A BIOMETRIC INVESTIGATION OF TWINS AND THEIR BROTHERS AND SISTERS

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PART I.

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1. INTRODUCTORY.

A GREAT deal of attention has been devoted to the subject of twins in the present century, not only because the phenomenon of twinning in man is full of fascination in itself but because it presents facets of scientific interest to so many different aspects of biological investigation. Accurate research into the subject has been specially stimulated during the last few years by the belief, originating from Galton's work, that a thorough study of the phenomenon will provide the key to some problems regarding the mechanism of inheritance which cannot be solved in any other way.

The anthropometric approach to this question, in common with its first approach to most problems, commenced with the measurement by numerous investigators of small numbers of pairs and the drawing of tentative conclusions. From this preliminary work some general principles emerged and, in particular, it became evident that twin pairs of the same sex must be a heterogeneous group of two kinds of twins arising from a different biological foundation. Long before this theory had been established upon a fairly secure foundation by the statistical work of Weinberg, Fisher and others, it was, of course, a matter of common observation that twins of the same sex were sometimes enclosed at birth in a common membrane and sometimes in separate membranes, and it was until recently tacitly assumed that careful examination of the foetal membranes would usually suffice to distinguish the two types of twins. Even if this criterion were infallible, which it is not, precise information as to the state of the membranes at birth is usually lacking, but there have for long been many who, undismayed by this, have confidently asserted that they could distinguish the so-called *identical* or *like* twins from the *fraternal* or *unlike* twins with little or no difficulty by looking at them. Assuming this to be possible, and taking it for granted that the former type arises from a single ovum and spermatozoon* and the latter from two separate ova and spermatozoa, it became evident that a careful anthropometric study of the degrees of resemblance found in the two types of pairs might provide an estimate of the relative importance of constitutional and environmental influences on the development of physical and mental faculties.

It was at this stage, in 1925, that the present study was commenced at the suggestion of Professor Karl Pearson, and owing to the necessarily prolonged nature of such an investigation and pressure of other work, it is only now that the first results can be presented. When the research was embarked upon I was thoroughly sceptical as to the possibility of diagnosing the monozygotic from the dizygotic type of twins with sufficient certainty to arrive at sound statistical conclusions therefrom, but it was hoped that in the process of the research some more reliable criterion than facial appearance and other signs in use at that time might be evolved.

It was partly for this reason that finger prints were taken whenever possible, and the expectation that they might prove of diagnostic value has, I think, been justified. Since the commencement of the research a good deal of attention has been devoted, in Japan, Germany and elsewhere, to the finger patterns of twins, but the published work has in general lacked conclusiveness owing to the absence of physical measurements of the same children, and of satisfactory statistical analysis of the results obtained.

There have also appeared in the last four years some careful anthropometric studies of the physical and mental characters of twins, particularly those by Dahlberg (1) in Sweden, Lauterbach (2) in America, and von Verschuer (4) in Germany, which cover some of the same ground as the present research. These have, however, by no means rendered this work superfluous, for they have left unsettled amongst other things a question which is of paramount importance for the main purposes in view, namely, how we are with an adequate certainty to separate the like sexed twins, pair from pair, into monozygotic and dizygotic groups. To be able to calculate the proportions of each type in any given collection of pairs, as Fisher did, was a step forward but it was not enough, for in order to make further progress in many directions we need to be able to say which pairs belong to which type without being obliged to relegate a large number to the category of "doubtful."

The present work also deals with the physiological characters of pulse and breathing rates and blood-pressure, and with measures of muscular strength and sensory acuity in twins, which have not been dealt with on a statistical basis in any researches hitherto published, as far as I am aware.

Dahlberg has so well reviewed the literature of the subject up to 1925 in his admirable monograph that it is superfluous to include any such introductory review in this work. The papers

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* This phenomenon has recently been anatomically demonstrated by Arey (9) in a human embryonic specimen showing separate yolk stalks arising from a common yolk sac.

which have appeared subsequent to the publication of Dahlberg's book will be referred to in the discussion of methods and results in the sections which follow.

In view of all this contemporary research the aims and schema of the investigation have undergone some modification and extension since its commencement, and they may be summarised as follows:

(i) To measure a series of twin children and their brothers and sisters in London schools in regard to stature, head length, head breadth, horizontal circumference of head, interpupillary distance, body weight, systolic and diastolic blood-pressure, pulse rate, respiration rate, strength of grip, acuity of vision, colour sense, range of hearing, cutaneous sensibility and certain mental abilities, classify them also according to eye and hair colour and degree of facial resemblance, and record their finger prints and handwriting.

(ii) Compare the mean differences and coefficients of correlation between these measurements, suitably corrected both for sex and age, in twin pairs of opposite sex on the one hand, and in brother-sister pairs of differing age on the other, and determine whether either (*a*) age of the pair, or (*b*) age interval between them, has any influence on the degree of resemblance.

(iii) Compare the mean differences and coefficients of correlation for brother-sister pairs of differing age on the one hand and like sexed pairs of differing age on the other, and thus determine the effect of sex difference on the degree of resemblance.

(iv) Calculate the expected mean and mean-square differences for fraternal or dizygotic pairs of twins of like sex by means of the values obtained in (ii) and (iii).

(v) Selecting a character for which the distributions of differences for dizygotic twins give a close fit to a normal curve, determine the actual mean and mean-square differences for the heterogeneous group of like sexed twins, and from these and the expected values for the dizygotic type alone, calculate the proportions of monozygotic and dizygotic twins in the group.

(vi) Determine, by contrasting the distributions of differences for like sexed and opposite sexed pairs, which characters give any assistance in the diagnosis of type, and if possible devise a method of separating the monozygotic from the dizygotic pairs which is of practical utility and independent of the personal judgments of the observer.

(vii) Separate the like sexed twins into their component groups by this method, check the resulting distributions of differences by those expected from (v) above, and calculate the coefficients of correlation for monozygotic and dizygotic pairs of like sex.

(viii) Correct all the coefficients for the effect of experimental errors and day-to-day variations in the measurements of individuals as determined from a special series of experiments and estimate the full extent of the correlations in monozygotic and dizygotic pairs.

(ix) By making certain assumptions as to the resemblances to be expected as a result of the independent development of two halves of a single cell under similar environment, see if it is possible to form an estimate of the relative influences of inherited constitution and environment on each character studied.

In Part I of this paper only the first ten of the measurements enumerated in (i) have been analysed, and a partial examination of the finger prints made for the purposes of (vii). The remaining characters, and also the cephalic index, which require special treatment and which were regarded as unlikely to assist materially in aims (v) and (vi), will be dealt with subsequently.

2. THE DATA.

(a) *Sources and Acknowledgment.*

The tests were made during 1925 to 1927 on twin children and their brothers and sisters in Elementary and Central Schools of the London County Council. For permission to carry out these measurements in the schools in co-operation with the School Medical Officers concerned I am indebted to the County Council and I wish especially to record my gratitude to Dr C. J. Thomas, of the School Medical Department, who has taken a great interest in the research throughout, for his assistance in the choice of schools where twins were known to be numerous and for much invaluable advice and administrative help in the conduct of the necessary visits. I desire also to thank the head teachers and in some instances the medical officers of the numerous schools visited for their hearty co-operation in the work, nor must I forget the parents, and the children themselves who cheerfully submitted to the tests.

In the work of testing and measuring the children I was assisted throughout by my wife, Augusta Stocks, by whose help many difficulties inseparable from such a work were overcome, and to whose patience the successful accomplishment of the tests was in many instances due. The measurements of height, weight and visual acuity, the recording of eye and hair colours and the taking of finger prints and handwriting were carried out by her, whilst the remaining tests were made by myself.

(b) *Method of Selection.*

It is important to record the method by which the twin pairs were chosen for measurement. A few years prior to the beginning of the work a census of twins had been taken in some London schools and from these records schools were chosen which had then presented a considerable number of pairs. The school was then visited and the head teachers of each department were asked to ascertain which children attending the school were twins. Every twin child so found who had at least one brother or sister at the school, whether a twin or not, was then, subject to the parents' permission, measured together with the one or more brothers or sisters. A pair of very similar twins would scarcely ever escape the notice of a head teacher; a pair of dissimilar twins of like sex who might be in separate departments or schools would sometimes remain unnoticed or unmeasured owing to absence of one of the pair, and a pair of opposite sexed twins, often in different departments, would frequently escape notice as twins under this system of selection. It therefore follows that the ratios between the totals of the three groups of monozygotic, dizygotic like sexed and opposite sexed twins in the data may not necessarily accord with any theoretical ratios which have been found in unselected material. The ratio of identical to fraternal types of like sexed twins must have been somewhat enhanced by the selection, and the ratio of like sexed to opposite sexed twins must also be greater than in the general population.

In choosing other pairs of siblings who were not brothers or sisters of twins to increase the control group, the head teachers were asked to choose at random some families represented in the school by two or more children.

The total number of children examined was 832, consisting of 392 boys and 440 girls. Of these 563 were members of twin pairs, 7 were surviving members of triplets, a few were odd twins who had a brother or sister at school and the remainder were either siblings of twins or pairs of siblings unconnected with twins. The majority of these were measured for all characters applicable at their ages, but owing to various administrative difficulties about one-fifth of them were measured only for height, weight and interpupillary distance and hence the totals for these characters are larger than for the others. The method of selection of the group with restricted measurements was precisely the same as for the others.

(c) *Methods of Measurement.*

Height and *weight* were measured on the scales used for the purposes of medical inspection and recorded to the nearest millimetre and hectogram respectively. Errors arising from the use of a different instrument at each school are of little importance, owing to the fact that pairs of twins or siblings were invariably measured by the same scale, and the differences therefore remain unaffected by such errors.

Head measurements. The maximum length and breadth were measured by Flower's craniometer and recorded to the nearest millimetre. The horizontal circumference was taken by a steel tape to the nearest millimetre. The interpupillary distance was measured by a millimetre scale between the mid-points of the pupils whilst the child was looking out of the window at a distant object.

Blood-pressure was measured by means of a Brunton sphygmomanometer with 12 cm. cuff, using the auscultatory method. The diastolic pressure was read at the fourth point (i.e. the end of the third phase) or, when this was not distinguishable, at the point of cessation of the sound, the assumption being that the fourth point is coincident with the fifth in such cases. In some young children it was found impossible to record the diastolic pressure, owing to feebleness of the sounds. Readings were invariably taken on the left arm with the child in a sitting posture. It was not found practicable to make more than one reading, advantageous though this would have been.

Pulse rate was observed immediately after the blood-pressure with the child in the sitting posture. The time occupied by 30 pulsations was taken by a stopwatch to the nearest tenth of a second, and this *pulse interval* has been used throughout this paper for the purposes of calculation; to convert it to pulse rate per minute we have the relation pulse rate = 1800/pulse interval.

Respiration rate was measured immediately after pulse rate with the child still sitting and unaware of what was being done. The time occupied by 15 respiratory cycles was observed with the stopwatch to the nearest tenth of a second and this *respiration interval* has been used as working unit in this paper; to convert to rate per minute we have the relation respiration rate = 900/respiration interval.

Eye colour was recorded by matching with Martin's scale, and *hair colour* by Fischer's scale.

Facial resemblance was recorded in the case of twins of like sex according to an arbitrary scale of degrees in four classes which may be defined thus:

IV = Very pronounced resemblance rendering it almost impossible to distinguish the twins.
III = Pronounced resemblance but differences evident.
II = A slight degree of resemblance such as one commonly sees in pairs of brothers or sisters of differing age.
I = No special resemblance.

Such a scale has, of course, only a very limited value for the purposes of this particular research, and the distributions obtained by its use would not be comparable with those obtained by any other observer.

The methods employed in the measurement of the other characters will be described when these are dealt with in a subsequent paper.

3. Methods employed for Reduction of the Data.

(a) *Standardisation for Age and Sex.*

The ideal method for an anthropometric research on twins would be that adopted by Fisher (5) in his study of triplet children, namely, to confine attention to pairs at a particular age or wait until the pair had reached that age before measuring them, a procedure which eliminates the very considerable difficulties arising from variation in age. As a practical proposition this presented insurmountable difficulties if large enough numbers were to be secured, and it was therefore necessary to correct carefully for both age and sex differences.

The range of ages was confined to 3 to 15 years, only a few being less than 5 or older than 13. The effect of age on the means and standard deviations for the ten characters was first carefully determined, and the necessary curves fitted for boys and girls separately. Only in the case of the three head measurements was it found unnecessary to correct the standard deviation for age. The relations of the mean measurements to age in boys and girls are shown in Fig. 1.

Let D_a = deviation of the measurement of a boy aged a from the smoothed mean for boys at age a exactly;
D_a' = deviation of the measurement of a girl aged a from the smoothed mean for girls at age a exactly;
S_a = standard deviation of boys at age a exactly;
S_a' = standard deviation of girls at age a exactly.

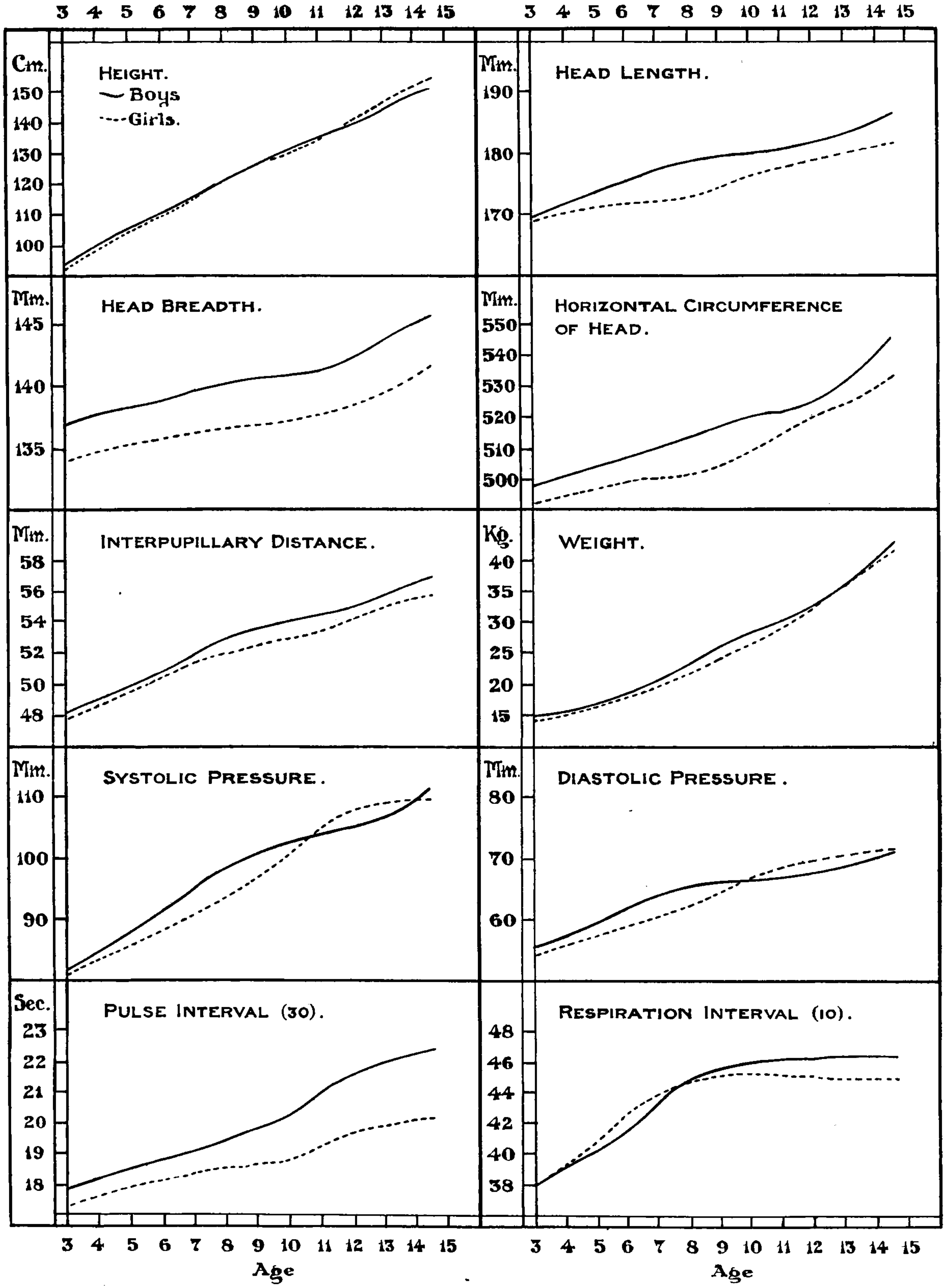
Then reducing to a common arbitrary age p, if $\bar{y}_p$, $\bar{y}_p'$ be the means and S_p, S_p' the standard deviations for boys and girls respectively at age p, the boy's corrected measurement becomes $\bar{y}_p + S_p \dfrac{D_a}{S_a}$ and the girl's $\bar{y}_p' + S_p' \dfrac{D_a'}{S_a'}$, on the usual assumption of the maintenance of ranking.

The corrected difference between two boys aged a and b respectively is therefore $S_p \left(\dfrac{D_a}{S_a} - \dfrac{D_b}{S_b}\right)$ in ordinary units, or in units of the standard deviation of the character in boys at the standard age p it is simply $\left(\dfrac{D_a}{S_a} - \dfrac{D_b}{S_b}\right)$. In computing this difference the correct signs must of course be given to D_a and D_b before subtraction. In pairs of twins $a = b$ and $S_a = S_b$.

