines of right hands is 11.9.7.5', which totals 31, a number which is exceeded by only a few palms. For example, one palm in our collection has the formula 13.11.9.5'', which totals 38, and another 12.11.8.5'', which totals 36. A very common formula for left hands is 7.5''.5'.3, which totals 19, but several left hands in our collection have the formula 7.5''.5'.1 which totals 17, and one has a formula of 7.5''.3.1, which totals only 16. The extreme high count for right hands is 38 and the extreme low for left hands is 16. If a single person had an extreme dextral pattern on right and an extreme sinistral pattern on the left hand, there would be a difference of + 22 points in favor of the right hand. Such a difference between the two hands of an individual may be considered his asymmetry index, a high right hand main line total indicating a strong dextral asymmetry, and represented by a plus (+) sign. If, however,

the left hand should have the higher total we would have an instance of sinistral asymmetry, or asymmetry reversal, and the numerical difference between left and right hand would be represented by a minus (—) sign. Thus a very common dextral index is +10 which indicates a fairly high normal, or dextral, asymmetry, while indices of —6 or —4 indicate fairly marked reversed, or sinistral, asymmetry.

In our studies of identical twins, it was found that a considerable number of left handers showed reversed asymmetry in the palms and this discovery led us to wonder whether single left handers were also reversed. The results of our investigation of this question shall now be presented.

*Normal and reversed asymmetry in palmar main line indices
in right versus left handers*

While the method of determining main line indices by using the sum of the four main line terminations is not entirely satisfactory as a quantitative measure of the total asymmetry, it seems better than any other yet devised. The numbers used are no more than indications of positions of termination of main lines, not of quantitative differences, yet the total figure does give an approximate measure of the general trends of the four main lines. The treatment accorded to right and left handers is exactly the same, and, therefore, any differences found in the two groups are real. Termination 5'' has been given a value of 5, termination 5', 4 and H (where a line ends in a hypothenar pattern) all have been given a value of 4. Abortive line C terminations, following the suggestion of Valsik ('28), are given a value of 8. Some students of dermatoglyphics may disagree with these valuations, but when the same valuations are used for both groups there should be no serious objection. It might be valuable to publish tables of all the 200 palmar formulae, but they would interest only a few persons and would cover several pages. I shall therefore give but a brief table of the totals found (table 1).

TABLE 1

The main line totals for the four groups of fifty each are as follows

GROUP CHARACTERIZED	LEFT HANDS	RIGHT HANDS	DIFFERENCE BETWEEN LEFT AND RIGHT HANDS
50 right-handed ♂'s	1215	1372	157
50 right-handed ♀'s	1259	1426	167
50 left-handed ♂'s	1289	1415	126
50 left-handed ♀'s	1381	1468	87
All right handers	2474	2798	324
All left handers	2670	2883	213

From this table (table 1) several significant facts may be gleaned. In our 100 left handers the average degree of dextral asymmetry is much less (34.3 per cent less) than in our 100 right handers. In right handers the indices of the right hands average 13.5 per cent higher than left hands, while in left handers the indices of the right hands is only 7.7 per cent higher than the left or not much more than half as great. The difference between right and left handers is therefore nearly half as great as is the average difference in asymmetry between the two hands in right handers. There is, therefore, a decrease of dextral dominance among left handers as compared with right handers.

Among the 100 left handers there are several individuals with unusually high dextral main line indices. Thus among left-handed women one has an index of +14, another +10; while among left-handed men one has an index of +12 and another of +10. The highest negative indices among left-handed women are -5 and -4; among left-handed men -4 and -3.

An interesting comparison may be made between left and right handers as to the numbers of individuals showing reversed asymmetry or equality (partial reversal) in the two hands:

	<i>Reversed asymmetry</i> per cent	<i>Equality</i> per cent	<i>Slight right-handed asymmetry (+1)</i> per cent
Right handers	6	8	6
Left handers	12	20	9

Thus 41 per cent of all our left handers show reversed asymmetry, no asymmetry, or very slight dextral asymmetry as compared with 20 per cent of the right handers. It is also significant that nine out of the twelve left-handed individuals with truly reversed main line index have known left-handed relatives, while only three have none. The six reversed cases among our 100 right handers may possibly represent a group of left handers trained to be right handers, although they are unaware of the fact.

Furthermore, among right handers the number of individuals with high dextral indices is considerably greater than that among left handers, 28 per cent in the former as compared with only 9 per cent among the latter.

That there is a genetic basis for the extent of normal and reversed asymmetry in palmar asymmetry indices is strongly indicated by comparing the asymmetry indices of left handers who have known left-handed relatives with those who have none. Among fifty left-handed women twenty-seven had left-handed or ambidextrous near relatives, twenty-three had none; while among left-handed men twenty-four had such relatives and twenty-six had none. Thus 51 per cent of all left handers had left-handed relatives and 49 had not, almost an even 1:1 ratio.

It is found that these left-handed individuals in both male and female groups, who have known left-handed relatives average much lower in their + (dextral) asymmetry index than do those left handers who have no known left-handed relatives. The actual figures are as follows:

	<i>Average + asymmetry index of those with left-handed relatives</i>	<i>Average + asymmetry index of those without left-handed relatives</i>
♀ left handers	+ 0.89	+ 2.74
♂ left handers	+ 1.75	+ 3.25
Average of both sexes	+ 1.32	+ 3.00

It should again be emphasized that the data for males and for females were collected quite independently of each other by two assistants. The fact that each sex group shows a very positive difference between the main line indices of left

handlers with left-handed relatives and those without such relatives must have some significance as to the hereditary character of many cases of left handedness. It is a striking fact that the cases that have hereditary relatives have, on the average, a very considerably lower grade of dextral asymmetry of palmar main line indices than those that have no left-handed relatives.

It is also significant to find that most of the reversed individuals (those with a sinistral index and those without any asymmetry, with a zero index), are concentrated in the group of left handlers with left-handed relatives. Thus among the latter there are nine individuals with sinistral (—) index and twelve with zero (0) index, while among those without left-handed relatives there are only three with sinistral index and only eight with zero index.