If the difference between two girls, or between a boy and a girl, is to be made comparable with this, we need to also correct for sex by eliminating any part of the difference which arises solely from the accident of sex, that is, to find what the girl's measurement at age p would have been if she had been a boy and had maintained the same rank relatively to boys aged p as she does relatively to girls aged p. Thus, by the usual method employed by biometricians, converting the girl's measurement reduced to age p to what it would be if she were a boy, the part $\bar{y}_p'$ becomes $\bar{y}_p$ and $S_p' \dfrac{D_a'}{S_a'}$ "the corrected deviation from the mean" must be multiplied by $\dfrac{S_p}{S_p'}$ to maintain the same ranking, so that the girl's measurement reduced to that of a boy aged p becomes $\bar{y}_p + S_p \dfrac{D_a'}{S_a'}$ in ordinary units. Hence the corrected difference between two girls aged a and b becomes $S_p \left(\dfrac{D_a'}{S_a'} - \dfrac{D_b'}{S_b'}\right)$ in ordinary units, or simply $\left(\dfrac{D_a'}{S_a'} - \dfrac{D_b'}{S_b'}\right)$ in units of S_p, which is the same unit as used for measuring the boy's difference.

Figure 1.

GROWTH CURVES IN TEN CHARACTERS FOR BOYS AND GIRLS.



The difference between a boy and girl aged a, after thus correcting for age and sex, likewise becomes $S_p\left(\frac{D_a}{S_a}-\frac{D_a'}{S_a'}\right)$ in ordinary units, or simply $\left(\frac{D_a}{S_a}-\frac{D_a'}{S_a'}\right)$ in units of S_p.

Thus in general for any two children, whether of like or opposite sex, if D, D' be the respective deviations from the means appropriate to their sex and ages of measurement, and S, S' be the standard deviations appropriate to their sex and ages of measurement, the difference between them after reducing to a common age and after allowance for sex difference, if present, is given by $\left(\frac{D}{S}-\frac{D'}{S'}\right)$, the unit being the standard deviation of the character in boys at the common age. If we followed the reverse procedure and converted boys to girls, the result would be precisely the same, except that we should then be thinking of differences in a population of girls aged p, measured in terms of their standard deviation S_p' as unit. By thus working in terms of the standard deviation as unit, it becomes possible also to combine measurements of allied characters together into groups, as explained below, without further correction since the units are equivalent so long as we are dealing with differences or deviations from the mean. Except in Fig. 1, where the means are plotted in scales of the actual units of measurement, all the "corrected differences," mean differences (m_d), mean-square differences (σ_d^2), mean deviations (m_0) from the mean of all children, and standard deviations (σ_0) of selected groups of children, are to be thought of in terms of the standard deviation in a population of children of uniform sex and age as unit, and are thus strictly comparable with one another, in so far as it is possible by statistical processes to make them so, whatever the sex or age of the children or the units of measurement employed.

(b) *Grouping of Characters and Evaluation of Probable Errors.*

Statistical studies of twins have always suffered from the ultimate difficulty that, after division into the necessary groups, the numbers of pairs become so small that it is scarcely possible to reach definite conclusions as to the identity or otherwise of the degrees of resemblance in the groups. In order to take full advantage of the data it is possible to combine together the corrected differences or deviates for certain characters to form composite tables and thus evaluate mean differences or coefficients of correlation based on larger numbers of observations. Thus we may deal with the length, breadth and horizontal circumference of the head together as representing head size, and by so doing increase the number of entries in the correlation tables threefold. If there was no correlation between the three characters this would have the effect of reducing the probable errors in the ratio $1 : \sqrt{3}$, but since they are correlated positively the effect on the probable errors will be somewhat less.

Let u_1 corrected measurements for one character be combined with u_2 for another character, measured on the same children and in equivalent units, the two characters being correlated to the extent r_{12}; and let $N =$ total measurements in the group $= u_1 + u_2$, presumed to be large; and if u_1 be not equal to u_2, then let u_1 be the greater, representing the total children in the group.

Now let

σ_0 = standard deviation of the whole distribution of N corrected deviates;
σ_m = standard deviation of the mean of all the corrected deviates;
$\bar{r}$ = mean correlation coefficient for all possible pairs of the N measurements.

Then (see(6))
$$\sigma_m{}^2 = \frac{\sigma_0{}^2}{N}\{1 + \bar{r}\,(N-1)\},$$

and since there are u_2 possible pairs with a correlation r_{12} and the remaining possible pairs have no correlation and the total possible pairs are $N(N-1)/2$, we have $\bar{r} = \dfrac{2u_2 r_{12}}{N(N-1)}$, leading to $\sigma_m^2 = \dfrac{\sigma_0^2}{N}\left[1 + \dfrac{2u_2 r_{12}}{N}\right]$, or in the case where $u_1 = u_2$, all the children being measured for both characters, this is simplified to $\sigma_m^2 = \dfrac{\sigma_0^2}{N}(1 + r_{12})$.

Hence for calculation of probable errors of the mean, in place of $\sqrt{N}$ we must use

$$\sqrt{N\Big/\left(1 + \frac{2u_2 r_{12}}{N}\right)},$$

or in the special case where $u_1 = u_2$ this becomes simply $\sqrt{N/(1 + r_{12})}$.

Similarly, if we are combining corrected measurements for three characters which are correlated r_{12}, r_{13}, r_{23} and the first character being measured on u_1 children, the second on only u_2 of the u_1 and the third on only u_3 of the u_2, and $N = u_1 + u_2 + u_3$, we obtain

$$\sigma_m^2 = \frac{\sigma_0^2}{N}\left[1 + \frac{2(u_2 r_{21} + u_3 r_{31} + u_3 r_{32})}{N}\right],$$

and for four characters

$$\sigma_m^2 = \frac{\sigma_0^2}{N}\left[1 + \frac{2}{N}\{u_2 r_{21} + u_3(r_{31} + r_{32}) + u_4(r_{41} + r_{42} + r_{43})\}\right];$$

or if we can put $u_1 = u_2 = u_3 \ldots$, a condition almost true in the present investigation, we have when p different characters are combined

$$\sigma_m^2 = \frac{\sigma_0^2}{N}\left[1 + \frac{2}{p}(\text{sum of the } p(p-1)/2 \text{ correlation coefficients})\right],$$

and N must be reduced by dividing it by the expression in the square brackets in each case.

It follows that in calculating the probable errors of mean differences or root mean-square differences in pairs of children for a group of characters corrective factors for N based on the above expressions must be used.

The following grouping of characters has been adopted throughout this paper for the purpose of calculating differences and correlations for the various sub-groups of twins and their siblings in order to reduce the labour of computation and at the same time increase the effective size of the groups.

(1) Height.
(2) Head size—combining length, breadth and horizontal circumference.
(3) Static characters—combining the four characters in (1) and (2) with interpupillary distance.
(4) Weight.
(5) Blood-pressure—combining systolic and diastolic pressures.
(6) Pulse and respiration—combining pulse interval and respiration interval.
(7) Physiological characters—combining the four characters in (5) and (6).
(8) Aggregate group—combining all ten characters.

The coefficients of correlation r_{12}, etc., between the corrected measurements in the whole data of boys and girls combined are given in Table I, and the factors by which N must be multiplied to obtain the probable errors in the composite groups (2), (3), (5), (6), (7), (8) are as follows:

(2) Head size ($p = 3$, the u's being equal) ... ... ·4722

(3) Static characters ($N = 3127$, $u_1 = 754$, $u_2 = 731$, $u_3 = u_4 = 548$, $u_5 = 546$, where 1 = height, 2 = interpupillary distance, 3 = head breadth, 4 = head circumference, 5 = head length) ... ... ·4333

(5) Blood-pressure ($N = 920$, $u_1 = 564$, $u_2 = 356$, where 1 = systolic pressure, 2 = diastolic pressure) ... ... ·6726

(6) Pulse and respiration ($N = 1099$, $u_1 = 572$, $u_2 = 527$, where 1 = pulse interval, 2 = respiration interval) ... ... ·8822

(7) Physiological characters ($N = 2019$, $u_1 = 572$, $u_2 = 564$, $u_3 = 527$, $u_4 = 356$, where 1 = pulse, 2 = systolic pressure, 3 = respiration, 4 = diastolic pressure) ... ... 1·1040

(8) Aggregate of 10 characters ($p = 10$ and u's taken as equal) ... ... ·3729

Table I. *Correlation Coefficients between corrected Deviates in Children aged* 3–15.

	Height	Weight	Interpupillary Distance	Head Length	Head Breadth	Horizontal Circumference of Head
Height	—	+·7160 ±·0143	—	—	—	—
Interpupillary Distance	+·3032 ±·0268	—	—	—	—	—
Head Length	+·2544 ±·0276	—	+·2363 ±·0277	—	—	—
Head Breadth	+·2871 ±·0270	—	+·2171 ±·0279	+·2566 ±·0274	—	—
Horizontal Circumference	+·3520 ±·0258	—	+·3078 ±·0266	+·8093 ±·0101	+·6110 ±·0183	—
			Systolic Pressure	Diastolic Pressure	Pulse Interval	Respiratory Interval
Systolic Pressure	+·2792 ±·0272	+·2516 ±·0275	—	—	—	—
Diastolic Pressure	+·2385 ±·0338	+·2491 ±·0333	+·6285 ±·0214	—	—	—
Pulse Interval	+·0498 ±·0293	+·0906 ±·0298	−·3154 ±·0264	−·3303 ±·0316	—	—
Respiration Interval	−·0317 ±·0299	−·0183 ±·0298	−·1582 ±·0292	−·0363 ±·0362	+·1390 ±·0292	—

In computing the multiplying factor for group (8), the correlation coefficients of weight with head measurements have been given the same values as for height, though they would probably be slightly smaller, and the coefficients between the four head measurements and the four physiological characters have been assumed to be zero.

(c) *Methods of measuring the Degree of Resemblance in Pairs.*

(i) Facial resemblance between twins of like sex was recorded under an arbitrary scale of four groups as defined in section 2 (*c*). This was supplemented by the differences between members of pairs on the eye and hair colour scales employed. See sections 2 (*c*) and 7 (*c*).

(ii) Resemblance in finger patterns was estimated by two alternative methods, (*a*) number of corresponding fingers having similar patterns on the same sided hands of the pair, (*b*) number of corresponding fingers having similar patterns on the same sided or opposite sided hands of the pair as contrasted with the number of corresponding fingers having similar patterns on the two hands of the same child. This is explained further in section 7 (*d*).

(iii) Resemblance in the ten anthropometric characters was expressed by the following alternative measures:

(*a*) *Mean difference* or mean of the corrected differences $D/S - D'/S'$ in pairs, denoted by m_d, which is obtained by regarding the differences when they have been computed as all positive in sign, since it is immaterial which child of the pair is taken first.

(β) *Root mean-square difference*, or root mean-square of the corrected differences in the pairs, denoted by σ_d, since this is also the standard deviation about the mean zero of the symmetrical distribution formed by entering each difference both with a plus and a minus sign.

(γ) *Correlation coefficient* between the corrected measurements in pairs. In order to compare twins with their brothers and sisters in regard to the measured characters it was necessary to compute the mean corrected deviate of the children comprising each group measured from the mean of all children, viz. $m_0 = \Sigma\,(D/S)/2n$, where n is the number of pairs and D is always given its correct sign, and also the standard deviations within the various groups, denoted by σ_0. Having obtained both σ_d and σ_0 the correlation coefficients were obtained at once by the formula $r = 1 - \frac{\sigma_d{}^2}{2\sigma_0{}^2}$. The correction of σ_d and r for experimental errors is dealt with in section (8).

(δ) The standard error of estimate $\sigma_0\sqrt{1 - r^2}$ was also computed for some of the groups, thus measuring the variability of one member of the pair when the other is held constant, an inverse measure of resemblance which has some advantages over either (α), or (β) or (γ).

(ϵ) Other measures employed were the mean, $\bar{\Delta}$, of the six corrected differences for the six physical characters (height, weight, three head measurements, interpupillary distance), and also the mean of the four corrected differences for the four physiological characters.

4. COMPARISON BETWEEN TWINS AND THEIR BROTHERS AND SISTERS.

The literature dealing with anthropometric work on twins contains very little evidence as to whether or not twin children tend to be smaller or larger than their brothers and sisters or to differ from them in any special respect in physiological characters. Fisher (5) concluded that triplet children measured at the age of 6½ failed to show any certain inferiority in height to children in the general population but admitted that the selection of an adequate control group was difficult. Merriman (7) and Lauterbach (2) failed to find evidence that twins were intellectually handicapped.

Table II. *Comparison between mean corrected Deviates and Variabilities of Twins and their Brothers and Sisters**.

	Twins of Like Sex			Twins of Opposite Sex			All Twin Children			Brothers and Sisters of the Twins		
	No.	m_0 ±p.e.	σ_0	No.	m_0 ±p.e.	σ_0	No.	m_0 ±p.e.	σ_0	No.	m_0 ±p.e.	σ_0
(1) Height	388	+·0567 ± ·0430	·9497	174	−·1586 ± ·0688	1·0524	562	−·0100 ± ·0368	·9876	145	+·1396 ± ·0696	1·0202
Head Length	258	·0000 ± ·0300	·9073	126	−·1587 ± ·0772	1·0299	384	−·0521 ± ·0412	·9506	145	+·1557 ± ·0685	1·0197
Head Breadth	260	+·0492 ± ·0547	1·0318	126	−·0825 ± ·0703	·9391	386	+·0062 ± ·0435	1·0044	145	−·0427 ± ·0607	·9028
Horizontal Circumference	260	+·0061 ± ·0462	·8714	126	−·1571 ± ·0799	1·0662	386	−·0471 ± ·0407	·9426	145	+·0466 ± ·0709	1·0558
(2) Head Size	778	+·0185 ± ·0419	·9397	378	−·1328 ± ·0638	1·0138	1156	−·0310 ± ·0352	·9672	435	+·0568 ± ·0497	·8796
Interpupillary Distance	386	−·0720 ± ·0368	·9536	174	−·0874 ± ·0631	·9889	560	−·0768 ± ·0346	·9647	142	+·1666 ± ·0691	1·0187
(3) Static Characters	1552	+·0055 ± ·0315	·9468	726	−·1281 ± ·0486	1·0177	2278	−·0370 ± ·0265	·9720	722	+·1019 ± ·0455	·9968
(4) Weight	394	−·0868 ± ·0401	·9332	176	−·1057 ± ·0614	·9914	570	−·0926 ± ·0333	·9408	146	+·2570 ± ·0677	1·0319
Systolic Pressure	264	+·0788 ± ·0535	1·0387	122	+·0377 ± ·0651	·8598	386	+·0658 ± ·0406	·9859	143	−·2170 ± ·0650	·9861
Diastolic Pressure	172	+·1012 ± ·0620	·9720	80	−·0825 ± ·0828	·9785	252	+·0429 ± ·0499	·9778	78	−·1765 ± ·0906	1·0125
(5) Blood-Pressure	436	+·0876 ± ·0495	1·0130	202	−·0099 ± ·0591	·9105	638	+·0567 ± ·0386	·9837	221	−·2030 ± ·0644	·9960
Pulse Interval	266	−·1203 ± ·0504	1·0161	126	+·0317 ± ·0654	·9876	392	−·0714 ± ·0421	1·0095	145	+·2697 ± ·0590	·9756
Respiration Interval	258	−·0612 ± ·0487	·9676	112	−·0232 ± ·0652	·9267	370	−·0497 ± ·0392	·9576	140	+·1279 ± ·0624	1·0129
(6) Pulse and Respiration	524	−·0912 ± ·0374	·9954	238	+·0059 ± ·0493	·9598	762	−·0609 ± ·0299	·9855	285	+·2012 ± ·0428	·9316

	Twins of Like Sex Subdivided											
	IV. Facially "identical"			I–II. Facially dissimilar			B_4. (Monozygotic)			Not B_4. (Dizygotic)		
	No.	m_0 ±p.e.	σ_0	No.	m_0 ±p.e.	σ_0	No.	m_0 ±p.e.	σ_0	No.	m_0 ±p.e.	σ_0
(1) Height	104	+·3635 ± ·0901	·9804	164	−·0951 ± ·0580	·8869	106	+·2849 ± ·1054	1·1540	106	−·0585 ± ·0654	·8203
(2) Head Size	234	+·1838 ± ·0890	1·0337	280	−·1236 ± ·0542	·8364	324	+·0981 ± ·0728	·9897	324	−·0333 ± ·0589	·9170
(3) Static Characters	442	+·1552 ± ·0684	1·0290	608	−·1033 ± ·0436	·9004	536	+·0821 ± ·0619	1·0264	536	−·0410 ± ·0471	·9008
(4) Weight	104	+·1077 ± ·0899	·9820	168	−·1667 ± ·0590	·9521	108	−·0315 ± ·0950	1·0659	108	−·1704 ± ·0735	·9175
(5) Blood-Pressure	130	+·1354 ± ·1100	1·1703	158	+·0633 ± ·0777	1·0025	176	+·1693 ± ·0900	1·1462	180	−·0378 ± ·0679	·9038
(6) Pulse and Respiration	160	−·0600 ± ·0686	·9778	192	−·1208 ± ·0589	·9760	216	−·1833 ± ·0585	·9767	216	+·0250 ± ·0539	·9287

* See footnote *, p. 60.

In Table II (p. 59) will be found a comparison as regards the mean corrected deviates m_0* and degrees of variability σ_0 between twin children variously grouped and the brothers and sisters of these twins, who should form an ideal control group since they had the same parentage, home and school environment.