One more rather striking difference between right and left handlers has to do with the totals (right + left) palmar main line values. Left handlers, in both male and female groups have a considerably higher total main line average value than have right handlers. The figures are given below:

Left-handed	♀'s have an average value per hand of 28.87 points	
Left-handed	♂'s have an average value per hand of 27.35 points	
Right-handed	♀'s have an average value per hand of 27.12 points	
Right-handed	♂'s have an average value per hand of 25.82 points	
Left-handed	♀'s and ♂'s average value per hand of 28.11 points	
Right-handed	♀'s and ♂'s average value per hand of 26.47 points	
Average difference between right and left handlers		1.64 points

This was a very unexpected result. One would naturally expect left handlers to have an average palmar main line index more like that of left hands, but the opposite is true; for left handlers in the two hands combined have a higher average dextral condition than do right handlers. The only explanation of this apparent anomaly that suggests itself at the present time is that left handlers are largely individuals showing the right-handed condition in both hands, to a higher degree than is the case in right handlers. This may mean that left handlers, on the average, lack a distinctly inferior hand, such as the left hand of right handlers. Further instances of the

same situation are found in most of the studies of individual lines and patterns to be dealt with in subsequent pages.

Individual palmar main lines in right and left handers

Line A. This line has its origin in the triradius at the base of the index finger and courses ulnarward and more or less proximally toward the wrist. It may terminate in positions 1, 2, 3, 4, 5' and 5''. For convenience we may group these into three types: type 3 (including classes 1, 2, 3) in which the termination is well down toward the wrist and the course of the line is diagonal across the palm; type 5 (including 5' and 5'') in which the line runs nearly transversely across the palm and ends at the ulnar border near the base of the little finger; and type 4, which includes all positions intermediate between type 3 and type 5.

The distribution of these types of line in right handers and left handers is shown in table 2 in per cent per individual.

TABLE 2
Showing percentages of the three modal types of line A terminations

	RIGHT HANDS			LEFT HANDS		
	Type 3	Type 4	Type 5	Type 3	Type 4	Type 5
Right-handed ♂'s	14	24	62	54	26	20
Right-handed ♀'s	4	18	78	64	16	20
Right-handed ♂'s and ♀'s	9	21	70	59	21	20
Left-handed ♂'s	12	28	60	32	20	48
Left-handed ♀'s	12	4	84	18	10	72
Left-handed ♂'s and ♀'s	12	16	72	25	15	60

This table (table 2) indicates that in right handers there is a great preponderance of type 5 terminations in right hands (70 per cent R to 20 per cent L), a great preponderance of type 3 terminations in left hands (59 per cent L to 9 per cent R) and the same percentage of type 4 in both hands (21 per cent). In left handers, however, this preponderance is very greatly reduced in both 3 and 5 types. Thus in type 5, right hands show 72 per cent of such types and left hands 60 per

cent; and in type 3 left hands show 25 per cent and right hands 12 per cent; while in type 4 there is no significant difference between the two hands. There is, therefore, in our collection a very marked contrast between right and left handers especially in the left hands, which not only show a very great increase in left handers of type 5 terminations, but also an almost equally great decrease in type 3 terminations. Right hands show about the same percentages of these two types in both right handers and in left handers. This means that left hands of left handers show strong dextral tendencies in both these respects, namely, a strong accentuation of the dextral character, type 5 terminations, and a strong diminution of the sinistral character, type 3 terminations.

These findings are in close agreement with those of Leche, the only difference being one of degree. This might be expected since Leche's unselected group doubtless includes a good many left handers, which would tend to increase the percentage of type 3 terminations and decrease that of type 5 terminations in left hands.

Another significant contrast between right and left handers concerns the total percentages in both hands combined of the three types of termination. Right handers show per hand 45 per cent of type 5, 21 per cent of type 4 and 34 per cent of type 3; while left handers show 66 per cent (an increase of 21 per cent) of type 5, 15.5 per cent of type 4 (a decrease of 5.5 per cent) and 18.5 per cent of type 3 (a decrease of 15.5 per cent). This may be interpreted as meaning that the average condition of the two hands combined is considerably more dextral in character in left handers than in right handers—a condition already noted with respect to the asymmetry index and to be noted with respect to several more characters discussed later in the paper.

Line B. The contrast between right and left handers is equally striking with regard to this line. The following table gives the data compactly:

TABLE 3
Showing percentages of the modal types of terminations in line B

	RIGHT HANDS				LEFT HANDS			
	Type 9 + 8	Type 7 + 6	Type 5'' + 5'	Type 4 + 3	Type 9 + 8	Type 7 + 6	Type 5'' + 5'	Type 4 + 3
Right-handed ♂'s	0	48	52	0	0	26	70	4
Right-handed ♀'s	4	52	44	0	2	34	64	0
Right-handed ♂'s and ♀'s	2	50	48	0	1	30	67	2
Left-handed ♂'s	4	54	42	0	2	36	62	0
Left-handed ♀'s	6	76	18	0	0	62	38	0
Left-handed ♂'s and ♀'s	5	65	30	0	1	49	50	0

This table (table 3) shows the following points of interest:

1. The right hands of right handers and the left hand of left handers show an almost equal balance between the two types of terminations $7 + 6$ and $5'' + 5'$.

2. The left hand of right handers show more than twice as many $5'' + 5'$ terminations as $7 + 6$ terminations, while the right hands of left handers show over twice as many $7 + 6$ type as $5'' + 5'$ type terminations. Thus the left hands of right handers show a strong sinistral condition which the left hands of left handers fail to show; while the right hands of left handers show a strong dextral tendency which the right hands of right handers fail to show.

3. The rare very dextral terminations ($9 + 8$) are found more frequently in the right hands of left handers than in those of right handers, while the even rarer sinistral terminations ($4 + 3$) are found exclusively in the left hands of right handers.

4. The more dextral terminations $9 + 8$ and $7 + 6$ are considerably more numerous in the two hands combined in left handers than in right handers, the ratio being 130 for left handers to 83 for right handers, while the more sinistral

terminations ($5 + 3$) are considerably less numerous in left handers than in right handers, the ratio being 80 for left handers and 117 for right handers. This strange paradox, that left handers are in both hands combined more dextral and less sinistral than right handers, is almost the rule in dermatoglyphics.

5. Leche's figures are less striking than ours, but agree in principle in most points. In her unselected group $7 + 6$ terminations in right hands are 20.3 per cent more numerous than $5'' + 5'$ terminations instead of being only 2 per cent greater as in our collection. Also $5'' + 5'$ terminations in left hands of left handers are 11 per cent more numerous than $7 + 6$ terminations instead of only 1 per cent greater as in our collection. The preponderance is in the same direction, however, in both collections. All of the other relations described are the same as in our collection but less marked.

Line C. Line C is frequently missing or abortive, and this tendency expresses itself in different degrees in left handers and right handers. Abortive conditions (designated X, x, and O) are commoner in left hands than in right hands in both handedness groups. In our right handers 11 per cent show abortive condition in left hands and 7 per cent in right hands. While in left handers 13 per cent of left hands have the abortive condition and 12 per cent of right hands. This sinistral predominance is, therefore, almost wiped out among left handers, which may be considered as another case of partial asymmetry reversal. The abortive line C condition may be considered as slightly sinistral in tendency. This sinistral feature is commoner per individual in left handers (11.5 per cent) than in right handers (9 per cent). These differences in our collection are possibly too small to be significant. Leche, however, finds much the same tendency for the abortive condition to predominate in left hands in both the selected (left-handed) and the unselected group. In both cases the condition is nearly twice as numerous in left hands, but the left handers show slightly fewer total instances of the abortive condition than do right handers—just the

reverse of what we find. Since the two findings are in opposite directions and neither very marked, it seems valueless to discuss significances.

The following table (table 4) gives the distribution in per cents of the four groups of terminations 5' and 5"; 6, 7 and 8; 9, 10 and 11; and X, x and O.

TABLE 4
Showing distribution of various terminations of line C

	RIGHT HANDS				LEFT HANDS			
	5", 5	6, 7, 8	9, 10, 11	X, x, O	5", 5	6, 7, 8	9, 10, 11	X, x, O
Right-handed ♂'s	12	30	46	12	28	38	22	12
Right-handed ♀'s	4	32	62	2	20	44	26	10
Right-handed ♂'s and ♀'s	8	31	54	7	24	41	24	11
Left-handed ♂'s	10	18	60	12	20	42	26	12
Left-handed ♀'s	2	22	68	8	6	42	38	14
Left-handed ♂'s and ♀'s	6	20	64	10	13	42	32	13

This table reveals the following relations:

1. In the control group (right handers) there is in right hands a great preponderance of terminations 9, 10 and 11 and a marked deficiency of 5" and 5' terminations, while in left hands there is a reversal of this proportion, for there is a preponderance of 5" and 5' (sinistral) and a deficiency of 9, 10, 11 (dextral) terminations.

2. In left handers the right hands show a considerable increase in the preponderance of 9, 10, 11 terminations and a slight decrease in 5", 5 terminations. Since these conditions are both interpreted as dextral, the right hands of left handers are even a little more dextral than those of right handers.

3. The left hands of left handers, however, differ sharply from those of right handers in showing an increase as com-

pared with right handers, of 9, 10, 11 terminations from 24 to 32 per cent and a decrease in 5', 5'' terminations from 24 to 13 per cent. In other words, the left hands of left handers are much more dextral and much less sinistral than those of right handers.

4. There is also in right handers as compared with left handers a preponderance in left hands of terminations 6, 7 and 8. In left handers the percentage in left hands of 6, 7, 8 terminations remains almost exactly the same as in those of right handers, but in right hands this sinistral tendency is reduced from 31 to 20 per cent.

5. Considering 9, 10 and 11 terminations as dextral criteria and 5'' and 5' terminations as sinistral, we find that, in both hands combined, left handers show an increase of dextral characters and a decrease in sinistral characters. The total dextral characters in right handers is 39 per cent per hand and in left handers 48 per cent, while the total sinistral characters in right handers is 16 per cent per hand and in left handers 9.5 per cent. This difference is due mostly to an increased dextral tendency in the left hands of left handers. In this respect it seems to be true that the left hands of left handers approach the conditions of right hands, while the right hands of right handers in most respects remain about the same as the right hands of right handers.

6. Leche's figures do not show such marked differences between right and left handers as ours do, but what differences there are appear to be in the same direction. Again, the lack of contrast may be due partly to the mixed character of her unselected group.

Line D. This line is in many respects the most important one of the four in expressing bimanual asymmetry. The terminations of this line may be grouped in three modal classes: a) 13, 12 and 11; b) 9 and 10; c) 7 and 8. We may for convenience designate these as 11-type, 9-type, and 7-type. The following table (table 5) shows the percentage distribution of these three types in right and left handers.

TABLE 5
Showing distribution of terminations of line D in percentages

	RIGHT HANDS			LEFT HANDS		
	11-type	9-type	7-type	11-type	9-type	7-type
Right-handed ♂'s	52	34	14	26	44	30
Right-handed ♀'s	60	36	4	34	46	20
Right-handed ♂'s and ♀'s	56	35	9	30	45	25
Left-handed ♂'s	56	30	14	36	42	22
Left-handed ♀'s	80	8	12	54	34	12
Left-handed ♂'s and ♀'s	68	19	13	45	38	17

The most suggestive facts revealed in this table (table 5) are:

1. In the control (right handers), right hands exhibit a very marked preponderance of 11-type terminations over 7-types, while in left hands 11-type terminations are only slightly preponderant over 7-type terminations, a case of partial asymmetry reversal.

2. In left handers the same situation prevails in right hands as was the case in right handers, with just about the same preponderance of the dextral 11-type terminations and about the same relative scarcity of the sinistral 7-type terminations. But in their left hands we find a considerable increase in dextral terminations and a decrease of sinistral terminations as compared with the left hand of right handers. In other words, left hands of left handers once again approach the right-handed condition.

3. In the two hands combined left handers are considerably ahead of right handers in the total number of dextral (11-type) terminations (55 per cent per hand as compared with 43 per cent), and are little behind right handers in total sinistral (7-type) characters (15 per cent per hand as compared with 17).

4. In Leche's collection the contrast between right and left handers is less sharp than in ours. In two particulars her left handers show a condition opposite to ours, namely, that her left handers as compared with the unselected group,

showed an increase in both hands of type 7 terminations while ours showed a slight increase in right hands, but a considerable decrease in left hands. Leche's figures also show a slight decrease in the total number of dextral (11-type) terminations in left handers, while our figures show about the same amount of increase. In view of these contradictory results, it would hardly be safe to conclude that any of these differences are real. Our results are more consistent with the rest of the data presented, however, while Leche comments on her results as being 'opposite to the findings in the other main lines.' A reexamination of the original data on this line would seem advisable, and this has been done with our data.

NORMAL AND REVERSED ASYMMETRY IN PALMAR PATTERNS IN RIGHT AND LEFT HANDERS

Thenar patterns have been shown independently by Newman and by Cummins and Leche to be much more numerous on left hands of the general population, while the latter authors have shown that the hypothenar pattern is more frequent and more complete in its expression on right hands than on left hands. Interdigital patterns II and III have been shown by both authors to be much more numerous in right hands, and interdigital IV more numerous on left hands. Thus of the five patterns, hypothenars and second and third interdigitals may be designated as dextral characters while thenar first interdigitals and fourth interdigitals as sinistral characters.