The groups from which the means m_0 have been computed consist for the most part of pairs of children with a correlation in regard to any one measurement between the members of the pair but not between one pair and another. Hence the standard error of the mean is increased from this cause, and the ordinary formula for the probable error of m_0 requires correction. Using the same formula as in section 3 (*b*), let N = number of measurements, v_1 = number of related pairs, in whom the correlation is r_1 for a given character, $\bar{r}$ = mean correlation coefficient for all the possible pairs, σ_{m_0} = standard error of the mean m_0, and σ_0 = standard deviation of the N measurements. Then when m_0 refers to a *single* character only, we have $N(N-1)/2$ possible pairs of measurements of which v_1 pairs are correlated to the extent r_1 and the rest uncorrelated, so that $\bar{r} = \frac{2r_1 v_1}{N(N-1)}$. Since N is a fairly large number in all the groups dealt with, we may take σ_0 as the standard deviation of the sampled population to a close enough approximation, and substituting the last expression for r in $\sigma^2_{m_0} = \frac{\sigma_0^2}{N}[1 + \bar{r}(N-1)]$ this gives

$$\sigma^2_{m_0} = \frac{\sigma_0^2}{N}\left[1 + \frac{2r_1 v_1}{N}\right].$$

In all the seven groups of twins in Table II, $v_1 = N/2$, and this is also approximately true in the group of brothers and sisters of twins; hence approximately $\sigma^2_{m_0} = \frac{\sigma_0^2}{N}[1 + r_1]$, so that the probable error of m_0 must be multiplied by $\sqrt{1+r}$, where r is the correlation coefficient between the members of pairs of the type comprising the group, as given in Tables V and XXXV. For groups comprising N measurements of *different* kinds it can be shown that the probable errors of m_0 after calculation as in section 3 (*b*) have also to be multiplied by the factor $\sqrt{1+r}$, where r is the composite coefficient for the group of characters. Hence all the probable errors of m_0 in Table II and the text have been thus approximately corrected.

The twins of like sex have been subdivided in the table (i) into groups formed by noting the degree of facial resemblance alone, and (ii) into groups formed by the use of finger patterns. The significance of this grouping is explained in section 7, but it may be stated here that group IV represents the twins of almost identical facial appearance, and almost all of these belong to the monozygotic type, whilst of groups I–II, presenting no special facial resemblance, almost all belong to the dizygotic type. It will also be shown in section 7 that the group B_4, formed by the aid of finger prints alone, provides a much better approximation to the monozygotic portion, and the residual group to the dizygotic portion of the like sexed twins†, than do groups IV and I–II. Representing as they do mean values of D/S measured from the curve of means for all children the values of m_0 can be approximately translated into the ordinary units by visualising

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* m_0 is measured from the mean of all children comprising the data, reduced to a common age and sex, as origin, and in terms of their standard deviation as unit. σ_0 is measured in terms of the same unit.

† The total of the children in these two groups represents all of the like sexed twins whose finger prints it was possible to obtain or decipher, and may be safely regarded as a random sample of the total like sexed twins who were measured.

them as fractions of the root mean-square of all these deviates in the whole population of children at all ages*, which have the values given below (see also Table XXXVIII).

Height	6·01 cm.	Head length	5·62 mm.
Weight	3·61 kgm.	Head breadth	4·48 mm.
Interpupillary Distance	2·92 mm.	Horizontal circumference	13·21 mm.
Systolic Pressure	11·66 mm.	Pulse interval (30)	2·84 sec.
Diastolic Pressure	8·20 mm.	Respiration interval (15)	6·43 sec.

Height and Weight. Comparing first all twin children with their brothers and sisters it appears that the mean height of the twins is the smaller by ·1496 ± ·0787, or about 1 cm., which, though not significant, goes hand in hand with a deficiency in weight of ·3496 ± ·0754, or about 1¼ kgm. Comparing opposite sexed twins with their siblings the deficiency is more pronounced for height, namely, ·2982 ± ·0978, or nearly 2 cm., which is significant and of the same order as the deficiency of ·3627 in weight. It would appear therefore that opposite sexed twin children tend to be slightly smaller in general size than their brothers and sisters and that the deficiency is not merely a nutritional one. When the composite group of like sexed twins is subdivided, a remarkable difference in height becomes evident between the facially identical and the facially dissimilar groups, and between the "monozygotic" and "dizygotic" groups as diagnosed by finger prints, the identical twins being superior to the extent of ·4586 ± ·1072, or about 1 inch, by the first criterion and ·3434 ± ·1240 by the second. For weight the relation is of the same kind, the differences being ·2744 ± ·1075 and ·1389 ± ·1201. When contrasted with the opposite sexed twins, all of whom are presumably dizygotic, the differences in weight are even greater, namely, ·5221 or ·4435, according to which criterion is used. The facially dissimilar and dizygotic groups of like sexed twins do not differ significantly from the opposite sexed twins as regards either height or weight.

There is evidence here, therefore, that monozygotic twins tend to be taller, during childhood at least, to the extent of about one inch than dizygotic twins of the same ages, and their brothers and sisters apparently occupy an intermediate position. As regards weight, the relation of monozygotic to dizygotic twins is of the same kind as for height, but twins of both types are inferior to their brothers and sisters.

Head Size. Comparing all twin children with their brothers and sisters there is no significant difference when the three head measurements are taken together, nor for head breadth nor horizontal circumference alone, but the mean head length of twins as a whole is less than that of their siblings by ·2078 ± ·0799, or about 1 mm. When opposite sexed twins are compared with siblings of twins the deficiency in head length is increased to ·3144 ± ·1032, whilst horizontal circumference shows a difference of ·2037 ± ·1064 which, though not significant, is of the same kind as for head length. Head breadth shows little variation between any of the groups. When like sexed twins are subdivided and the three measurements taken together, the facially identical group has a larger mean head size than the dissimilar group by ·3074 ± ·1042, but when subdivided by finger prints the difference of ·1314 ± ·0936 is not significant.

Interpupillary Distance. Comparing all twin children with their brothers and sisters, the twins have a smaller mean distance between the pupils, the difference being ·2434 ± ·0773, or about ¾ of a millimetre. Twins of like and opposite sex give almost the same mean value.

Static Characters. It is noteworthy that all the five measurements dealt with above show the

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* The groups in Table II do not differ significantly as regards their age distributions from all the children taken together.

same kind of differences, and they may therefore be examined as a combined group as in Table II, the values of m_0 being:

Dizygotic twins	Opposite sexed		− ·1281 ± ·0486
	Like sexed	Facially dissimilar	− ·1033 ± ·0436
		Other than B_4	− ·0410 ± ·0471
Monozygotic twins	Facially identical group		+ ·1552 ± ·0684
	B_4 group		+ ·0821 ± ·0619
Brothers and sisters of twins			+ ·1019 ± ·0455

There can be little doubt that twin children of dizygotic type tend to be slightly inferior in the static measurements, and also in weight, to their brothers and sisters when measured at the same ages, but this is certainly not the case with monozygotic twins as regards the static measurements, though they seem to also suffer slightly in weight.

Blood-Pressure. Comparing all twins with their brothers and sisters, they have a higher mean blood-pressure, the difference amounting to ·2828 ± ·0766 for systolic pressure and ·2194 ± ·1044 for diastolic pressure, of which the former is certainly significant. This excess is common to twins of like and opposite sex, the differences from the means for brothers and sisters of twins being ·2958 ± ·0842 and ·2544 ± ·0920 respectively for systolic pressure, which represent about 3 mm. of mercurial pressure. For diastolic pressure like sexed twins also show an excess of ·2777 ± ·1097, equivalent to about 2 mm. of pressure. When the twins of like sex are subdivided and systolic and diastolic pressures considered together, the monozygotic or identical groups give higher mean values than the dizygotic or dissimilar, but the differences between them are not significant. The excess for the monozygotic group (B_4) over brothers and sisters of twins is very pronounced, namely, ·3723 ± ·1107, which is equivalent to about 4 mm. of mercury.

Pulse and Respiration Rates. The aggregate group of all twins exhibits a shorter mean pulse interval than the brothers and sisters of twins, the difference being ·3411 ± ·0725, which signifies a higher mean pulse rate to the extent of about three pulsations per minute. The quicker pulse is common to twins of like sex and opposite sex but more pronounced for the former, the differences from the values for brothers and sisters of twins being ·3900 ± ·0776 and ·2380 ± ·0881 respectively. For respiration interval there is again a slightly shorter mean interval, which signifies a quicker rate of breathing, for twins than for their brothers and sisters, but the difference ·1776 ± ·0737 is of doubtful significance; it is, however, common to like sexed and opposite sexed twins. When those of like sex are subdivided and pulse and respiration considered together the differences between monozygotic and dizygotic twins are insignificant. As with blood-pressure, the excess in pulse and breathing rates is very pronounced when the monozygotic (B_4) group is contrasted with the brothers and sisters of twins, the difference being ·3845 ± ·0725.

Physiological Characters. The findings for the four physiological characters are at any rate consistent in indicating a tendency for higher blood-pressure and quicker pulse and respiration in twins, especially in monozygotic twins, than in their brothers and sisters. This combination suggests that the effect may be psychological rather than organic, namely, that the twins were more highly strung or nervous of examination than their brothers and sisters, and it is possible that this was enhanced by the fact that the usual procedure was to measure the twins first, whilst in some cases a brother or sister was in the room.

Variability. An examination of the σ_0 columns in Table II shows that there are no important differences between twins as a whole or twins of opposite sex and their brothers and sisters in regard to variability. When division into monozygotic and dizygotic groups is effected by the finger-print method there is however a notably smaller degree of variability in dizygotic than in monozygotic twins for every character. Thus for height the B_4 group, selected by finger-pattern resemblance as the sole criterion, has a variability given by $\sigma_0 = 1{\cdot}1540 \pm {\cdot}0527$ as contrasted with $\sigma_0 = {\cdot}8203 \pm {\cdot}0328$ for the residual groups of dizygotic twins, the difference of ·3337 being more than five times its probable error. The reason for this is not clear and it may have an important biological significance.

5. EFFECTS OF AGE AND SEX ON THE RESEMBLANCES IN TWINS AND SIBLINGS.

(*a*) *Effect of Sex on Differences between Brothers and Sisters of Twins.*

Owing to the fact that the like sexed twins form a heterogeneous group of two types whilst the opposite sexed twins appear to be a homogeneous group, we must turn to the brothers and sisters of twins in order to examine the effect of sex likeness or difference on the degree of resemblance. In Table III are given the distributions of the corrected differences in class intervals of ·2 for the following groups of pairs:

TT′, twin pairs of opposite sex;
TS′, pairs consisting of a twin with an opposite sexed sibling who is not a twin;
SS′, brother-sister pairs, neither being a twin;
TS, pairs consisting of a twin with a like sexed sibling who is not a twin;
SS, brother-brother or sister-sister pairs, neither being a twin;

and in Table IV the distributions per mille are given in class intervals of ·5 for the three groups:

TT′, twin pairs of opposite sex;
TS′ + *SS′*, brother-sister pairs other than twin pairs;
TS + *SS*, brother-brother or sister-sister pairs other than twin pairs.

Table III. *Distribution of corrected Differences in Pairs of Siblings and opposite sexed Twins.*

	Sex	Group	Difference ($D/S - D'/S'$)																							Total Pairs
			0–	·2–	·4–	·6–	·8–	1·0–	1·2–	1·4–	1·6–	1·8–	2·0–	2·2–	2·4–	2·6–	2·8–	3·0–	3·2–	3·4–	3·6–	3·8–	4·0–	4·2–	4·6–	5·2–	
Height	Opposite	*TT′*	17	12	12	15	9	9	3	2	1	3	3	1	.	.	.	.	.	.	.	.	.	.	.	.	87
		TS′	33	23	24	23	13	14	8	12	8	4	.	4	1	1	1	1	.	.	.	.	.	.	.	.	170
		SS′	8	11	6	9	4	4	5	3	1	.	3	1	.	.	.	.	.	.	.	.	.	.	.	.	55
	Like	*TS*	27	28	35	14	23	18	10	6	5	6	1	2	4	1	.	.	1	.	.	.	.	.	.	.	181
		SS	15	12	13	10	12	10	2	1	2	1	.	1	.	.	.	.	1	.	.	.	.	.	.	.	80
Head Size	Opposite	*TT′*	28	24	29	19	24	29	16	5	5	3	4	2	.	.	1	.	.	.	.	.	.	.	.	.	189
		TS′	66	54	65	38	48	39	26	17	14	15	9	7	3	2	2	1	.	2	.	.	.	.	.	.	408
		SS′	18	12	9	12	5	5	11	4	5	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	84
	Like	*TS*	58	44	38	47	39	43	31	28	19	8	11	5	3	2	5	.	.	.	.	.	.	.	.	.	381
		SS	23	22	18	27	21	16	13	4	7	5	2	1	3	.	.	.	.	.	.	.	.	.	.	.	162
Static Measurements	Opposite	*TT′*	62	51	52	43	40	44	25	13	7	10	9	3	.	1	1	.	.	.	1	1	.	.	.	.	363
		TS′	132	89	111	83	76	70	48	43	30	23	12	14	6	3	4	3	.	3	.	1	.	.	.	.	751
		SS′	33	32	21	27	15	12	22	9	6	1	7	5	.	2	.	1	.	.	.	.	.	.	.	.	193
	Like	*TS*	108	95	96	75	85	73	55	44	33	21	20	10	8	5	6	1	1	.	.	.	.	.	.	.	736
		SS	48	50	42	48	39	29	17	6	13	7	4	2	3	2	.	.	1	1	.	.	.	.	.	.	312
Weight	Opposite	*TT′*	13	14	13	10	15	4	6	4	4	1	1	2	1	.	.	.	.	.	.	.	.	.	.	.	88
		TS′	20	34	25	16	18	16	13	6	9	4	4	1	1	1	2	1	.	.	.	.	.	.	.	1	172
		SS′	7	7	9	7	5	11	2	3	.	2	.	.	.	1	1	.	.	.	.	.	.	.	.	.	55
	Like	*TS*	24	26	19	26	25	23	14	10	1	3	4	2	1	1	.	1	1	1	.	.	.	.	.	.	182
		SS	12	10	10	12	12	7	5	3	3	.	2	.	.	1	.	1	.	.	.	.	.	.	.	.	78
Blood-Pressure	Opposite	*TT′*	15	14	21	10	9	7	5	6	3	3	2	3	.	1	.	1	.	1	.	.	.	.	.	.	101
		TS′	37	26	30	20	22	19	12	12	6	7	8	1	2	1	.	.	.	1	.	.	.	.	.	.	204
		SS′	7	2	11	10	5	2	.	2	2	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	44
	Like	*TS*	30	28	27	23	17	13	6	11	10	9	5	2	5	3	1	.	.	.	1	.	.	.	.	.	191
		SS	11	15	14	11	7	2	11	5	6	3	3	2	2	1	2	.	.	.	.	.	.	.	.	.	95
Pulse and Respiration Intervals	Opposite	*TT′*	17	17	11	9	14	15	3	11	4	7	4	2	3	.	.	1	1	.	.	.	.	.	.	.	119
		TS′	28	33	34	42	23	34	12	11	10	4	6	7	11	3	1	3	.	1	2	.	.	.	.	.	265
		SS′	7	4	8	7	7	4	2	3	3	2	1	1	1	1	.	.	.	2	.	.	.	.	.	.	53
	Like	*TS*	34	28	22	27	16	29	27	17	12	4	9	8	8	3	1	1	1	4	.	.	.	1	1	.	253
		SS	12	12	15	17	11	12	6	13	8	1	.	4	2	2	1	1	.	.	.	.	.	.	.	.	117

From the data of Table IV four sets of histograms have been drawn in Fig. 2 (p. 66) to illustrate the distributions as regards height, weight, head dimensions and physiological characters respectively.

Table IV. *Per mille Distributions of corrected Differences in Pairs of Siblings and of opposite sexed Twins.*

			Differences $D/S - D'/S'$											No. of pairs
			0–	·5–	1·0–	1·5–	2·0–	2·5–	3·0–	3·5–	4·0–	4·5–	5·0–	
Height	Twins	TT'	437	300	149	58	46	—	—	—	—	—	—	87
	Siblings	$TS'+SS'$	422	262	178	85	40	9	4	—	—	—	—	225
		$TS+SS$	387	337	169	65	15	19	8	—	—	—	—	261
Head Size	Twins	TT'	344	312	259	48	32	5	—	—	—	—	—	189
	Siblings	$TS'+SS'$	376	289	189	89	37	14	6	—	—	—	—	492
		$TS+SS$	332	289	219	101	44	15	—	—	—	—	—	543
Static Measurements	Twins	TT'	377	306	212	61	33	6	—	5	—	—	—	363
	Siblings	$TS'+SS'$	380	276	195	85	43	13	7	1	—	—	—	944
		$TS+SS$	353	301	192	93	40	17	3	1	—	—	—	1048
Weight	Twins	TT'	387	352	125	91	45	—	—	—	—	—	—	88
	Siblings	$TS'+SS'$	370	282	216	75	22	27	4	—	—	—	4	227
		$TS+SS$	335	342	223	42	35	8	15	—	—	—	—	260
Blood-Pressure	Twins	TT'	376	307	149	89	49	10	20	—	—	—	—	101
	Siblings	$TS'+SS'$	387	299	177	81	48	4	—	4	—	—	—	248
		$TS+SS$	367	273	140	126	59	32	—	3	—	—	—	286
Pulse and Respiration	Twins	TT'	344	227	202	134	76	—	9	8	—	—	—	119
	Siblings	$TS'+SS'$	302	305	192	75	66	35	13	12	—	—	—	318
		$TS+SS$	284	238	229	119	65	41	13	5	3	3	—	370

TT' = opposite sexed twins. $TS'+SS'$ = opposite sexed siblings one of whom may be a twin. $TS+SS$ = like sexed siblings one of whom may be a twin.

In Table V are given the mean differences m_d and the root mean-square differences σ_d as defined in section 3 (*c*) and the correlation coefficients r between the corrected measurements in pairs for all the groups used in Tables III and IV, together with the mean values m_0 and the standard deviations σ_0 of the corrected deviates in all the children comprising the pairs.

Comparing the TS' with the TS groups, the values of σ_d and r do not differ significantly for any characters whether separately or grouped (Table V); thus for all the characters combined we have for TS', $r = \cdot 3551 \pm \cdot 0259$ and for TS, $r = \cdot 3290 \pm \cdot 0267$.