Hypothenar patterns

In our collection there is a fairly marked difference between left handers and right handers with regard to the incidence of hypothenar patterns on right and left hands. We have counted as hypothenar patterns only definite and certain patterns including whorls, single and double loops and definite radial arches. All doubtful or vestigial patterns have been omitted from the counts for both groups. The distribution of patterns is as follows (table 6):

TABLE 6
Showing percentages of hypothenar patterns in right and left hands

	RIGHT HANDS	LEFT HANDS
Left-handed ♂'s	36	34
Left-handed ♀'s	52	44
Left-handed ♂'s and ♀'s	44	39
Right-handed ♂'s	36	26
Right-handed ♀'s	46	44
Right-handed ♂'s and ♀'s	41	35

From this table (table 6) the following points of interest may be gleaned:

1. In left handers the predominance of the dextral character (hypothenars) on right hands has been slightly reduced as compared with the condition in right handers. The R/L predominance, however, still remains in left handers. In Leche's left handers the reduction in dextral predominance was rather more marked than ours, but both collections are in agreement that there is a reduction in right hand preponderance—a case of partial asymmetry reversal.

2. The most striking fact that is to be noted has to do with the numbers of hypothenars in the two hands combined in the two handedness groups. In our right handers hypothenars occur in 76 out of 200 hands, which means 38 per cent of the hands; while in our left handers hypothenars occur in 83 out of 200 hands, or in 41.5 per cent of the hands. Leche's comparable figures for her unselected group are 37.15 per cent and for her left handers 38.55 per cent. In both collections hypothenar patterns are definitely increased in left handers, another instance of the accentuation of dextral characters in left handers.

Thenar first interdigital patterns

The thenar pattern is quite rare on the palms of most Caucasian peoples. It is usually small when it does occur, but is rather easily detected even when vestigial. We have counted only clearly identifiable thenar patterns, including under this

term both thenar and first interdigital patterns and combinations of these.

The incidence of thenar patterns in our right and left handers is tabulated below:

TABLE 7
Distribution in right and left hands of thenar patterns in percentages

	RIGHT HANDS	LEFT HANDS
Left-handed ♂'s	10	16
Left-handed ♀'s	6	18
Left-handed ♂'s and ♀'s	8	17
Right-handed ♂'s	4	10
Right-handed ♀'s	6	8
Right-handed ♂'s and ♀'s	5	9

From this table (table 7) the following facts may be gleaned:

1. In both right handers and left handers there is a pronounced sinistral predominance of thenar patterns, the ratio in both groups being about 2:1. In Leche's collection the sinistral predominance was also present in both groups, but was somewhat less marked than in ours.

2. In our left handers the percentage of thenars is decidedly increased in both hands as compared with right handers. This results in a very positive accentuation in left handers of this sinistral feature. This is the opposite of what we have usually found, for in most respects left handers show an accentuation of dextral characters and a diminution of sinistral characters. That there is no mistake in our findings is indicated by the fact that Leche calls attention to exactly this situation in her group of left handers, which have nearly twice as high a percentage of thenars as occur in her unselected group.

Interdigital patterns

Of the four interdigital patterns the first interdigital has already been dealt with as a part of the 'thenar-first inter-

digital' complex. The second interdigital is a rare pattern and of not much value for statistical comparisons, but interdigitals III and IV are numerous. In our material we have counted only well-defined patterns, whorls, deltas and loops, omitting vestigial and merely suggested patterns.

The following table (table 8) gives the percentage occurrence per individual of the three independent interdigital patterns.

TABLE 8
Percentage per individual of interdigitals II, III, IV

PATTERN	LEFT HANDERS						RIGHT HANDERS					
	Male		Female		Both sexes		Male		Female		Both sexes	
	L	R	L	R	L	R	L	R	L	R	L	R
II	0	8	12	16	6	12	4	8	0	8	2	8
III	22	64	38	74	30	69	20	44	28	64	24	54
IV	102 ¹	52	68	32	85	42	92	58	76	54	84	56

¹ This high percentage per individual is due to the fact that it is especially common among left handers to have two no. IV patterns in a single palm, both of which have been counted.

The following facts may be gleaned from the table (table 8):

Second interdigitals. This pattern is so infrequent that the number occurring in 100 right handers and 100 left handers is too small for statistical comparison. As the figures stand, however, we find that 80 per cent of these patterns occur on right hands and 20 per cent on left hands among right handers, while only 66.6+ per cent occur on right and 33.3+ per cent on left hands among left handers. Thus there is a reduction in the R/L ratio among left handers as compared with right handers. Leche, with considerably larger numbers of individuals, finds the same situation. Among her unselected group 84.33+ per cent of second interdigitals were in right hands and 15.66+ per cent in left hands, while in her left-handed group 73.76+ per cent were in right hands and 26.23+ per cent in left hands.

More remarkable, however, is the fact that in both Leche's and our collection the total numbers of second interdigitals in

both hands combined is much greater in left handers than in right handers. In our collection there are only 10 per cent of these patterns per person among right handers and 18 per cent among left handers. In Leche's unselected group there were 8.3 per cent of these patterns and 17.23 per cent among left handers. This is another instance of the accentuation among left handers of a definitely dextral character, which is not due merely to an increase of the character in left hands, but to an increase in right hands as well.

Third interdigital. This is a numerous pattern which shows a strong preponderance in right hands in both right handers and in left handers. In our collection of right handers, 69.23+ per cent occur on right hands and 30.76+ per cent in left hands; while among left handers 69.63+ occur in right hands and 30.36+ per cent in left hands. In other words, the R/L ratio remains about the same in the two groups. But, whereas in right handers the total number of these patterns on both hands combined is 39 per cent, there are 44.5 per cent among left handers. And again the increase is in both right and left hands. Once more, then, we have an example of a positive increase of a definitely dextral character in left handers beyond the condition seen in right handers. Leche's results are in close agreement in this respect in that the percentage for both hands combined in the unselected group was 40.8, while among her left handers the per cent was 46.94 per cent.

Fourth interdigital. This pattern exhibits a strong sinistral dominance in both right handers and left handers. In our right handers 84 per cent of individuals have this pattern on left hands and 56 per cent on right hands, while in our left handers 85 per cent have the pattern on left hands and 42 per cent on right hands. Thus the sinistral dominance is somewhat increased among the left handers. There is, however, a considerable decrease among left handers of this definitely sinistral character in both right and left hands—a condition equivalent to an accentuation of dextrality in left handers.

In Leche's collection this relation does not seem to hold. She found, as we did, that the degree of sinistral dominance of fourth interdigitals is almost exactly the same in left handers as in the unselected group, but her results disagree with ours in that more of these patterns are on both hands of left handers than in those of right handers. Her totals for left handers are very close to ours, but those of her unselected group differ very much from those of our right handers. In case of a discrepancy of this sort there is no way of determining which of the two situations is correct. I have gone over my prints three times and the results check completely. In view of the fact that our results are consistent with those found for most of the other items of palmar dermatoglyphics while Leche's are out of line, we shall tentatively conclude that left handers show in this pattern the customary accentuation of a dextral condition.

PART III

FINGER DERMATOGLYPHICS AND HANDEDNESS

Very little attention has been paid to bimanual differences in the papillary patterns of the fingers and no data have been published concerning the finger patterns of left handers.

Of course, finger prints have been extensively studied and classified since the time of Galton, but most of these studies have had very little direct biological significance, being used mainly as a means of personal identification. Christine Bonnevie, however, has done much to reveal to us the real value of finger prints as a genetic material. The part of her fine work on finger patterns that has a direct bearing on the problem of handedness is that in which she gives the relative percentages in right and left hands of the various main types of finger print patterns, whorls, loops and arches, and certain variants of these.

It will be interesting to compare these indications of bimanual variation with those found in our right handers and left handers.

Apart from the fact that Bonnevie has shown that the various features of finger patterns are strongly hereditary, she has shown that there is a definite statistical bimanual asymmetry of many of the pattern characters. The following table (table 9) gives the difference between right and left hands in the percentage of the main pattern variants in 245,180 fingers.

TABLE 9

Showing the distribution in percentages of the finger pattern types in Bonnevie's collection

CHARACTERIZATION OF PATTERNS	PERCENTAGE ON RIGHT HANDS	PERCENTAGE ON LEFT HANDS
Whorls on all fingers	29.38	21.92
Whorls on digit I	44.98	29.22
Whorls on digit IV	41.66	28.42
Loops on all fingers	66.95	70.22
Loops on digit I	55.73	66.33
Loops on digit IV	51.95	66.03
Arches on all fingers	6.92	7.88
Arches on digit I	2.52	5.22

The data presented above (table 9) were obtained from the records of 24,518 Danish criminals. The numbers are so large that the error of random sampling is practically negligible. The main facts are that whorls are considerably more numerous on right hands and especially on digits I and IV, that loops are somewhat more numerous on left hands, especially on digits I and IV, and that arches are more numerous on left hands, especially on digit I. Presumably, this large collection of subjects consisted of right and left handers in the usual ratio of about 90 per cent of right handers to about 10 per cent of left handers. The figures therefore should correspond rather closely to those obtained from a group of right handers.

Let us proceed to our own data. In the table below (table 10) is tabulated the distribution of pattern types with respect to their relative percentage frequencies in right and left hands of fifty men and fifty women who are full right handers in the sense that they exhibit none of the left-handed behavior

preferences found in left handers. Note first that all of the dextral or sinistral preponderances are in the same direction as those found by Bonnevie to prevail in the general population of Danish criminals, but that the percentage differences and total frequencies of the various pattern types differ to some extent from those in Bonnevie's collection. There are several reasons for these discrepancies. First, there are known to be racial differences in these respects and our collection consists of several races other than north Europeans. Second, Bonnevie's material includes both right and left handers. Third, we have included as whorls patterns that

TABLE 10

Our collection of 100 right hands (distribution of patterns in two hands)

CHARACTERIZATION OF PATTERNS	PERCENTAGE ON RIGHT HANDS			PERCENTAGE ON LEFT HANDS		
	Men	Women	Both sexes	Men	Women	Both sexes
Sex distribution						
Whorls on all fingers	39.20	38.00	38.60	30.40	31.60	31.00
Whorls on digit I	40.00	36.00	38.00	28.00	36.00	32.00
Whorls on digit IV	64.00	62.00	63.00	38.00	46.00	42.00
Loops on all fingers	55.40	61.60	58.50	63.60	62.80	63.20
Loops on digit I	54.00	64.00	59.00	62.00	62.00	62.00
Loops on digit IV	34.00	38.00	36.00	58.00	50.00	54.00
Arches on all fingers	5.40	0.40	2.90	6.00	5.60	5.80
Arches on digit I	6.00	0.00	3.00	8.00	2.00	5.00

are sometimes called pocket-loops, that is, small whorls with two triradii enclosed in a large loop. It is possible that Bonnevie classed patterns of this sort as loops, though she defines a whorl as any pattern with two triradii. In any case, our subjects show nearly 10 per cent more whorls than Bonnevie's. That our data are probably representative for American right handers is indicated by the fact that the percentages for the fifty males and fifty females agree very closely. This correspondence would hardly be expected unless the two groups were fairly representative. In the above table (table 10) it will be noted that:

a. Whorls are nearly 9 per cent more numerous on right hands, and especially more numerous on digit IV where the difference is 21 per cent in favor of right hands.

b. Loops are somewhat more numerous on left hands, and especially so on digit IV where the difference is 18 per cent in favor of left hands.

c. Arches, which are relatively rare patterns, are more numerous on left hands, 5 per cent on left hands as compared with 3 per cent for right hands.

Let us now investigate the situation in left handers, to see whether these percentage relations tend to be reversed with respect to right and left hands. The data are given in table 11.