Comparing the SS' with the SS groups the numbers are somewhat small when single characters are compared, which probably accounts for the contrast between the two values of r for blood-pressure (viz. SS' ·5590 and SS ·3073, with probable errors of the order ·08); there are no significant differences, however, and for all the characters combined we have for SS', $r = \cdot 4339$ and for SS, $r = \cdot 4462$, with probable errors of the order ·05 and ·04 respectively. Putting together all pairs of children other than twinned pairs (i.e. combining TS with SS or TS' with SS') the values of r obtained are shown in Table VI on p. 66. The probable errors for head size and static measurements are of the order ·03, for blood-pressure and pulse and respiration rates of the order ·04, and for the total aggregate of the order ·02.

Only in the case of weight are the differences appreciable and in no case are they significant; the values of r for weight differ by $\cdot 1053 \pm \cdot 0525$, which is only twice its probable error. It is therefore evident that difference in sex does not, provided an adequate method of correction is employed, tend to diminish the correlation coefficients between siblings born at different times.

Table V. *Measures of Resemblance in Pairs of Siblings and of opposite sexed Twins.*

			n	m_d	σ_d ±p.e.	r	m_0	σ_0	$\sigma_0\sqrt{1-r^2}$
Opposite Sex	Height	TT'	87	·7202	·8992 ±·0460	·6350	−·1586	1·0524	·8131
		TS'	170	·7960	1·0211 ±·0374	·4943	−·0682	1·0152	·8824
		SS'	55	·7759	·8750 ±·0563	·4923	+·0218	·9598	·8356
		$TS'+SS'$	225	·7911	1·0082 ±·0321	·4944	−·0462	1·0026	·8715
Like Sex		TS	181	·7923	1·0048 ±·0356	·4793	+·0646	·9846	·8642
		SS	80	·6920	·8806 ±·0470	·4794	+·0137	·8630	·7572
		$TS+SS$	261	·7616	·9685 ±·0286	·4794	+·0490	·9492	·8331
Opposite Sex	Head Size	TT'	189	·7916	·9566 ±·0483	·5548	−·1328	1·0138	·8433
		TS'	408	·8412	1·0959 ±·0377	·3816	−·1672	·9741	·9005
		SS'	84	·7519	·9362 ±·0709	·5854	+·0726	1·0280	·8335
		$TS'+SS'$	492	·8259	1·0439 ±·0327	·4415	+·1262	·9877	·8861
Like Sex		TS	381	·9052	1·1214 ±·0399	·3491	−·0003	·9716	·9105
		SS	162	·8118	·9868 ±·0538	·5918	+·2056	1·0922	·8804
		$TS+SS$	543	·8774	1·0740 ±·0320	·4385	+·0611	1·0135	·9109
Opposite Sex	Static Measurements	TT'	363	·7816	·9544 ±·0363	·5602	−·1281	1·0177	·8429
		TS'	751	·8468	1·0759 ±·0285	·4127	−·1028	·9927	·9040
		SS'	193	·8176	1·0367 ±·0541	·4613	+·2015	·9988	·8861
		$TS'+SS'$	944	·8408	1·0680 ±·0252	·4342	−·0406	1·0040	·9040
Like Sex		TS	736	·8859	1·0972 ±·0293	·3661	+·0485	·9745	·9067
		SS	312	·7711	·9713 ±·0398	·5646	+·2206	1·0409	·8590
		$TS+SS$	1048	·8512	1·0610 ±·0237	·4350	+·1013	·9981	·8984
Opposite Sex	Weight	TT'	88	·7790	·9636 ±·0490	·4821	−·1057	·9914	·8688
		TS'	172	·8635	1·1247 ±·0409	·3292	+·0161	·9709	·9168
		SS'	55	·8231	1·0141 ±·0652	·2091	+·4054	·8063	·7883
		$TS'+SS'$	227	·8537	1·0988 ±·0348	·3278	+·1176	·9476	·8954
Like Sex		TS	182	·8478	1·0529 ±·0372	·4579	+·1450	1·0112	·8989
		SS	78	·7969	·9926 ±·0536	·3442	+·0936	·8667	·8137
		$TS+SS$	260	·8326	1·0335 ±·0306	·4331	+·1296	·9706	·8750
Opposite Sex	Blood-Pressure	TT'	101	·8480	1·1090 ±·0641	·2582	−·0099	·9105	·8794
		TS'	204	·8260	1·0443 ±·0425	·3090	−·2431	·8883	·8447
		SS'	44	·7450	·9053 ±·0794	·5590	−·2886	·9640	·7993
		$TS'+SS'$	248	·8116	1·0210 ±·0377	·3599	−·2512	·9024	·8420
Like Sex		TS	191	·8964	1·1524 ±·0485	·3999	−·0503	1·0519	·9645
		SS	95	·9563	1·1989 ±·0715	·3073	−·1453	1·0186	·9690
		$TS+SS$	286	·9163	1·1681 ±·0412	·3717	−·0818	1·0419	·9672
Opposite Sex	Pulse and Respiration	TT'	119	·9667	1·2021 ±·0559	·2157	+·0059	·9598	·9371
		TS'	265	·9855	1·2443 ±·0388	·1875	+·1144	·9761	·9588
		SS'	53	1·0203	1·3024 ±·0908	·2212	+·1377	1·0436	1·0170
		$TS'+SS'$	318	·9913	1·2542 ±·0357	·1938	+·1181	·9877	·9688
Like Sex		TS	253	1·0837	1·3686 ±·0437	·1245	+·0767	1·0342	1·0260
		SS	117	·9884	1·2005 ±·0563	·1943	+·1932	·9457	·9275
		$TS+SS$	370	1·0536	1·3178 ±·0348	·1464	+·1135	1·0086	·9986
Opposite Sex	Physiological Characters	TT'	220	·9122	1·1603 ±·0355	·2341	−·0014	·9375	·9112
		TS'	469	·9161	1·1615 ±·0243	·2611	−·0411	·9555	·9219
		SS'	97	·8954	1·1396 ±·0525	·3884	−·0557	1·0303	·9493
		$TS'+SS'$	566	·9133	1·1583 ±·0199	·2852	−·0436	·9687	·9285
Like Sex		TS	444	1·0029	1·2799 ±·0276	·2158	+·0221	1·0220	·9979
		SS	212	·9740	1·1995 ±·0374	·2710	+·0415	·9934	·9561
		$TS+SS$	656	·9937	1·2546 ±·0222	·2328	+·0283	1·0129	·9738
Opposite Sex	Aggregate of ten Characters	TT'	671	·8241	1·0411 ±·0314	·4458	−·0836	·9889	·8853
		TS'	1392	·8722	1·1114 ±·0273	·3551	−·0662	·9786	·9147
		SS'	345	·8404	1·0633 ±·0447	·4339	+·1617	·9993	·9003
		$TS'+SS'$	1737	·8659	1·1020 ±·0206	·3766	−·0209	·9869	·9143
Like Sex		TS	1362	·9176	1·1537 ±·0244	·3290	+·0528	·9959	1·0080
		SS	602	·8457	1·0598 ±·0337	·4462	+·1438	1·0069	·9010
		$TS+SS$	1964	·8965	1·1262 ±·0198	·3660	+·0807	1·0001	·9307

TT' = opposite sexed twins. TS' = pairs consisting of one twin and a brother or sister not of the same sex. SS' = opposite sexed siblings, neither a twin. TS = one twin with a brother or sister of same sex. SS = like sexed siblings, neither a twin.

Figure 2.

PERMILLE DISTRIBUTIONS OF DIFFERENCES IN PAIRS OF SIBLINGS & FRATERNAL TWINS.

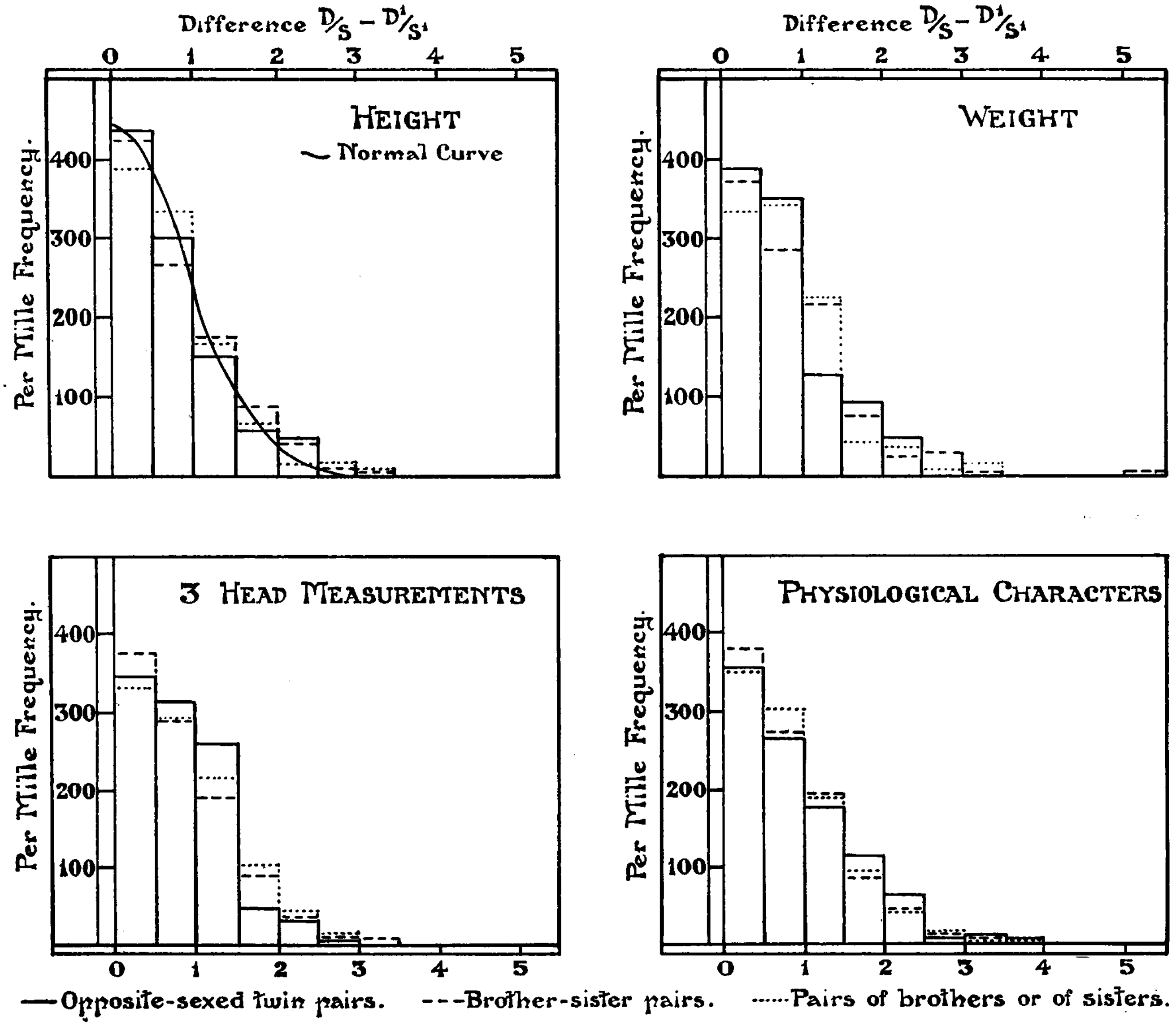

Table VI.

Characters	Height	Head Size	Static	Weight	Blood-Pressure	Pulse and Respiration	Physiological	All
Opposite sexed siblings 227 pairs	·4944	·4415	·4342	·3278	·3599	·1938	·2852	·3766
Like sexed siblings 261 pairs	·4794	·4385	·4350	·4331	·3717	·1464	·2328	·3660

The distributions in Table IV show that for all characters the proportion of differences which fall in the group 0–0·5 is greater for opposite sexed pairs than for like sexed pairs of siblings; thus the per mille figures are:

Table VII.

Characters	Height	Head Size	Static	Weight	Blood-Pressure	Pulse and Respiration	Physiological	All
Opposite sexed	422	376	380	370	387	302	339	366
Like sexed	387	332	353	335	367	284	320	340

which means that the distributions of differences are slightly more leptokurtic for opposite sexed than for like sexed pairs. This effect disappears, however, when the groups 0–1 are compared.

(*b*) *Effect of one Member of a Pair being a Twin.*

We may now combine the like sexed *TS* and opposite sexed *TS'* groups and likewise the *SS* and *SS'* groups and compare the mean differences and correlation coefficients for (1) all pairs, *TS* + *TS'*, in which one child is a twin, and (2) all pairs, *SS* + *SS'*, in which neither is a twin, giving the following results.

Table VIII.

		Height	Head Size	Static Characters	Blood-Pressure	Pulse and Respiration	Aggregate of all Characters
Mean of m_d for like and opposite sexed pairs	*TS, TS'*	·7942	·8732	·8663	·8612	1·0346	·8949
	SS, SS'	·7340	·7818	·7943	·8506	1·0043	·8430
Mean of r for like and opposite sexed pairs	*TS, TS'*	·4868	·3653	·3894	·3545	·1560	·3420
	SS, SS'	·4858	·5886	·5130	·4331	·2077	·4400

The effect of one child in a pair of siblings being a twin is apparently to diminish these degrees of resemblance in head dimensions and physiological characters, but for height there is no effect on the correlation coefficients though m_d is increased as for the other characters.

The mean values of the standard errors of estimate $\sigma_0\sqrt{1-r^2}$ are shown in Table IX.

Table IX.

		Height	Head Size	Static Characters	Blood-Pressure	Pulse and Respiration	Aggregate of all Characters
Mean of $\sigma_0\sqrt{1-r^2}$ for like and opposite sexed pairs of siblings	*TS, TS'*	·8733	·9055	·9053	·9046	·9924	·9613
	SS, SS'	·7964	·8570	·8725	·8842	·9722	·9006

There is evidently no important difference in this measure of resemblance as regards the physiological characters, and the differences noticed in the correlation coefficients must arise chiefly from differing variability of the groups. For the head measurements and the aggregates of static characters and of all characters combined, the three measures of resemblance employed in Tables VIII and IX agree in indicating a slightly smaller degree of likeness between twins and their brothers and sisters than between brothers and sisters neither of whom is a twin. It appears from the further analysis in Table X that this is true whether the twin in the pair is monozygotic or dizygotic.

Table X.

Sub-groups of *TS* and *TS'* pairs	Static Characters	
	m_d	$\sigma_d \pm$p.e.
Sibling with a twin of an opposite sexed pair	·8948	1·129 ± ·033
Sibling with a twin of a like sexed dizygotic pair (Groups I–II)	·8681	1·074 ± ·040
Sibling with a twin of a like sexed monozygotic pair (Group IV)	·8589	1·076 ± ·056

(c) *Effect of Interval between Births on Resemblance.*

The next important questions to decide are (1) whether the degree of resemblance in pairs of children born of the same parents at different times is the same as in pairs born at the same time but originating from separate ova, that is, dizygotic twins, and (2) whether the age interval between the births affects the degree of resemblance when full correction of each individual for age is made.

Table XI. *Degrees of Resemblance in Pairs of dizygotic Twins and in Pairs of Siblings born at different Intervals of Time.*

		Opposite Sexed Pairs				
		Dizygotic Twins	Brother-Sister Pairs with a Difference in Age of			
			¾–2¾ yrs.	2¾–5¾ yrs.	5¾–10¾ yrs.	Total
Height	n	87	80	105	40	225
	m_d	·7202 ±·0393	·8245 ±·0470	·7852 ±·0390	·7395 ±·0596	·7911 ±·0269
	σ_d	·8992 ±·0460	—	—	—	1·0082 ±·0321
	r	·6350 ±·0433	—	—	—	·4944 ±·0340
Head Measurements	n	189	177	231	84	492
	m_d	·7916 ±·0427	·8848 ±·0493	·8077 ±·0394	·7519 ±·0608	·8259 ±·0276
	σ_d	·9566 ±·0483	—	—	—	1·0439 ±·0327
	r	·5548	—	—	—	·4415
Static Characters	n	363	338	440	166	944
	m_d	·7816 ±·0318	·8569 ±·0361	·8209 ±·0303	·8629 ±·0519	·8408 ±·0212
	σ_d	·9544 ±·0363	—	—	—	1·0680 ±·0252
	r	·5602	—	—	—	·4342
Weight	n	88	83	104	40	227
	m_d	·7790 ±·0423	·7621 ±·0426	·9265 ±·0463	·8545 ±·0689	·8537 ±·0289
	σ_d	·9636 ±·0490	—	—	—	1·0988 ±·0348
	r	·4821 ±·0514	—	—	—	·3278 ±·0400
Blood-Pressure	n	101	90	113	45	248
	m_d	·8480 ±·0524	·8951 ±·0586	·7738 ±·0452	·7395 ±·0684	·8116 ±·0320
	σ_d	1·1090 ±·0641	—	—	—	1·0210 ±·0377
	r	·2582	—	—	—	·3599
Pulse and Respiration	n	119	113	150	55	318
	m_d	·9667 ±·0480	·8535 ±·0435	1·1448 ±·0507	·8559 ±·0626	·9913 ±·0301
	σ_d	1·2021 ±·0559	—	—	—	1·2542 ±·0357
	r	·2157	—	—	—	·1938
Physiological Characters	n	220	203	263	100	566
	m_d	·9122 ±·0298	·8719 ±·0297	·9855 ±·0294	·8075 ±·0391	·9133 ±·0186
	σ_d	1·1603 ±·0355	—	—	—	1·1583 ±·0199
	r	·2341	—	—	—	·2852
Aggregate of ten Characters	n	671	624	807	306	1737
	m_d	·8241 ±·0266	·8492 ±·0284	·8881 ±·0261	·8413 ±·0505	·8659 ±·0173
	σ_d	1·0411 ±·0314	—	—	—	1·1020 ±·0206
	r	·4458	—	—	—	·3766

n = Number of pairs of measurements. m_d = Mean corrected difference. σ_d = Root mean square difference. r = Coefficient of correlation.