TABLE 11

Our collection of 100 left handers, showing percentage distribution of pattern types in the two hands

CHARACTERIZATION OF PATTERNS	PERCENTAGE ON RIGHT HANDS			PERCENTAGE ON LEFT HANDS		
	Men	Women	Both	Men	Women	Both
Sex distribution						
Whorls on all fingers	35.6	29.2	32.4	32.4	35.6	34.0
Whorls on digit I	56.0	36.0	46.0	38.0	40.0	39.0
Whorls on digit IV	28.0	48.0	38.0	40.0	54.0	47.0
Loops on all fingers	60.4	67.6	64.0	62.0	57.2	59.6
Loops on digit I	40.0	62.0	51.0	56.0	56.0	56.0
Loops on digit IV	52.0	50.0	51.0	58.0	38.0	48.0
Arches on all fingers	4.0	3.2	3.6	5.6	7.2	6.4
Arches on digit I	2.0	0	1.0	4.0	4.0	4.0

From an examination of this table (table 11) the following facts may be gleaned:

a. The relative frequencies of whorls, which was 8.6 per cent higher in right hands of right handers, is in left handers 1.6 per cent higher on left hands. This is a more than 10 per cent reversal of asymmetry.

b. In relative frequencies of whorls in the two hands most of the shift toward left hand condition was in the female group of left handers, the males showing a slight preponderance of whorls in right hands, but much less than in right handers.

c. In right handers there is a 15.76 per cent preponderance of whorls on the thumbs of right hands. In left handers this dextral preponderance is reduced to 7 per cent. But in the

two hands combined left handers show a 9 per cent increase over right handers in this dextral character.

d. In left handers there are 9 per cent more whorls on digit IV of left hands as compared with 21 per cent more on the same digit of right hands of right handers, making a 30 per cent reversal of direction of preponderance.

e. In left handers there are 4.4 per cent more loops on right hands, while in right handers there are 4.7 per cent more loops on left hands—a complete reversal of direction of preponderance of 9.1 per cent.

f. There is a 3 per cent higher frequency of loops on digit IV on the right hands of left handers, as compared with 18 per cent higher frequency on left hands of right handers—a reversal of preponderance of 21 per cent.

g. Arches continue to preponderate on left hands of left handers, even more so than in right handers, but these are relatively rare patterns and this distribution may not be very significant. The preponderance of arches on left hands is, however, less in left handers than in right handers, showing a slight reversal of direction of preponderance.

A few further comparisons between right handers and left handers have to do with the asymmetry of individual patterns. Loops, for example, may open on the ulnar or the radial side of a digit, ulnar loops being very numerous and radial loops relatively rare. Whorls, moreover, may be twisted or spiral in form and the twist may be in an ulnar or radial direction, the ulnar direction being by far the more common and the radial and non-twisted (symmetrical) conditions being relatively rare. There is a considerable difference in the frequency of the rarer radial patterns and of symmetrical patterns in right and left hands and we shall soon see that the direction of preponderance differs in right and left handers.

Radial loops are more numerous on the right hands of right handers by 6.1 per cent and are more numerous on the left hands of left handers by 6.2 per cent—a reversal of direction of preponderance of over 12 per cent.

Radially twisted whorls are nearly two and a half times more numerous on the right hands than left hands of right handers and are equally numerous on both hands of left handers—a marked change in preponderance, although the preponderance does not quite change over to the left hand.

The twisting tendency itself, including both ulnar and radial twists, also shows a reversal of right-left frequencies as between right and left handers. Right handers have 140 twisted whorls on right hands and 126 on left hands; while left handers have 122 twisted whorls on right hands and 136 on left. This represents a definite reversal of preponderance.

Symmetrical whorls also show much the same situation, but in the opposite direction. Right handers have more symmetrical whorls on the left hands and left handers on right hands. The figures are as follows: Right handers have fifty-three symmetrical whorls on right hands and thirty-one on left hands, while left handers have thirty-seven symmetrical whorls on right hands and thirty on left hands. Thus the preponderance of symmetrical whorls on right hands of right handers is not reversed in left handers, but is greatly reduced.

Friction-ridge count in right and left handers

Finger patterns differ not merely in type and direction of asymmetry, but also in the size of pattern, or the number of friction ridges involved in the pattern. Bonnevie, in 1924, published an important monograph on finger patterns, in which she showed that not merely are pattern types strongly inherited, but the quantitative expression of the pattern is also strongly inherited. Newman ('30 b) showed that in identical twins there is a correlation in total ridge counts of the two hands combined of 0.95 ± 0.01 , while that of fraternal twins was 0.46 ± 0.08 . Having acquired experience in ridge counting and being familiar with Bonnevie's method of rating the actual counts, it seemed advisable for us to determine whether there exists any bimanual asymmetry with respect to these quantitative differences. All of the counts were made by Mrs. Helen Seevers and checked by the writer, the same

method being used for both right and left handers. The Bonnevie method of rating ridge counts was used consistently throughout, having been adopted as standard. These data were laboriously acquired and checked over with the utmost care. Since no difference of consequence was brought out between right and left handers with respect to preponderance of ridge counts on right or left hands, our labors at first seemed wasted, but an unsuspected relation came to light that was a partial reward for our efforts. This relation is discussed below. The following table (table 12) gives the boiled down results of the ridge count investigation:

TABLE 12
Ridge count values in right and left hands

CHARACTERIZATION OF GROUP	TOTAL FOR RIGHT HANDS	TOTAL FOR LEFT HANDS	DIFFERENCE IN FAVOR OF RIGHT HANDS	AVERAGE DIFFERENCE BETWEEN R AND L PER INDIVIDUAL
50 right-handed ♂'s	1302	1233	+ 69	1.38
50 right-handed ♀'s	1334	1296	+ 38	0.76
100 right-handed ♂'s and ♀'s	2636	2529	+ 107	1.07
50 left-handed ♂'s	1110	1014	+ 96	1.92
50 left-handed ♀'s	1171	1165	+ 6	0.12
100 left-handed ♂'s and ♀'s	2281	2179	+ 102	1.02

From this table (table 12) it is easily seen that, although left-handed women show a slight reversal, the average of left-handed males and females combined shows almost, though not quite, the same degree of higher ridge count values on right hands as do right handers. The difference 1.07 per individual for right handers and that of 1.02 for left handers is surely not very significant.

In spite of this nearly negative result so far as asymmetry reversal is concerned, the data in table 12 show very clearly that total ridge count values (that is, values for right and left hands combined) average very definitely higher for right handers than for left handers, and this holds independently for both sex groups. Thus, right-handed males have an average ridge count value per hand of 25.35, left-handed males of 21.24 per hand, the difference in favor of right handers

being 4.11 points per hand—a large difference. Similarly, right-handed females have an average per hand of 26.32, and left-handed females an average of 23.36, the difference in favor of right handers being 2.96 per hand—a difference in the same direction, but somewhat less than in males. When both sexes are combined, we find that right handers average 3.53 units per hand higher than do left handers.

Thus, the total ridge values in right handers is much higher than in left handers. This is, of course, only a statistical difference between the two groups, but we believe the difference is a real one. Bonnevie's studies of large numbers of friction ridge counts also support our finding that right hands in the general population have a higher average ridge count. Apparently this difference between right and left handers may be considered as well established. Since right hands statistically exceed left hands in ridge count values, the higher value may be considered a dextral character. With respect to this character, left handers are distinctly less dextral than right handers.