The first of these questions has been answered in the affirmative by Fisher (3), who found from Lauterbach's data correlation coefficients in opposite sexed twin pairs of ·4549 for height, ·4611 for stem length, ·3802 for weight and ·5370 for cephalic index, and concluded that "the average correlation ·4583, with a standard error about ± ·053, agrees sufficiently well with the usual values, about ·5" for brother-sister pairs. Dahlberg (1) concluded that brothers born at different times have nearly the same average differences in static characters when measured about age 21 as like sexed dizygotic twins, but lower differences than opposite sexed twins; the last of these findings, however, was simply attributable to absence of correction for sex differences and the measurement of the two sexes by separate examiners, and therefore tells us little. The second question regarding the effect of age interval on the degrees of resemblance does not seem to have been answered, and the present data afford an opportunity of actually comparing the resemblance between twins with that between other siblings separated by various intervals of years *in the same families*, and measured by the same observers, using a constant technique and method of computation.

Table XI (*continued*).

		Like Sexed Pairs						
		Twins determined to be Dizygotic by Various Criteria			Brother Pairs or Sister Pairs with a Difference in Age of			
		Not M_1	Not B_4	Not B_5	$\frac{3}{4}$–$2\frac{3}{4}$ yrs.	$2\frac{3}{4}$–$5\frac{3}{4}$ yrs.	$5\frac{3}{4}$–$10\frac{3}{4}$ yrs.	Total
Height	n	56	53	51	100	116	45	261
	m_d	·6209 ± ·0423	·6203 ± ·0434	·6603 ± ·0471	·8695 ± ·0443	·6704 ± ·0317	·7572 ± ·0575	·7616 ± ·0240
	σ_d	·8248 ± ·0526	·8338 ± ·0546	·8621 ± ·0576	—	—	—	·9685 ± ·0286
	r	·5881 ± ·0590	·4840 ± ·0710	·4858 ± ·0722	—	—	—	·4794 ± ·0321
Head Measurements	n	171	162	156	185	254	104	543
	m_d	·7907 ± ·0448	·8131 ± ·0474	·8110 ± ·0481	·8995 ± ·0490	·8436 ± ·0392	·9216 ± ·0670	·8774 ± ·0279
	σ_d	·9897 ± ·0513	1·0125 ± ·0552	1·0144 ± ·0564	—	—	—	1·0740 ± ·0320
	r	·3536	·3904	·3220	—	—	—	·4385
Static Characters	n	284	268	258	373	482	193	1048
	m_d	·7594 ± ·0349	·7756 ± ·0367	·7886 ± ·0380	·8925 ± ·0358	·8173 ± ·0288	·8684 ± ·0484	·8512 ± ·0203
	σ_d	·9710 ± ·0418	·9944 ± ·0440	1·0058 ± ·0454	—	—	—	1·0610 ± ·0237
	r	·3916	·3907	·3479	—	—	—	·4350
Weight	n	57	54	52	101	115	44	260
	m_d	·7311 ± ·0493	·6847 ± ·0475	·7572 ± ·0535	·9233 ± ·0468	·7482 ± ·0355	·8450 ± ·0649	·8326 ± ·0263
	σ_d	·9442 ± ·0596	·9043 ± ·0587	·9702 ± ·0642	—	—	—	1·0335 ± ·0306
	r	·5821 ± ·0591	·5163 ± ·0673	·4377 ± ·0756	—	—	—	·4331 ± ·0340
Blood-Pressure	n	92	90	85	109	133	44	286
	m_d	·8082 ± ·0523	·7173 ± ·0480	·7936 ± ·0534	·9448 ± ·0562	·8815 ± ·0474	·9222 ± ·0863	·9163 ± ·0336
	σ_d	1·0623 ± ·0644	·8992 ± ·0551	1·0036 ± ·0633	—	—	—	1·1681 ± ·0402
	r	·2989	·5043	·3199	—	—	—	·3717
Pulse and Respiration	n	114	108	104	133	169	68	370
	m_d	·7977 ± ·0405	·7976 ± ·0416	·7995 ± ·0425	·9822 ± ·0462	1·1039 ± ·0460	1·0701 ± ·0704	1·0536 ± ·0304
	σ_d	1·0223 ± ·0486	1·0073 ± ·0492	1·0272 ± ·0511	—	—	—	1·3178 ± ·0348
	r	·4117	·4117	·4213	—	—	—	·1464
Physiological Characters	n	206	198	189	242	302	112	656
	m_d	·8005 ± ·0270	·7611 ± ·0262	·7988 ± ·0282	·9706 ± ·0302	1·0055 ± ·0280	·9987 ± ·0457	·9937 ± ·0188
	σ_d	1·0291 ± ·0325	·9597 ± ·0310	1·0182 ± ·0336	—	—	—	1·2546 ± ·0222
	r	·3778	·4532	·3796	—	—	—	·2328
Aggregate of ten Characters	n	547	520	499	716	899	349	1964
	m_d	·7719 ± ·0275	·7606 ± ·0278	·7885 ± ·0295	·9232 ± ·0288	·8695 ± ·0242	·9115 ± ·0407	·8965 ± ·0169
	σ_d	·9906 ± ·0331	·9723 ± ·0333	1·0055 ± ·0352	—	—	—	1·1262 ± ·0198
	r	·4167	·4305	·3734	—	—	—	·3660

The data for deciding these questions are set out in Table XI.

In order to compare dizygotic twins of like sex with pairs of brothers or of sisters born at different times it is necessary to devise a satisfactory method of separating the dizygotic from the monozygotic twins, and this will be discussed in sections 6 and 7. The degrees of resemblance found in the resulting groups are of course partly a function of the method of separation employed, and in Table XI the values of m_d, σ_d and r for "dizygotic" groups as obtained by three alternative methods are given, the respective merits of which are discussed later; it is sufficient to state here that the group "Not M_1" was obtained by employing finger prints *plus* facial resemblance, the group "Not B_4" by employing finger prints alone, and the group "Not B_5" by employing finger prints *plus* certain physical measurements. The most reliable conclusions will be obtained from the opposite sexed groups, since these are presumably all of dizygotic origin.

First comparing the aggregates of brother-sister pairs with *opposite sexed* twins, we find from Table XI that for height, head dimensions and weight m_d and σ_d are apparently slightly less in the twin pairs but not significantly less, whilst for the physiological characters the values of m_d and σ_d are almost identical in the two groups. For the aggregates of five static measurements and of ten characters we have the following:

Table XII.

		Opposite Sexed Twins	Brother-Sister Pairs	Difference
Static Characters	m_d	·7816 ±·0318	·8408 ±·0212	·0592 ±·0382
	σ_d	·9544 ±·0363	1·0680 ±·0252	·1136 ±·0442
Aggregate of ten Characters	m_d	·8241 ±·0266	·8659 ±·0173	·0418 ±·0317
	σ_d	1·0411 ±·0314	1·1020 ±·0206	·0609 ±·0375

The resulting correlation coefficients are apparently somewhat higher in the opposite sexed twin pairs than in the brother-sister pairs for all characters except blood-pressure. It must be noted, however, that the brother-sister correlations may be somewhat depressed by the fact that in a large proportion of the pairs one child of the pair was a twin. It is therefore necessary to also compare with the twins those opposite sexed pairs in which neither child was a twin, the SS' groups, and this can best be done by examining the values of r from Table V for the TT', SS' and $TS' + SS'$ groups simultaneously as in Table XIII.

Table XIII. *Correlation Coefficients in opposite sexed Pairs.*

	(1) TT'	(2) SS'	(3) $TS' + SS'$	Difference between (1) and (2)	Difference between (1) and (3)
Height	·6350	·4923	·4944	+·1427 ±·0814	+·1406 ±·0550
Head Dimensions	·5548	·5854	·4415	−·0306	+·1133
Static Characters	·5602	·4613	·4342	+·0989	+·1260
Weight	·4821	·2091	·3278	+·2730 ±·1010	+·1543 ±·0651
Blood-Pressure	·2582	·5590	·3599	−·3008	−·1017
Pulse and Respiration	·2157	·2212	·1938	−·0055	+·0219
Physiological Characters	·2341	·3884	·2852	−·1543	−·0511
Aggregate of ten Characters	·4458	·4339	·3766	+·0119	+·0692

When the TT' and SS' pairs are compared, the values of r are virtually the same in regard to head dimensions and pulse and respiration rates; for height the difference between the r's is less than twice its probable error and for weight less than three times its probable error; for blood-pressure the correlation in twin pairs is apparently lower than in brother-sister pairs, but the probable error of this difference must be of the order of ·1. For the aggregate of all characters the correlation coefficients are almost identical.

Next comparing the aggregates of *like sexed* siblings with dizygotic twins of like sex, it appears from Table XI that in all characters the values of m_d and σ_d are somewhat greater in the pairs of different age than in the twins; thus if the means of the three alternative values for dizygotic twins be used for comparison we have the result in Table XIV, which indicates a significantly smaller difference in the twins for all characters combined.

It was found in section 4, however, that the like sexed dizygotic twins had also a smaller variability σ_0 than the other groups, and when the correlation coefficients are computed they do not in fact indicate any greater degree of resemblance in dizygotic twins of like sex than in other like sexed siblings. The means of the three alternative coefficients for dizygotic twins, as shown in Table XV, slightly exceed the fraternal coefficients ($TS + SS$ groups) for height and weight, but not significantly; for head dimensions the relation is reversed and for blood-pressure the values are virtually the same. For pulse and respiration rates the dizygotic twins showed a remarkably high degree of resemblance, significantly greater than that for brothers and sisters.

Table XIV.

		Like Sexed Dizygotic Twins	Like Sexed Pairs of Different Age	Difference
Static Characters	m_d σ_d	·7745 ± ·0365 ·9904 ± ·0437	·8512 ± ·0213 1·0610 ± ·0237	·0767 ± ·0423 ·0706 ± ·0497
Aggregate of ten Characters	m_d σ_d	·7737 ± ·0249 ·9895 ± ·0339	·8965 ± ·0169 1·1262 ± ·0198	·1228 ± ·0301 ·1367 ± ·0392

If the comparison be extended as before by separating from the latter pairs the SS groups as in Table XV, there seem to be no significant differences between the resemblances in the twins and in the SS groups, in which neither child was a twin.

It must be concluded therefore that the degree of resemblance in any pairs of twins arising from separate ova, as determined by measuring during childhood the ten characters here studied, is not appreciably different, after adequate correction for age and sex has been made, from the degree of resemblance in brothers and sisters born at different times, when pairs with all age intervals are grouped together.

Table XV. *Correlation Coefficients in like sexed Pairs.*

	(1) TT dizygotic	(2) SS	(3) $TS+SS$	Difference between (1) and (2)	Difference between (1) and (3)
Height	·5193	·4794	·4794	+·0399 ± ·0890	+·0399 ± ·0746
Head Dimensions	·3553	·5918	·4385	−·2365	−·0832
Static Characters	·3767	·5646	·4350	−·1879	−·0583
Weight	·5120	·3442	·4331	+·1678 ± ·0949	+·0789 ± ·0755
Blood-Pressure	·3744	·3073	·3717	+·0671	+·0027
Pulse and Respiration	·4149	·1943	·1464	+·2206	+·2685
Physiological Characters	·4035	·2710	·2328	+·1325	+·1707
Aggregate of ten Characters	·4069	·4462	·3660	−·0393	+·0409

We may next inquire whether the mean differences in fraternal pairs tend to change with increasing interval between the births. It appears from the values in Table XI for three groups of age intervals, namely $\frac{3}{4}$–$2\frac{3}{4}$ years, $2\frac{3}{4}$–$5\frac{3}{4}$ years and $5\frac{3}{4}$–$10\frac{3}{4}$ years, that m_d is unaffected by the interval between births when the aggregates of ten characters or of five static measurements are considered, and the same applies to weight. Thus the averages of the mean differences found for opposite sexed and like sexed pairs are as follows:

Table XVI.

	$\frac{3}{4}$–$2\frac{3}{4}$ years	$2\frac{3}{4}$–$5\frac{3}{4}$ years	$5\frac{3}{4}$–$10\frac{3}{4}$ years
Aggregate of five Static Characters	·8747	·8191	·8657
Weight	·8427	·8373	·8497
Aggregate of ten Characters	·8862	·8788	·8764

For height there appears to be a tendency, both in opposite sexed and like sexed pairs, for m_d to decrease with increasing age interval, and the same is true for head dimensions and blood-pressure in the opposite sexed but not in the like sexed group. The means of all the corrected differences for opposite sexed and like sexed pairs combined are as follows:

Table XVII.

	¾–2¾ years	2¾–5¾ years	5¾–10¾ years	TT'
Height	·8416 ±·0311	·7248 ±·0248	·7555 ±·0444	·7207
Head Dimensions	·8923 ±·0348	·8265 ±·0278	·8452 ±·0457	·7916
Blood-Pressure	·9287 ±·0409	·8320 ±·0329	·8253 ±·0543	·8480

For these characters there is some indication of a greater divergence in pairs born at short intervals of 1 or 2 years apart than in either twins or pairs born at longer intervals, but this cannot be established with certainty from the data. For pulse and respiration rates there is a significantly greater mean difference in opposite sexed pairs with an age interval of 2¾–5¾ years (m_d = 1·1448 ± ·0507) than in pairs with smaller (m_d = ·8535 ± ·0435) or larger intervals (m_d = ·8559 ± ·0626), and in like sexed pairs the relation is of the same kind, though the differences are not significant.

If the pairs are divided into two approximately equal groups, with age intervals under and over 3¾ years, the mean differences are as shown in Table XVIII.

Table XVIII.

	Opposite Sexed Pairs differing in Age by		Like Sexed Pairs differing.in Age by	
	Less than 3¾ years	More than 3¾ years	Less than 3¾ years	More than 3¾ years
Height	·8397 ±·0379	·7281 ±·0530	·7795 ±·0458	·7373 ±·0504
Head Dimensions	·8621 ±·0387	·7808 ±·0391	·8920 ±·0386	·8603 ±·0403
Weight	·8251 ±·0370	·8913 ±·0458	·8174 ±·0339	·8536 ±·0416
Blood-Pressure	·8840 ±·0580	·7146 ±·0431	·9697 ±·0464	·8402 ±·0480
Pulse and Respiration	·9657 ±·0396	1·0225 ±·0463	1·0083 ±·0382	1·1091 ±·0467

It is clear from these comparisons that there is no definite evidence that the interval between births affects the degree of resemblance, though in regard to height, head dimensions and blood-pressure there is some suggestion of a slightly greater divergence between children born at short intervals of one or two years apart than in others.

(*d*) *Effect of Age at Measurement on Resemblance in Twins.*

Dahlberg (1) found that when his twins were divided into three groups, aged respectively under 10½ years, 10½–15½ and over 15½ years, the mean differences in absolute measure for body measurements and head dimensions tended to increase with age in monozygotic twins, but this was scarcely evident in dizygotic twins.

Von Verschuer (4) also found a tendency for mean percentage differences* of body and head measurements and weight to increase slightly with age in monozygotic twins when three age groups 2½–10, 11–20 and 21–64 years were used, but this was only statistically significant for weight and the data for height, head length and head breadth showed no such increase when division was made into ages 2½–16, and 17 years or over. His data showed a relation of the same kind, but not significant, in like sexed dizygotic twins. Weinberg, from an analysis of data by Lauritzen, Schatz and others, and Dahlberg (1), by analysing material published by

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* That is, differences expressed as percentages of the mean measurement for the pair.

Silberstein, Rabinowitsch, Hust and Tauber, concluded that *at birth* the mean differences in height and weight for monozygotic pairs were as great as, or even greater than, for dizygotic pairs, and from this it seems to follow that the differences produced in monozygotic pairs by unequal rate of development *in utero*, arising from differences in position, tend to be levelled out after birth when the opportunities for free development become more equal. Probably this process of "growing more alike" as regards body size through the forging ahead of the backward twin of a monozygotic pair is more or less completed within the first year or two of life, and evidence of it is scarcely to be expected from subdivision of school children into groups of ages. It is of interest from several points of view, however, to determine whether the mean differences in twin pairs, measured not in absolute scale units but in terms of a unit which is itself corrected both for sex and age, tend to increase or decrease with advancing age. For this purpose the twins were divided into three groups of ages 3–6, 7–9, and 10–15 years, and the values of m_d are given in Table XIX.

Table XIX. *Mean corrected Differences in Twin Pairs according to Age at Measurement.*

		Opposite Sexed Pairs (dizygotic)			Like Sexed Pairs (mono- and dizygotic)			Facially Identical Group (IV) of Like Sexed Pairs (mostly monozygotic)		
Age at measurement		3–6	7–9	10–15	3–6	7–9	10–15	3–6	7–9	10–15
Height	n	24	34	29	68	52	74	17	19	16
	m_d	·741 ± ·077	·800 ± ·070	·610 ± ·058	·570 ± ·036	·400 ± ·028	·462 ± ·027	·358 ± ·044	·278 ± ·032	·212 ± ·027
Head Size	n	54	57	78	123	105	161	36	45	36
	m_d	·740 ± ·078	·826 ± ·078	·802 ± ·051	·654 ± ·038	·568 ± ·029	·708 ± ·027	·366 ± ·044	·526 ± ·031	·511 ± ·026
Static Characters	n	102	125	136	259	209	308	70	83	68
	m_d	·737 ± ·056	·743 ± ·051	·758 ± ·050	·637 ± ·031	·527 ± ·028	·633 ± ·028	·379 ± ·035	·442 ± ·038	·397 ± ·037
Weight	n	24	34	30	69	52	76	17	19	16
	m_d	·841 ± ·087	·788 ± ·069	·719 ± ·067	·720 ± ·038	·430 ± ·030	·573 ± ·033	·311 ± ·040	·342 ± ·040	·262 ± ·033
Blood-Pressure	n	25	31	45	56	58	104	17	27	21
	m_d	·587 ± ·073	·719 ± ·080	1·126 ± ·104	·732 ± ·061	·675 ± ·055	·794 ± ·048	·817 ± ·123	·714 ± ·085	·500 ± ·068
Pulse and Respiration	n	34	37	48	82	70	110	26	30	24
	m_d	·823 ± ·077	·878 ± ·078	1·137 ± ·089	·834 ± ·050	·762 ± ·049	·800 ± ·041	·715 ± ·076	·740 ± ·073	·716 ± ·088
Physiological Characters	n	59	68	93	138	128	214	43	57	45
	m_d	·723 ± ·046	·805 ± ·047	1·110 ± ·056	·792 ± ·033	·723 ± ·031	·797 ± ·026	·755 ± ·056	·711 ± ·046	·615 ± ·058
Aggregate of ten Characters	n	185	227	259	466	389	598	130	159	129
	m_d	·746 ± ·046	·824 ± ·046	·880 ± ·046	·695 ± ·027	·577 ± ·024	·684 ± ·023	·495 ± ·036	·527 ± ·035	·456 ± ·034

In the first place we note that the facially identical group IV of like sexed twins, which we may regard as composed almost entirely of monozygotic pairs, gives differences of the order ·3 to ·4 at ages 3–6 for height, weight and head dimensions, as contrasted with differences of the order ·7 to ·8 in opposite sexed dizygotic twins at the same ages, and that this contrast remains about the same when we pass to older ages. This indicates that between birth, when it has been shown that the mean differences in height and weight are no less for monozygotic than for dizygotic twins, and the age of 3–6 years when the mean differences are shown by these data to be only about half as great in monozygotic as dizygotic, the former group must have grown more alike by the smaller child of the pair growing more rapidly and tending to come up to its twin in development. For these characters the ratios of monozygotic difference to dizygotic difference are as follows, comparison being made also with ratios which I have computed from the mean differences given by Dahlberg (reference (1), Tables 30 and 32) and from the mean percentage differences given by von Verschuer (reference (4), Table 12) for their twins of both types.

Table XX A.

Ratios of monozygotic to dizygotic mean differences		Height	Weight	Head Size	Static Characters
At Birth:					
(Dahlberg's Table 9)	7th–8th month gestation	·95	1·25	—	—
	9th–10th month gestation	1·18	1·14	—	—
During childhood:					
Author's data	At ages 3–6	·48	·37	·49	·51
	At ages 7–9	·29	·43	·64	·59
	At ages 10–15	·35	·37	·64	·52
Dahlberg's data	Under 10½	·32	—	·32[1]	—
	Ages 10½–15½	·39	—	·51[1]	—
	Over 15½	·23	—	·58[1]	—
Von Verschuer's data	Ages 2½–10	—	—	—	·38
	Ages 11–20	—	—	—	·35

[1] Mean ratio for head length and head breadth.

It is evident that the differentiation between the monozygotic and dizygotic degrees of resemblance in regard to these characters takes place between birth and ages 3–6, after which no consistent change in the ratio occurs. Table XIX suggests that the mean difference in height for monozygotic pairs tends to diminish slightly with advancing age, but the numbers of pairs are too small to establish this with certainty; there is no evidence of any similar relation for the head measurements, and when the static characters are grouped together the mean differences remain virtually unaffected by age both in monozygotic and dizygotic twins. For weight there is a tendency, significant for like sexed twins, for m_d to decrease with advancing age, but it may be noted that von Verschuer's data showed an increase in passing further to ages over 17. In considering the like sexed heterogeneous group in Table XIX it should be observed that the proportions of monozygotic to dizygotic differ somewhat at the various ages, being highest at 7–9 and lowest at 10–16, and this partly accounts for the lower m_d values in the middle age group.

When opposite sexed twins and monozygotic twins are studied in the same way as regards the *physiological* characters a very different phenomenon is noticeable. In the first place we find that at ages 3–6 the mean difference for blood-pressure, pulse and respiration rates grouped together is virtually the same for monozygotic pairs as for opposite sexed dizygotic pairs, namely ·755 ± ·056 and ·723 ± ·046 respectively as shown in Table XIX. At ages 7–9 the former has slightly decreased whilst the latter has slightly increased, and at ages 10–15 this divergence is very greatly accentuated, the ratio of monozygotic to dizygotic mean difference falling to ·55, which is almost the same as that for the static characters combined (·52). For blood-pressure the change in ratio between ages 3–6 and 10–15 is much more dramatic, namely from 1·39 to ·44, whilst for pulse and respiration rates the ratio falls only slightly from ·87 to ·63. Thus we have:

Table XX B.

		Static Characters	Blood-Pressure	Pulse and Respiration	Physiological Characters
Ratio of monozygotic m_d to dizygotic (opposite sexed) m_d	At birth	1	?	?	?
	Ages 3–6	·51	1·39	·87	·96
	Ages 7–9	·59	·99	·84	·88
	Ages 10–15	·52	·44	·63	·55

The question arises whether the great increase in mean difference for blood-pressure from ·587 at 3–6 years to 1·126 at 10–15 years in opposite sexed twins has anything to do with increased differentiation in environment between boys and girls as they grow up, and it is therefore advisable to determine whether the same change occurs for dizygotic like sexed twins. The values of m_d for these can be calculated by using the value of p, the proportion of monozygotic pairs in all the like sexed pairs as estimated in section 6, and assuming that the values of m_d for group IV in Table XIX represent the values for monozygotic pairs. Thus at ages 10–15 for blood-pressure m_d for dizygotic like sexed pairs is given by $(\cdot 794 - \cdot 500p)/(1 - p)$, and substituting the value for p estimated in section 6 this gives 1·084 which agrees closely with 1·126 for the opposite sexed pairs. Applying this method to blood-pressure and pulse and respiration rates the following mean differences are found:

Table XXI.

Mean Differences m_d	Blood-Pressure			Pulse and Respiration		
	3–6	7–9	10–15	3–6	7–9	10–15
Like sexed dizygotic (from p formula)	·659	·638	1·084	·941	·770	·871
Opposite sexed dizygotic (Table XIX)	·587	·719	1·126	·823	·878	1·137
Group IV, monozygotic (Table XIX)	·817	·714	·500	·715	·740	·716

and t appears from this Table that whilst for pulse and respiration rates the changes with age are clearly attributable to differing sex, this is not the case for blood-pressure, for in this character a sudden and pronounced differentiation between the two types of twins certainly occurs with the approach of adolescence. The degree of resemblance in blood-pressure is, if anything, smaller in the monozygotic than the dizygotic twins during early childhood, but it becomes rapidly greater with the approach of puberty, just as the resemblance for the static characters becomes greater in monozygotic than dizygotic twins during the year or two immediately following birth. It is as though the inherited factors which govern the establishment of an individual base level for blood-pressure remain in abeyance until the onset of puberty and then come into operation. There is evidently an increase in m_d for dizygotic pairs with approach of adolescence, as contrasted with a decrease for monozygotic pairs, and when these effects are combined in the heterogeneous like sexed group they tend to cancel out.

From this we may draw the conclusion that the hereditary factors concerned in producing similar levels of blood-pressure in adult siblings or twins do not come into operation to an appreciable degree until the approach of puberty, and it seems to follow that during early childhood variations in pressure must be chiefly dependent on environment. The relative effects of these factors will be further discussed in section 9.

6. DETERMINATION OF THE PROPORTION OF MONOZYGOTIC TWINS AMONG LIKE SEXED PAIRS.

In an unselected group of twin births it is possible, by applying Weinberg's "differential rule," to estimate the number of monozygotic pairs to be expected, for it is given by the difference between the numbers of like sexed and opposite sexed pairs. The basis of this is that approximately one-half of all dizygotic twin pregnancies will be opposite sexed, since it is presumed that in this type of twinning the sex of one twin will be determined independently of the sex of the other. The statistical evidence for the truth of this assumption and the validity of the differential rule have been well analysed by Dahlberg, and his rather broad conclusion is that monozygotic twin births form 20 to 30 % of the total number of twin births, which is equivalent to about 33 to 46 % of the like sexed twin births.

I have already pointed out in section 2 (*b*) that, owing to the method of discovering the twins in schools used in this research, the data cannot be regarded as unselected in regard to the proportions of like sexed to opposite sexed, and we cannot therefore apply Weinberg's rule to estimate the number of monozygotic twins. The like sexed pairs should contain a proportion of monozygotic twins slightly enhanced by the method of selection, and between 40 and 55 % of the like sexed twins may be expected on this basis to be of monozygotic origin.

Fortunately there is a more precise method of calculating this proportion from the mean and the mean square differences m_d and σ_d^2, if we can find a character for which these differences in dizygotic and monozygotic twins are distributed according to a normal curve. After I had evolved and tried out this method in the belief that it was new, I found that an essentially similar method had already been used by Fisher (3), who gave so little explanation of it, however, that I venture to set it down here in the form in which I approached it.

If ${}_1m_d$ = mean corrected difference in monozygotic pairs;
${}_2m_d$ = mean corrected difference in dizygotic pairs of like sex;
m_d = mean corrected difference in the total like sexed pairs;
${}_1\sigma_d^2$ = mean square of corrected differences for monozygotic pairs;
${}_2\sigma_d^2$ = mean square of corrected differences for dizygotic pairs of like sex;
σ_d^2 = mean square of corrected differences for total like sexed pairs;
p = proportion of monozygotic pairs in total like sexed pairs;

then, provided we can assume normal distributions of the differences for monozygotic and for dizygotic pairs when taken separately,

$$ {}_1\sigma_d = \sqrt{\frac{\pi}{2}}\,{}_1m_d \quad\text{and}\quad {}_2\sigma_d = \sqrt{\frac{\pi}{2}}\,{}_2m_d, $$

and since $p\,{}_1m_d + (1-p)\,{}_2m_d = m_d$ we obtain by substituting,

$$ p\,{}_1\sigma_d + (1-p)\,{}_2\sigma_d = m_d\sqrt{\frac{\pi}{2}} \qquad \text{......(1).} $$

Also, by definition

$$ p\,{}_1\sigma_d^2 + (1-p)\,{}_2\sigma_d^2 = \sigma_d^2 \qquad \text{......(2),} $$

and eliminating ${}_1\sigma_d$ from (1) and (2)

$$ p\,\sigma_d^2 - p\,{}_2\sigma_d^2 + p^2\,{}_2\sigma_d^2 = \left[p\,{}_2\sigma_d - {}_2\sigma_d + m_d\sqrt{\frac{\pi}{2}}\right]^2; $$

giving

$$ p = \frac{{}_2\sigma_d^2 - 2m_{d\,2}\sigma_d\sqrt{\frac{\pi}{2}} + m_d^2\frac{\pi}{2}}{{}_2\sigma_d^2 - 2m_{d\,2}\sigma_d\sqrt{\frac{\pi}{2}} + \sigma_d^2} \qquad \text{......(3),} $$

or alternatively, expressing p in terms of the known value ${}_2m_d$ instead of the known value ${}_2\sigma_d$, we have

$$ p = \frac{{}_2m_d^2 - 2\,{}_2m_d\,.\,m_d + m_d^2}{{}_2m_d^2 - 2\,{}_2m_d\,.\,m_d + \frac{2}{\pi}\sigma_d^2} \qquad \text{......(4).} $$

The data will give m_d and σ_d for the total twins of like sex, and the values ${}_2m_d$ and ${}_2\sigma_d$ for dizygotic pairs of like sex can be determined by the following device[*].

Let ${}_3m_d$, ${}_3\sigma_d$ refer to pairs of twins of opposite sex;
${}_4m_d$, ${}_4\sigma_d$ refer to pairs of brothers or pairs of sisters other than twin pairs;
${}_5m_d$, ${}_5\sigma_d$ refer to brother-sister pairs other than twin pairs;

then it has been shown in section 5 that the effect of sex likeness on the differences for siblings is in any case only slight and it may be assumed that the ratio ${}_2m_d/{}_3m_d$ for dizygotic twin pairs is the same as the ratio ${}_4m_d/{}_5m_d$ for ordinary pairs of siblings, and similarly for σ_d. This gives

$${}_2m_d = {}_3m_d \cdot {}_4m_d/{}_5m_d \qquad \text{......(5)},$$

and

$${}_2\sigma_d = {}_3\sigma_d \cdot {}_4\sigma_d/{}_5\sigma_d \qquad \text{......(6)},$$

and since all the values on the right hand of these equations are known, ${}_2m_d$ and ${}_2\sigma_d$ can be found and used in equations (3) and (4) to calculate p. The value given by (4) may differ slightly from that given by (3) if ${}_2\sigma_d$ be not exactly equal to $\sqrt{\frac{\pi}{2}} \cdot {}_2m_d$, and in this case we may use the mean of the two values of p as giving the best approximation to it.

It remains to find a character which gives a very close approximation to a normal curve in its distribution of corrected differences for dizygotic twins. Normality in the distribution of differences for monozygotic twins also can then be assumed for the moment, p calculated on that assumption[†], the two normal distributions multiplied by $(1 - p)$ and p respectively and added together and the resulting total distribution tested for its goodness of fit to the actual total distribution of differences in the heterogeneous group of like sexed twins. If the fit be good the assumption of normality in the monozygotic, as well as in the dizygotic, twin differences may be regarded as well founded.

For *height* the whole group of like sexed twins gives $m_d = \cdot 4830$, $\sigma_d = \cdot 6565$, and from Table V (*TT′* group) ${}_3m_d = \cdot 7202$, ${}_3\sigma_d = \cdot 8992$. Hence $\frac{\pi}{2}\,{}_3m_d^2 = \cdot 8148$ and ${}_3\sigma_d^2 = \cdot 8086$ and these differ by only ·0062. The probable error of this difference[‡] ${}_3\sigma_d^2 - \frac{\pi}{2}\,{}_3m_d^2$ is given by

$$\pm \cdot 6745 \frac{{}_3\sigma_d^2}{\sqrt{n}} (2\pi - 6) \quad \text{or} \quad \pm \cdot 1875 \frac{{}_3\sigma_d^2}{\sqrt{n}},$$

which for $n = 87$ pairs gives $\pm \cdot 0163$, so that the difference $\cdot 0062 \pm \cdot 0163$ is certainly small as compared with its probable error. The curve is of course symmetrical owing to the double entry of differences between pairs, hence $\beta_1 = 0$, and the other constants are $\mu_4 = 2 \cdot 0075$ and $\beta_2 = 3 \cdot 070$; hence the distribution of differences approximates very closely to a normal curve, as may be seen from Fig. 2.

Proceeding to find ${}_2m_d$ and ${}_2\sigma_d$ by formulae (5) and (6) we have from Table V, ${}_4m_d = \cdot 7616$, ${}_4\sigma_d = \cdot 9685$ (*TS* + *SS* group) and ${}_5m_d = \cdot 7911$, ${}_5\sigma_d = 1 \cdot 0082$ (*TS′* + *SS′* group); hence

$${}_2m_d = \cdot 7202 \times \cdot 7616/\cdot 7911 = \cdot 6933 \quad \text{and} \quad {}_2m_d^2 = \cdot 48072,$$

whilst ${}_2\sigma_d = \cdot 8657$, ${}_2\sigma_d^2 = \cdot 74938$, and substituting these values equation (3) gives $p = \cdot 5124$

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[*] Fisher assumed these to be the same as in twins of opposite sex; the correction is in any case a small one.

[†] Fisher was content, in his use of a method similar to this, to regard this assumption as sufficiently reasonable to require no further check on it.

[‡] See Fisher, reference (3), p. 574.

and equation (4) gives $p = \cdot 5152$, the mean value being $p = \cdot 5138$. This means that 51 % of the like sexed twins were monozygotic, which is within the limits anticipated.

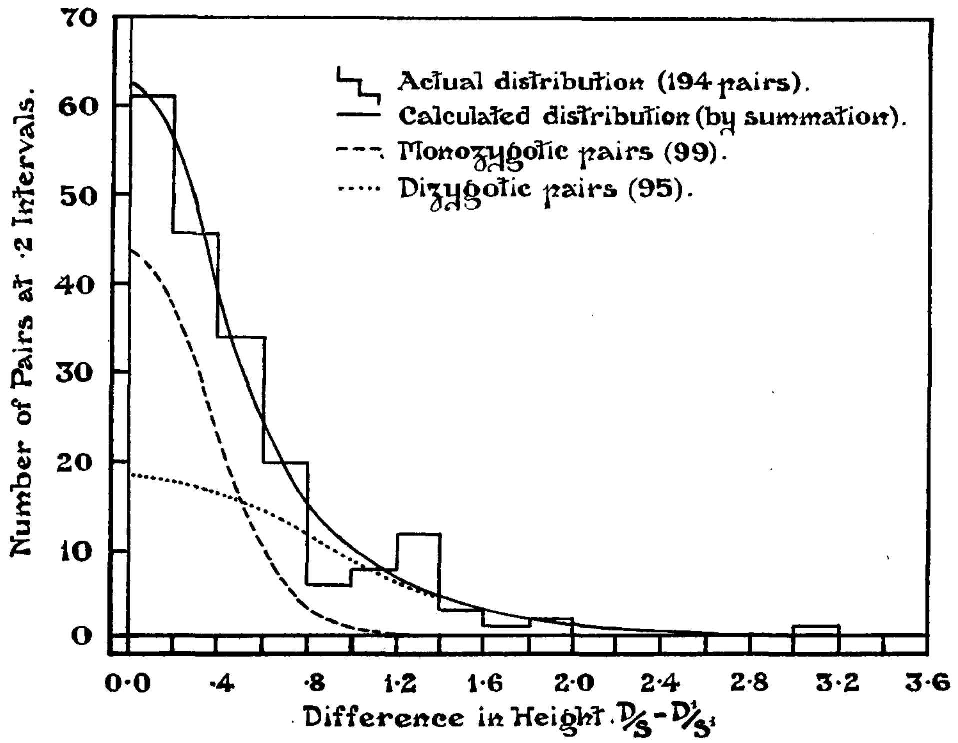
If it be a correct assumption that the distribution of differences in height is normal for monozygotic as well as for dizygotic twin pairs of like sex, the composite distribution for all like sexed pairs cannot be normal, but $\sigma_d^2 - \frac{\pi}{2} m_d^2$ should be significantly positive. Actually

$$\sigma_d^2 = \cdot 4309, \quad \frac{\pi}{2} m_d^2 = \cdot 3664,$$

the difference ·0645 ± ·0060 being over 10 times its probable error, the number of pairs being 194.