Summary of data on finger patterns

All the various qualitatively different finger pattern conditions show some degree of asymmetry reversal in left handers as compared with right handers. Males and females show independently the same reversals in nearly the same degree. These facts, when it is taken into consideration that finger patterns are fixed long before birth, preclude the idea that they could be influenced by functional handedness. There is, then, some real relation between finger pattern reversal and that in functional handedness.

The equally striking fact that right and left handers differ markedly in the quantitative expression of patterns, as shown by ridge count values, still further supports the idea that there is a real and deep-seated biological basis for handedness, and that left handers, as a group, are reversed to some extent in their fundamental bodily asymmetries.

DISCUSSION AND CONCLUSIONS

Functional diagnosis of handedness. When one advertises for a group of left handers those who respond are likely to consider themselves functionally more or less left-handed. Behavior tests of such a group of self-styled left handers reveals that they are indeed a mixed lot. We are well aware that a number, possibly one-fourth, of our group of left handers are merely ambidexters. It seems pretty certain also that about 5 per cent of those included among our left handers are improperly so included, judging by behavior tests, but we included them because they considered themselves as more or less left-handed. It seems certain, then, that so-called left handers in the general population constitute a heterogeneous group consisting of few genuinely reversed individuals (true left handers), ambidexters who have equal facility with the two hands, and a few right handers who in some way have acquired some slight left-handed skill.

Functional right handers, even when chosen carefully, are also undoubtedly a mixed group, consisting of a large majority of true right handers, some ambidexters, and a few left handers who have been trained to prefer the right hand in all one-handed operations. The ambidexters are, as might be supposed, individuals with no pronounced bimanual asymmetry. For them it would be a matter of chance whether they got started functionally to perform one-handed operations with the right or the left hand. Doubtless, many more become right handers than left handers, because of training and example, but a small number of them are allowed to grow into left handers.

Considering the inevitably mixed character of our two groups, functional right handers and left handers, one would hardly expect them to differ so strikingly in their dermatoglyphic features as they actually do. If our two functional groups were biologically homogeneous, we would expect a much sharper difference.

No claim is made that every 'right hander' in the collection shows clearly the appropriate dextral asymmetry in dermato-

glyphics, nor does every 'left hander' show sinistral asymmetry, but each group as a whole differs from the other sharply and consistently in a large number of dermatoglyphic items. The consistency and regularity of these items goes far toward the proof of their reality. Also, whatever kinds of differences are found in the males of our collection are also found in the females, though frequently there is a difference in degree. Our data on bimanual asymmetry in finger patterns agree with Bonnevie's, while our data on palm patterns agree with those of Cummins and Leche. These facts serve to remove the objection that groups of 100 are insufficient for statistical adequacy.

The differences between the right handers and left handers are of three sorts. Left handers are characterized by the following statistical modifications of the right-handed condition:

a. Reversals of normal (dextral asymmetry). Under this head should be placed cases of partial reversal consisting of definitely reduced dextral asymmetry.

b. Accentuation of some few strikingly sinistral features, especially in right hands.

c. Accentuation of many dextral conditions, especially in left hands.

d. Nearly all dextral units are much more numerous in both hands combined in left handers than in right handers.

The best instances of real asymmetry reversal are found in finger patterns, where whorls are more numerous on the right hands of right handers and on the left hands of left handers. Loops have just the reverse predominance as to hands, with left handers showing reversed predominance. Many palmar items illustrate partial reversal consisting of a reduction in left handers of the typical dextral, R/L, predominance characteristic of right handers.

There are only two well-established instances of an accentuation of sinistral characters in left handers:

a) The total ridge count of ten fingers of left handers is relatively low as compared with that of right handers; b) thenar-first interdigital patterns in the palm. These seem

to be rather definitely sinistral, and are more numerous on both hands combined in left as compared with right handers.

Nearly all of the score or more of other items in this study, however, show an accentuation of dextral features usually on both hands, but more strikingly on left hands, of left handers.

We seem now to have arrived at the paradoxical conclusion that left handers are, on the whole, more right-handed than are right handers. Certainly, both hands of left handers average much more like the right hands than left hands of right handers. It seems fair to say that statistically, functional left handers tend in their dermatoglyphics to be double right-handed, lacking a true left hand. Of course, there is the possibility that this statistical result is due to the large percentage of ambidexters in our group of 'left handers,' but there are also many ambidexters among the 'right handers,' who should balance the effect of those among the left handers.

If dermatoglyphics are adequate indicators of real biological asymmetry in the hands, as we believe they are, we must conclude that there are comparatively few of our 'left handers' who are distinctly reversed in their total dermatoglyphic asymmetry. Only 13 per cent of these individuals, when all features of palms were checked off dextral against sinistral, showed a balance of sinistral features. These thirteen individuals are no more strongly left-handed functionally than the average, three of them being among those showing only two out of five left-handed operations. Hence there is no very close correlation among 'left handers' between the degree of functional reversal and dermatoglyphic reversal.

These findings, if accepted, would tend to discredit the idea that human beings are divisible into three well-defined asymmetry groups: right handers, left handers and ambidexters. All of the evidences both from functional tests and from dermatoglyphics point to the conclusion that there exists a graded series of asymmetry types, ranging from pronounced right handers, which are relatively numerous, through weak right handers and ambidexters, to left handers.

The relatively few individuals that show strong functional left handedness correlated with definite asymmetry reversal in dermatoglyphics may possibly be survivors of identical twin pairs. Only 4 per cent of our 'left handers' and 1 per cent of our 'right handers' show a degree of dermatoglyphic reversal at all comparable with that characteristic of the left handers of identical twin pairs. Considering the high prenatal mortality rate of one or both twins, it seems more than probable that the left-handed member of some few pairs survive after the death of its partner and is born as a single individual. It is impossible to estimate just how many individuals among the general population of left handers are survivors of twin pairs, but our data indicate that they may amount to as much as 10 or 12 per cent. It may well be that in our collection all those showing fairly strong correlation between functional reversed asymmetry and dermatoglyphic reversed asymmetry may be twin survivors.