Figure 3.

Distributions of Height Differences in Like-sexed Twins.



From the evaluation of p these 194 pairs should consist of 99 monozygotic and 95 dizygotic pairs, and knowing ${}_1\sigma_d$ and ${}_2\sigma_d$ for these normal distributions the theoretical distribution can be calculated and compared with the actual. Thus for the monozygotic pairs, σ_d can be found from formula (1) which gives ·3588 or formula (2) which gives ·3598, and employing the mean of these ${}_1\sigma_d = \cdot 3593$. Using class intervals of ·2 the calculated frequencies for the two normal curves given by (1) $N/2 = 99$, ${}_1\sigma_d = \cdot 3593$ and (2) $N/2 = 95$, ${}_2\sigma_d = \cdot 8657$ are as shown in Table XXII.

Adding the theoretical frequencies (1) and (2) the composite distribution in the third line is obtained and the actual distribution for all like sexed twins is reproduced in the fourth line from Table XXXII. Applying the test for goodness of fit it is found that for $n' = 12$, $X^2 = 11 \cdot 355$ and $P = \cdot 415$, so the fit is a good one.

It will be shown in section 7 that the calculated distributions (1) and (2) also give remarkably good fits to distributions of height differences in certain groups formed by means of finger print resemblances alone, and that this provides strong evidence that the criterion used in forming those groups is a sound one for diagnostic purposes. The four distributions obtained below are represented in Fig. 3.

Table XXII.

	Corrected Difference for Height in Twin Pairs																Total
	0–	·2–	·4–	·6–	·8–	1·0–	1·2–	1·4–	1·6–	1·8–	2·0–	2·2–	2·4–	2·6–	2·8–	3·0–	
(1) Monozygotic	42	31	16	7	2	1	—	—	—	—	—						99
(2) Dizygotic	17	17	15	12	10	8	6	4	2	2	1	1					95
Total like sexed twins (1) and (2)	59	48	31	19	12	9	6	4	2	2	1	1					194
Total like sexed twins Actual	61	46	34	20	6	8	12	3	1	2	—					1	194

There is no special virtue in using height as the character for calculating p apart from the fact that the distribution of differences for dizygotic twins passed the test for normality satisfactorily, the difference ${}_3\sigma_d^2 - \frac{\pi}{2}\,{}_3m_d^2$ being only ·0062 ± ·0163. Unless this test is very nearly fulfilled the method cannot be employed.

7. Evolution of a Practical Method of separating Monozygotic from Dizygotic Twins of like sex.

The various criteria which have been employed in the attempt to distinguish monozygotic or "identical" from dizygotic or "fraternal" twins of like sex must now be passed in review in the endeavour to discover a method on which reliance can be placed, and which is not so dependent upon the personal equation of the observer as the methods at present in use. To demonstrate the importance of this last factor it is only necessary to compare the mean differences between monozygotic twins obtained by two independent workers, each of whom felt confident as to his diagnosis, employed an adequate number of pairs and undoubtedly carried out his investigation with the utmost care.

Table XXIII.

	(1) Monozygotic Pairs		(2) Dizygotic Pairs		Ratio of (2) to (1)	
	Dahlberg's Table 16	von Verschuer's Table 6	Dahlberg's Table 16	von Verschuer's Table 6	Dahlberg	von Verschuer
Height	1·134 ± ·089	·62 ± ·05	3·539 ± ·280	1·55 ± ·17	3·1	2·5
Head Length	1·422 ± ·110	·90 ± ·07	2·998 ± ·232	1·70 ± ·18	2·1	1·9
Head Breadth	1·199 ± ·092	·91 ± ·07	2·736 ± ·212	1·58 ± ·17	2·3	1·7

The data of Dahlberg (1) and von Verschuer (4) did not differ greatly in general age distribution, and the figures quoted above in Table XXIII represent in each case the mean of differences between twins when each difference has first been reduced to a percentage of the average measurement of the pair, so that the effect of age is partly corrected for; nevertheless not only are the means themselves much greater throughout in Dahlberg's data, a point he has himself commented on, but, what is more significant for our purpose, the *ratios* of dizygotic to monozygotic are consistently higher in Dahlberg's than von Verschuer's data, indicating that the former observer was using a broader basis for his monozygotic group than the latter.

This example, taken from the best research data, could be amplified by others, and it is therefore surprising to find with what assurance many writers on the question of twins regard their own ability to diagnose the monozygotic from the dizygotic with certainty, which can only be explained by the fact that no satisfactory check has so far been devised as to whether the diagnosis was right or wrong.

(*a*) *Foetal Membranes.*

It has long been thought that if each child has a separate chorion the twins are dizygotic, but if covered by a common chorion and attached to a common placenta they are monozygotic. Recently some cases have been reported of twins very closely similar who were known to have been born with separate chorions, and *vice versa*, but rather than disproving the correctness of the above theory it seems much more probable that this is simply another illustration of the difficulty of diagnosing monozygotism from close physical resemblance alone and *vice versa*. Siemens finds that 14–26 % of twin births have a single chorion, and this is not necessarily incompatible with the proportion of twin births estimated to be monozygotic by Weinberg's method, namely 20–30 % according to Dahlberg's analysis of the evidence. It must also be noted that there are some cases in which it is by no means easy to decide whether the membranes were originally separate or not, so that the criterion is not free from ambiguity. Since accurate record of the condition of the membranes at birth is rarely available, this criterion is only exceptionally of practical assistance when an observer is faced with a pair of grown up twins, and need not be considered further here, for it was found to be of little service in the present work.

(*b*) *Symmetry Reversal.*

It has been thought by Wilder, Newman and others that this phenomenon, in which one twin is the mirror image of the other in regard to certain characters, indicates their monozygotic origin. Thus the direction of the whorl of the hair on the head was studied by Lauterbach (2), right and left handedness by several observers, the mode of clasping hands by Dahlberg, asymmetries of body form by von Verschuer (4) and the presence of naevi by Siemens, and it has been concluded that symmetry reversal in many characters occurs more frequently in monozygotic than dizygotic twins, but not with sufficient constancy to make it valuable for the purpose of individual diagnosis. This phenomenon will be studied on the present data in a subsequent paper.

(*c*) *Facial Resemblance, including Colour of Hair and Eyes.*

The criterion which has been most extensively used has been the degree of facial resemblance. No exact measure of such resemblance can be made, but in its ultimate analysis it could be resolved into a large number of differences in corresponding measurements on the head and face and the general effect of all these differences being small is to make the faces indistinguishable. The advantages of this method are the ease and rapidity with which the likeness can be observed, and the fact that in comparing two faces one is simultaneously taking into account the degrees of resemblance in many factors such as colouring, size and conformation of all the parts which go to make up the facial expression. If all these factors were independently inherited and uncorrelated, the chance of a pair of fraternal twins having faces which were so alike as to be almost indistinguishable would be a small one, but since some of the measurements of different parts of the same face are correlated amongst themselves it is by no means justifiable to discount entirely the possibility that a pair of twins having a high degree of facial resemblance may nevertheless be of dizygotic origin. Pairs of brothers or of sisters slightly different in age sometimes reach such high degrees of resemblance as to be mistaken by their friends in spite of the difference in age and the independent exposure of the elder for a year or two to the influences of an environment to which the younger had not been subjected. On the other hand, a pair of monozygotic twins may develop distinctive differences in facial expression through accident or illness affecting one of the pair during the period of growth, and it is not therefore safe to assume that a pair of twins without any striking facial resemblance is necessarily of dizygotic origin.

It will be shown below, and can be seen at once by looking at Tables III, XXVIII and XXX, that whatever anthropometric character, with the exception of finger prints, is examined, a considerable degree of difference may be expected as a fairly frequent occurrence in monozygotic pairs, and, on the other hand, an approximation to identity in any one character is quite common in dizygotic pairs. It is, therefore, not to be expected that facial resemblance can enable us to separate the two groups with certainty, though it is undoubtedly a considerable help in doing so. My own experience has been that (1) about two-thirds of like sexed twins can be at once separated by facial resemblance into two groups labelled "identical" and "fraternal," leaving one-third as "doubtful," and (2), even as regards the two groups believed to be free from doubt, other evidence suggests that the diagnosis is really incorrect in a small proportion.

It is therefore obvious that other characters must be taken into account, and Siemens (10) has drawn up a scheme, involving no actual measurements, by use of which he boldly claims that "an actual mistake in determining the identity of twins need never occur." This involves consideration of the degree of resemblance in hair, eye and skin colour, body hair, location of freckles, telangiectases, acne and other peculiarities of the skin, the tongue and the teeth, form of the face, ear and hands, and body build, and Siemens states that he has first roughly evaluated the probabilities of agreement in these different traits in monozygotic and dizygotic twins, but how this has been done without using the scheme itself for diagnosis is not clear. In no branch of scientific investigation is the circular method of reasoning so common, and I am not sure that I shall escape the accusation of having fallen into it myself. At present the scheme of Siemens awaits confirmation of its usefulness; it seems to present the advantage of embracing a number of characters which are probably inherited independently, but, on the other hand, some of them are often not present at all, and most of the degrees of resemblance are subject to a large personal equation on the part of the observer.

Eye and hair colour will be fully dealt with in a subsequent paper; it will suffice to state here that, after getting rid of the effect of heterogeneity in like sexed twins, colour differences seem to present little or no relation to differences in any of the ten measured characters. Their use in diagnosis is referred to again in the next subsection (see Table XXVIII).

Table XXIV.

		$\bar{\Delta}$ = Mean of Corrected Differences for five Static Characters and Weight																			Total
		0–	·1–	·2–	·3–	·4–	·5–	·6–	·7–	·8–	·9–	1·0–	1·1–	1·2–	1·3–	1·4–	1·5–	1·6–	1·7–	1·8–	
Degree of Facial Resemblance	I–II	—	—	—	4	4	7	7	5	8	5	1	—	2	1	1	—	1	—	1	47
	III	—	—	3	5	10	10	4	5	5	—	1	1	—	—	—	—	—	—	—	44
	IV	1	6	10	7	3	8	3	—	—	1	—	—	—	—	—	—	—	—	—	39

Table XXIV shows the amount of separation which can be achieved by facial resemblance (which of course involves eye and hair colour) in relation to $\bar{\Delta}$, the mean of the six corrected differences for the static characters and weight. The one pair in group IV with a $\bar{\Delta}$ exceeding ·7 (no. 40, Table XXIX) was almost certainly not monozygotic from finger print evidence, there being only four corresponding fingers of the same sided hands with similar patterns. It will be seen in the next section that a $\bar{\Delta}$ exceeding ·9 is not to be expected in monozygotic pairs.

(*d*) *Finger Print Patterns in Conjunction with Anthropometric Measurements.*

When the anthropometric measurements were correlated separately with facial resemblance nothing very promising for diagnosis was found from the distributions, and it is unnecessary to reproduce the results in detail since in any event the groups I–IV are arbitrary and dependent on the observer's opinion, group III is a doubtful group forming one-third of the whole, and there is obviously too much overlap for such distributions to help greatly in diagnosis. Up to this point, therefore, it had to be admitted that no accurate analysis of the measurements of like sexed twins could be made except to a limited extent for height by the method of section 6. Attention was therefore directed to finger prints.

Galton examined the finger patterns of 34 pairs of twins of like sex and noticed that there was a high degree of similarity between the patterns on corresponding fingers in some of the pairs. Wilder (11) concluded, on insufficient evidence, that such similarity between finger patterns did not extend to the finer details such as the number of ridges nor to the "minutiae" of the patterns. In 1914 Poll (12) examined finger prints from 82 pairs thought to be monozygotic and classified the type of pattern into eight groups (arch, whorl, three radial and three ulnar types of loop), from which he concluded that complete correspondence in all ten fingers must be very rare, and in nine fingers not common even in twins closely resembling each other. Owing to the uncertainty of his diagnosis of monozygotism and absence of comparison with similar data for opposite sexed pairs, he failed to perceive the usefulness of the method. Ganther and Rominger (13) in 1923 examined the palm and finger prints of 47 pairs of twins at whose births the condition of the foetal membranes had been noted, which enabled them to separate 5 pairs as certainly monozygotic, and found that in these from 7 to 9 fingers had the same kind of pattern on corresponding fingers. Leven (14) in 1924 found that the finger patterns of 15 pairs thought to be monozygotic exhibited greater likeness than those of 8 pairs thought to be dizygotic. Bonnevie (15) in the same year measured the similarity in finger patterns of 15 pairs thought to be monozygotic and 16 pairs thought to be dizygotic and found the degree of resemblance in the former to equal or slightly exceed that found between the right and left hands of individuals, this being also true for quantitative measures based upon ridge counting.

The researches I have referred to above suggested that finger patterns might provide a sharper differentiation between the monozygotic and dizygotic types than the other factors studied. Although it was not possible to secure legible finger prints from all the children measured, they were obtained from 108 pairs of like sex and 52 pairs of opposite sex, and from a large number of their brothers and sisters. For the purposes of Part I of this paper, only a partial analysis of this collection of finger patterns has yet been made without any attempt to count the ridges or to examine the minutiae of the patterns. The method adopted has been to simply examine the patterns as a whole with the aid of a lens and decide whether the patterns on corresponding fingers were "similar" or not. The definition of similarity is, of course, important and I would define it as used in this work as follows: *A pair of finger patterns were classed as similar when they were not merely of the same class (arch, whorl or loop) but so much alike as regards general configuration, inclination of axes, position of deltas and number of ridges, as to make them appear the same to a casual examination, without actually counting the ridges or looking for minutiae.* When opposite sided hands were being compared, "sameness" of pattern means, of course, that one is the mirror image of the other.

It may be objected that in classifying patterns by such a definition no two observers will agree in every case, but this would be true in some degree of any system of classification of finger prints which has been devised, and the more minute the examination becomes the more difficult it is to decide whether two patterns are to be classed as identical or not. I have personally found little difficulty in deciding at once whether two patterns were similar on the basis of the above definition, but I should find it very hard to decide whether a difference of 1 or 2 in a ridge count ought to exclude similarity or not. In order to minimise the effect of personal equation, and keeping in mind Bonnevie's statement that similarity in monozygotic pairs is equal to or greater than that between the two hands of the same child, I simultaneously examined (*a*) corresponding fingers of the same sided hands of the pair, (*b*) corresponding fingers of the opposite sided hands of the pair, (*c*) corresponding fingers of the two hands of each individual child, allowing for reversal of the patterns in the case of (*b*) and (*c*). I then counted for each twin pair the number of correspondences α, β and γ, defined as follows:

α = number out of the 10 possible sets of corresponding fingers of the same sided hands of the pair which presented similar patterns*;

β = number out of the 10 possible sets of corresponding fingers which presented similar patterns either on the same sided hands of the pair, or, failing that, on the opposite sided hands of the pair*;

γ = number out of the 10 possible sets of corresponding fingers of the opposite sided hands of each individual of the pair which presented similar patterns*.

To do this α was first recorded and the fingers with similar patterns marked off; the fingers *remaining* were then compared with the corresponding fingers on the opposite hands of the other twin to see if the pattern had "crossed over," and any similarities so found were added to α, giving β; finally the two hands of each child individually were compared with each other, giving γ. Having entered α, β, γ on the cards for each of the 160 pairs of twins, β was correlated against γ as in Table XXV and α against γ as in Table XXVI, for opposite sexed twin pairs and like sexed twin pairs separately. The subdivisions of column 6 in Table XXVI will be explained below.

Table XXV.

OPPOSITE SEXED TWIN PAIRS LIKE SEXED TWIN PAIRS

β =No. of corresponding fingers alike on the same sided or opposite sided hands of the pair.

γ =No. of corresponding fingers having patterns alike on the two hands of the same child		0	1	2	3	4	5	6	7	8	9	10	Total	0	1	2	3	4	5	6	7	8	9	10	Total	Not B_4	B_4
	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	2	.	2
	3	.	.	.	1	.	.	.	.	.	.	.	1	.	.	1	.	1	.	1	.	2	.	.	5	1	4
	4	.	2	.	1	1	.	.	.	.	.	.	4	.	.	1	1	5	.	5	1	2	.	.	15	7	8
	5	.	1	5	3	3	8	(1)	.	.	.	.	21	.	.	1	2	4	1	1	3	.	.	.	12	8	4
	6	.	3	4	1	1	3	1	1	.	.	.	14	.	1	.	1	3	5	7	9	2	1	.	29	17	12
	7	.	.	1	4	1	1	2	.	.	.	.	9	.	.	2	2	1	2	1	3	4	2	.	17	8	9
	8	.	1	.	1	.	.	.	.	.	.	.	2	.	.	.	1	3	3	4	3	3	1	.	18	11	7
	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	1	4	.	7	1	6
	10	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	1	.	1	3	1	2
	Total	1	7	10	11	6	12	4	1	.	.	.	52	.	1	6	7	17	11	22	20	15	8	1	108	54	54

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* In a few instances only 8 or 9 sets were sufficiently legible or complete to enable a decision to be made; in these cases α, β or γ was taken as the expected number of similar sets in 10, being calculated by 10 × number of similar sets/number of sets in which a decision was possible. If less than 8 sets were satisfactory the pair was rejected.

Table XXVI.

Opposite Sexed Twin Pairs | Like Sexed Twin Pairs

a = No. of corresponding fingers alike on the same sided hands of the pair.