Reversed individuals in identical twins, however, are the result of a somatic modification incident to the twinning process, and, therefore, this type of left handedness should not be hereditary as such. We find, however, that nine of the twelve left handers that are reversed in their dermatoglyphics have left-handed relatives. If these really reversed individuals are to be thought of as survivors of twin pairs, then left handedness and twinning must have a genetic relationship of some sort. Is it possible that hereditary tendencies toward reversed handedness tend to be expressed also in twinning, or vice versa? We have no data as to twinning in the families of our left handers and therefore cannot follow up this lead.

The small number of really reversed individuals among left handers leads us to venture some suggestions as to the possibility that reverse training of left handers may lead to stammering and other nervous disturbances. Now the great majority of 'left handers' seem to be merely weakly asymmetrical rather than reversed individuals, and unless they are really fully reversed so as to involve the centers of speech and

the unilateral motor centers of the brain, it seems hardly likely that reversed training could have any harmful consequences. It may well be, however, that the few left handers that show true dermatoglyphic asymmetry reversal (and these may be twin survivors) may be reversed even in brain centers. If, then, any left handers are likely to be injured by reversed training, it should be those that bear biological evidences of asymmetry reversal. A study of the palm and finger patterns of left handers should enable the psychologist to determine with reference to any individual whether he is reversed or not.

Before beginning the serious study of the relation of reversed training to stammering, etc., one would first wish to assure himself that stammering is definitely commoner among left handers in proportion to their numbers than among right handers. All of the few stammerers among my own acquaintances are right handers. Moreover, among our 100 identical twins, several of whom were left-handed and had been urged or forced to become at least partially right-handed, there were no cases of stammering or other definite mental aberration. In view of these considerations, one may well be skeptical as to the validity of the quite common theory that it is dangerous to try to reverse the handedness of left handers.

GENERAL SUMMARY

1. The problem is one of determining whether functional handedness is correlated with inborn morphological characters in which right handers and left handers differ. It is found that dermatoglyphic differences of a great many kinds differentiate the two handedness groups.

2. Methods of securing and testing the handedness of left handers are discussed at length. It appears that there are all grades of left handedness. 'Left handers' are not a homogeneous group.

3. In dealing with dermatoglyphics, it is shown that the various types of patterns and main lines have a tendency to predominate in either right or left hands. Where a condition prevails in the right hand, it is considered as dextral and

the condition may be termed R/L predominance; but where a condition prevails in left hands, it is considered sinistral and may be termed L/R predominance.

4. The palmar index of asymmetry, a general expression of dexterity or sinistrality averages + 3.24 points in right handers. In left handers it is reduced to + 2.13 points. This indicates a lowered, but not reversed, R/L ratio and means that the two hands are more nearly alike.

5. In hereditary left handers (those with known left-handed relatives), constituting 51 per cent of all our left handers, the average palmar asymmetry index is reduced still further, to + 1.32 points, but is still not reversed.

6. Individuals with reversed (L/R) index and ambidextrals with O index, are much more numerous among left than right handers, 41 per cent in the former to 20 per cent in the latter.

7. High plus palmar indices being dextral in tendency, it is interesting to note that, in the two palms combined, left handers have an average per hand of 28.11 points, right handers 26.47 points. Thus left handers show an accentuation of the total dextral condition.

8. Line A. As compared with right handers, left handers show much the same condition in their right hands, but their left hands are very dextral in character, though not quite as dextral as their right hands. In every item the two hands combined of left handers are much more dextral than those of right handers.

9. Line B. In general, the left hands of left handers are more like the right hands of right handers than like their own right hands. Also the right hands of left handers are more dextral than those of right handers. In the two hands combined left handers are decidedly more dextral than right handers.

10. Line C. The right hands of left handers are considerably more dextral than those of right handers. In the two hands combined, left handers are markedly more dextral than right handers.

11. Line D. In this line there is a very marked R/L preponderance in right handers, which is reduced to almost equality in left handers. In the two hands combined left handers are far more dextral than right handers.

12. Hypothenar patterns have a definite R/L preponderance in right handers. In left handers this R/L preponderance is only slightly reduced. But in left handers (both hands combined) there is a considerable increase in the percentage of hypothenar patterns, which are dextral in preponderance.

13. Thenar-first interdigital patterns have a marked L/R preponderance in right handers. In left handers this L/R ratio is decidedly increased. In the two hands combined there is a much higher percentage of this sinistral pattern in left handers than in right handers. This is the opposite of the condition prevailing for most dermatoglyphic units.

14. Second interdigital patterns have an R/L preponderance in right handers. This R/L is decreased in left handers. In the two hands combined left handers show nearly twice as many instances of this dextral pattern as do right handers.

15. Third interdigital patterns show an R/L preponderance in right handers. This R/L is not much changed in left handers, but in the two hands combined there is a considerably higher per cent of this dextral pattern in left handers than in right handers.

16. Fourth interdigital patterns have a pronounced L/R predominance in right handers. This L/R predominance is slightly increased in left handers, but in the two hands combined there is a lower percentage of this sinistral character in left handers as compared with right handers, which is tantamount to an increase in dextrality.

17. Finger whorls exhibit a R/L predominance especially in digits I and IV in right handers. In left handers there is a reversal of asymmetry, there being a L/R predominance.

18. Finger loops exhibit L/R predominance in right handers, especially in digits I and IV. In left handers there is a R/L predominance—a reversal of asymmetry.

19. Finger arches have a definite L/R predominance in right handers. This L/R is somewhat decreased in left handers, indicating a decrease in sinistral asymmetry.

20. Radial loops in fingers exhibit a R/L preponderance in right handers and a reversed, or L/R, preponderance in left handers.

21. The tendency of whorls to twist exhibits an R/L preponderance in right handers and a L/R preponderance in left handers—a case of true asymmetry reversal.

22. Symmetrical finger whorls show a L/R preponderance in right handers and a reduced L/R preponderance in left handers—a case of partial asymmetry reversal.

23. Right hands of right handers show a distinctly higher ridge count of finger patterns than do left hands. This R/L relation is only very slightly reduced in left handers.

24. High ridge count being a dextral character, it is interesting to find that, in the two hands combined, left handers show a reduction of about 3.5 units per hand as compared with right handers. This is a second instance of the accentuation of a sinistral condition in left handers, while most other characters show a reduction of sinistral and an accentuation of dextral tendencies.

25. It is suggested that the few left handers with definite total asymmetry reversal in dermatoglyphics may be survivors of identical twin pairs, and that there may be a genetic connection between twinning and left handedness.

26. Since so little asymmetry reversal seems to exist among left handers, there seems little ground for the theory that reverse training of left handers may cause nervous disturbances, such as stammering.

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