γ = No. of corresponding fingers having patterns alike on the two hands of the same child	Opposite Sexed 0	1	2	3	4	5	6 (a)	6 (b)	7	8	9	10	Total	Like Sexed 0	1	2	3	4	5	6 (a)	6 (b)	7	8	9	10	Total	Not B_5	B_5
0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	2	.	2
3	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.	1	1	.	.	.	1	.	2	.	.	5	2	3
4	.	2	.	1	1	.	.	.	.	.	.	.	4	.	.	1	3	5	.	.	3	1	2	.	.	15	9	6
5	1	3	5	3	4	5	.	.	.	.	.	.	21	.	2	2	2	2	.	.	2	2	.	.	.	12	8	4
6	.	4	3	.	3	2	1	1	.	.	.	.	14	.	1	.	3	3	6	2	6	5	2	1	.	29	15	14
7	.	1	.	4	1	2	.	1	.	.	.	.	9	.	.	3	1	1	2	.	3	4	2	1	..	17	7	10
8	1	.	.	1	.	.	.	.	.	.	.	.	2	.	.	.	1	4	3	2	3	2	2	1	.	18	10	8
9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	1	4	.	7	1	6
10	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	.	1	.	1	3		3
Total	3	10	9	9	9	9	1	2	.	.	.	.	52	.	3	8	11	15	11	4	21	15	12	7	1	108	52	56

The left-hand portion of Table XXV shows that in 52 opposite sexed twin pairs (i) only 1 pair had more than 6 fingers with direct or crossed similarity, as shown by the vertical division, and (ii) only 2 pairs had $\beta > \gamma$, as shown by the zigzag line. The distribution is roughly symmetrical in both directions with means $\bar{\beta} = 3{\cdot}461$ and $\bar{\gamma} = 5{\cdot}712$ and standard deviations $\sigma_\beta = 1{\cdot}62$ and $\sigma_\gamma = 1{\cdot}20$. Since sex differences in finger patterns are of no importance, we should expect a similar distribution for dizygotic pairs of like sex as for those of opposite sex, and since it was found in section 6 that about 48·6 % of the like sexed pairs must be dizygotic it was to be expected that 51 to 54 of the 108 pairs (which may be regarded as a random sample of the 194 like sexed pairs analysed in section 6) would be dizygotic. I therefore attempted to divide the like sexed distribution of Table XXV into two parts by some simple criterion for monozygotism in such a way that one portion containing 51–54 pairs would be an approximate replica of the distribution for opposite sexed pairs, the remaining portion representing the monozygotic pairs. The results of this attempt are shown in Table XXVII.

Table XXVII.

Table No.	Experimental Criteria for Monozygotism by Finger Prints alone	Dividing line in Table XXV or XXVI	Frequencies resulting: Like Sexed Pairs: Mono-zygotic	Like Sexed Pairs: Dizygotic	Opposite Sexed: Included	Opposite Sexed: Excluded
XXV	B_2 = At least 6 corresponding fingers alike on the same sided or opposite sided hands of pair. ($\beta > 5$)	Vertical line between $\beta = 5$ and $\beta = 6$	42	66	5	47
XXV	B_2' = At least 7 as above. ($\beta > 6$)	Vertical line between $\beta = 6$ and $\beta = 7$	64	44	1	51
XXV	B_3 = More corresponding fingers alike on same or opposite sided hands of pair than on opposite hands of same child. ($\beta > \gamma$)	Zigzag diagonal line separating $\beta = \gamma$ from $\beta > \gamma$	73	35	2	50
XXV	B_4 = Either B_2' or B_3. ($\beta > 6$ or $\beta > \gamma$)	Thick black line	54	54	2	50
XXVI	B_1 = At least 6 corresponding fingers alike on the same sided hands of pair. ($a > 5$)	Vertical line between $a = 5$ and $a = 6$	48	60	3	49
XXVI	B_1' = At least 7 as above. ($a > 6$)	Vertical line between $a = 6$ and $a = 7$	73	35	0	52

The B_2, B_2' and B_3 groups do not satisfy the conditions as to frequency, but B_4 produces the correct frequencies, the only fault being that 2 out of 52 opposite sexed pairs also apparently satisfied this criterion for monozygotism. It may be noted that in one of these two pairs ($\beta = 6$, $\gamma = 5$) all the finger patterns were not legible, so it is possible that in this case $\beta = 6$, $\gamma = 6$, which would bring the pair within the dizygotic area. The remaining pair (no. 72, see Table XXIX) cannot be so explained, and it may therefore be expected that the criterion will fail in a small percentage of cases.

In the attempt to discover the best criterion for diagnosis other experimental groups were formed by introducing a condition that the degree of facial resemblance must be greater than that defined in group II, thus:

M_2 = group B_2 with facial resemblance III or IV, gives 53 dizygotic
M_2' = group B_2' ,, ,, gives 72 ,,
M_3 = group B_3 ,, ,, gives 66 ,,
M_4 = group B_4 ,, ,, gives 61 ,,

and these groups will be examined presently; only M_2 fulfils the condition as to the proportion expected.

Turning next to Table XXVI*, it was noticed that no opposite sexed pairs had more than six corresponding fingers alike on the same sided hands of the pair, and only three pairs had six alike (nos. 72, 44, 211, see Table XXIX). The form of the distribution for like sexed pairs and comparison with the left half of the table suggested that all pairs in which $\alpha = 7$, 8, 9 or 10 are monozygotic and all pairs in which $\alpha = 0$, 1, 2, 3, 4 or 5 are dizygotic, with some overlap in the column $\alpha = 6$. A vertical division was therefore made through $\alpha = 6$ by means of various additional criteria to assist the diagnosis, such that from 51 to 54 pairs fell into the dizygotic group. If the division was made between $\alpha = 5$ and $\alpha = 6$ or between $\alpha = 6$ and $\alpha = 7$ by finger prints, groups B_1 and B_1' shown in Table XXVII were obtained, producing 48 and 66 dizygotic pairs respectively, so that some definition was evidently required which would separate off only a small proportion of the $\alpha = 6$ cases as dizygotic.

If a degree of facial resemblance exceeding group II was added as a condition for monozygotism this gave another experimental group: M_1 = group B_1 with facial resemblance III or IV, giving 57 pairs as dizygotic, a proportion somewhat too large.

The next step was therefore to introduce some of the simpler measurements in order to subdivide the doubtful column $\alpha = 6$, and after trial the following definition for monozygotism was arrived at:

B_5 = pairs with patterns on seven or more corresponding fingers of the same sided hands alike, or with six alike provided that the heights and three out of the four head measurements of the pair do not differ by more than the standard deviation, for the respective measurement appropriate to the age of the pair. The four head measurements specified are length, breadth, horizontal circumference and interpupillary distance.

The justification for the last part of the specification will be seen presently. In Table XXVI the dividing line between 6 (*a*) and 6 (*b*) represents the effect of this criterion; 56 pairs or 52 % fall into the monozygotic group, which is the estimated proportion, but two pairs of opposite sexed twins also come within the definition (nos. 72, 211, see Table XXIX).

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* Bonnevie's suggestion that monozygotics are characterised by a condition represented here by $\alpha =$ or $> \gamma$ would lead to 8 out of the 52 pairs of opposite sex satisfying the criterion for monozygotism, or if $\alpha > \gamma$ only 27 out of 108 like sexed pairs would be monozygotic.

We may now seek for further evidence as to which one of the criteria B_4, B_5, M_1, M_2 approximates most closely to the truth. In Table XXVIII the number of finger patterns alike, a, is correlated with degree of facial resemblance and differences in eye and hair colour in like sexed twins. The differences in colour are here roughly measured by subtracting the scale numbers. On Martin's eye scale the 16 colours are arranged in decreasing intensity of brown pigment, and though each interval does not represent the same increment of pigment, for the present purpose, which is to see whether the standard colour scales can be used to assist in practical diagnosis, it is sufficiently accurate to measure the colour differences by scale differences as they stand, and has the advantage of dealing only with a measure which can be easily computed by anyone. On Fischer's hair scale, Nos. 4 to 20 are a series grading from dark brown to very light, and the vast majority of English children can be matched on this part of the scale; a few who had shades involving other pigments represented in other parts of the scale were omitted entirely.

Table XXVIII. *Relation of Similarity in Finger Patterns to degree of Facial Resemblance and Differences in Eye and Hair Colour in like sexed Twins.*

			No. of Pairs	Degree of Facial Resemblance				Scale Difference in Colour of Eyes (Martin's Scale)													Scale Difference in Colour of Hair[1]								
				I	II	III	IV	0	1	2	3	4	5	6	7	8	9	10	11	12	0	1	2	3	4	5	6	7	8
a = No. of corresponding fingers alike on same sided hands of the pair		1	3	.	.	2	1	.	2	.	1	.	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	.
		2	8	1	5	2	.	2	4	1	.	.	.	.	1	.	.	.	.	.	.	2	.	2	.	.	1	.	.
	Not B_5	3	11	3	3	4	1	1	5	2	.	2	.	.	.	.	.	1	.	.	4	4	.	1	2	1	.	.	1
		4	15	4	4	4	3	3	1	5	.	2	2	.	1	.	1	.	.	.	3	3	4	2	1	.	2	.	.
		5	11	3	4	3	1	3	6	.	.	.	1	.	.	.	.	.	.	1	2	2	2	3	1	.	.	1	.
		6 *a*	4	1	1	2	.	2	1	.	.	.	.	.	.	.	1	.	.	.	3	1	.	.	.	.	.	.	.
		6 *b*	21	1	4	5	11	9	5	6	1	.	.	.	.	.	.	.	.	.	6	8	6	.	.	.	.	1	.
		7	15	.	2	7	6	9	3	2	.	1	.	.	.	.	.	.	.	.	4	6	.	2	1	1	.	.	.
	B_5	8	12	.	.	4	8	5	6	.	1	.	.	.	.	.	.	.	.	.	4	5	2	1	.	.	.	.	.
		9	7	.	.	2	5	3	2	1	1	.	.	.	.	.	.	.	.	.	3	4	.	.	.	.	.	.	.
		10	1	.	.	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
		Total	108	13	23	36	36	37	35	17	4	6	3	.	2	.	2	1	.	1	29	37	16	11	5	2	3	2	1

[1] Portion 4 to 20 only of Fischer's Scale.

Table XXIX. *Details of some anomalous Pairs of Twins referred to in the text.*

	Index No.	Facial Group	a	Age	Eye Scale Difference	Hair Scale Difference	Difference $D/S-D'/S'$								Classification
							Height	Head Length	Head Breadth	Head Circumference	Inter-pupill. Distance	Weight	Mean Static & Weight	Mean Physiological	
Like Sexed Pairs	28	IV	1	$12\frac{8}{12}$	1	2	·493	·354	1·556	·075	·346	·350	·527	·595	Not B_4, not B_5
	33	IV	3	$8\frac{1}{12}$	1	1	·270	·535	·670	·230	1·054	·254	·502	2·177	B_3, B_4, not B_5
	21	IV	4	$7\frac{6}{12}$	5	2	1·146	·714	0	·690	·361	1·187	·683	·438	Not B_4, not B_5
	40	IV	4	$8\frac{9}{12}$	2	2	·266	·885	2·000	1·123	·696	·701	·945	·510	,,
	145	IV	4	$6\frac{2}{12}$	2	0	·222	·177	·222	0	0	·190	·135	1·412	,,
	36	IV	5	5	1	0	·820	·107	·666	·749	·700	·487	·588	·449	,,
	97	III	6	$11\frac{1}{12}$	0	1	·614	1·418	·445	1·272	—	·491	·848	·499	M_1, not B_4, not B_5
	2	III	6	$10\frac{10}{12}$	0	1	·156	·354	1·111	1·198	1·735	·479	·839	·849	M_1, not B_4, not B_5
	18	III	7	$12\frac{5}{12}$	0	0	·126	1·072	1·119	·843	·296	·154	·602	·452	B_4, M_1, B_5
	152	III	10	6	4	1	·340	0	·448	·307	·387	·093	·263	·327	B_4, B_5, M_1
	91	III	5	$5\frac{10}{12}$	0	7	1·093	·177	·667	0	·349	·507	·465	·996	B_4, not B_5
	61	III	7	$15\frac{5}{12}$	2	0	·678	·708	·889	·748	1·035	1·173	·872	·117	B_4, B_5
	121	I	6	$9\frac{6}{12}$	0	1	·169	·117	1·111	·599	·696	·058	·458	·922	B_5, not B_4
	70	II	7	$12\frac{6}{12}$	0	0	·213	·885	·888	1·377	1·039	·994	·899	1·008	B_4, B_5
Opposite Sexed	72	—	6	$12\frac{3}{12}$	—	—	·011	·048	1·358	·434	·023	·266	·524	·271	$\beta=7$, B_4, B_5
	44	—	6	14	—	—	1.018	·886	1·082	1·418	2·006	·886	1·422	1·034	Not B_4, not B_5
	211	—	6	$12\frac{7}{12}$	—	—	·456	1·737	·481	·794	·359	·854	·843	·468	,,

It may be noted that 6 pairs out of the 36 in group IV with a high degree of facial resemblance had less than 6 finger patterns alike, and details of these pairs are given in Table XXIX (nos. 28, 33, 21, 40, 145, 36) together with other anomalous pairs to which reference will be made. Of these six pairs, no. 21 showed a scale difference of 5 in eye colour and a large difference in height, and no. 40 gave large differences in head measurements and could be classed as dizygotic on these grounds, but nos. 28, 33, 145 and 36 could only be excluded from monozygotism on the grounds of finger pattern differences; all except no. 33, however, also fail to satisfy the B_4 criterion. The M_1 group is enclosed by the dotted line and brings in two pairs which were not included in the B_2 group owing to failure to satisfy the condition regarding head measurements and were also excluded from B_4 group (nos. 2, 97, see Table XXIX). The B_5 group includes six pairs whose facial resemblance was classified as only slight (II), all of these being also in the B_4 group. There is also one pair included in group B_5 but not in B_4 with no special facial resemblance (I) and this pair (no. 121, see Table XXIX) presented almost identical shades of eyes and hair and very minute differences in height, weight and head length*.

There was one pair with all 10 corresponding fingers with similar patterns, and in this pair a scale difference of 4 in eye colour was recorded (no. 152, see Tables XXIX and XXVIII), and another pair with seven finger patterns alike also gave a scale difference of 4. It appears from Table XXVIII that greater differences in eye colour than this are not to be expected when more than six finger patterns are alike, and a pair with a high degree of facial resemblance (IV) but a scale difference of 5 in eye colour was from other evidence judged to be dizygotic (no. 21, mentioned above). It may therefore be stated that if the eye colours of a pair of like sexed twins differ by more than 4 on Martin's scale they are almost certainly dizygotic. On the other hand, Table XXVIII shows that differences in hair colour can afford little help in diagnosis.

Turning to the *anthropometric measurements* for assistance in diagnosis, the distributions of corrected differences for each character separately have been set out in Table XXX, dividing the like sexed group of twins into its components by the alternative criteria B_1, B_4, B_5, M_1 and M_2.

The differences here all refer to twins of like sex for whom $S = S'$, and they therefore express the absolute differences $D - D'$ in terms of the standard deviation S of the character at that age. For height it appears that 27 pairs out of 194, or 14 %, had a difference in excess of S; in the facially identical group IV and the finger print group B_4 this occurred in only one pair in about 50 (nos. 21, 91, see Table XXIX), whilst in groups B_1 and M_1 no such case occurred in 50 pairs. This suggested that a pair differing in height by more than the standard deviation at their age may be regarded as unlikely to be monozygotic, and that this simple rule would assist in diagnosis. From the B_1 distribution it appears that no like sexed pair with six or more similar finger patterns on the same sided hands was found to have a height difference exceeding S, though one opposite sexed pair with six similar patterns was found to give a difference 1·0185 (no. 44, see Table XXIX). Hence this criterion was introduced into the definition of the B_5 group in order to help to exclude dizygotic pairs from the ambiguous $\alpha = 6$ group.

This did not suffice, however, to produce the right frequencies, and attention was turned to the head measurements. Since it is an easy matter to tabulate the standard deviations of height, head length, breadth and horizontal circumference, and interpupillary distance and to determine whether the differences found in any pair of twins exceed these or not without any calculation whatever being required, a definition was sought for based upon the number of these characters

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* It seems likely that there may have been an error in the facial classification.

Table XXX. *Distributions of corrected Differences in like sexed Twins divided into experimental Groups by Finger Patterns, Facial and Physical Resemblances.*

	0–	·2–	·4–	·6–	·8–	1·0–	1·2–	1·4–	1·6–	1·8–	2·0–	2·2–	2·4–	2·6–	2·8–	3·0–	3·2–	Total
HEIGHT.																		
Total Pairs	61	46	34	20	6	8	12	3	1	2	.	.	.	.	.	1	.	194
Group IV	24	15	9	2	1	1	.	.	.	.	.	.	.	.	.	.	.	52
Total Finger Print Pairs	32	29	19	12	3	3	4	1	1	1	.	.	.	.	.	1	.	106
Group B_1	25	18	9	6	1	.	.	.	.	.	.	.	.	.	.	.	.	59
M_1	22	16	6	5	1	.	.	.	.	.	.	.	.	.	.	.	.	50
M_2	22	17	7	5	2	1	.	.	.	.	.	.	.	.	.	.	.	54
B_4	21	17	10	3	1	1	.	.	.	.	.	.	.	.	.	.	.	53
B_5	24	18	8	4	1	.	.	.	.	.	.	.	.	.	.	.	.	55
Not B_4	11	12	9	9	2	2	4	1	1	1	.	.	.	.	.	1	.	53
Not B_5	8	11	11	8	2	3	4	1	1	1	.	.	.	.	.	1	.	51
THREE HEAD MEASUREMENTS.																		
Total Pairs	77	78	60	53	39	30	14	12	10	3	6	6	.	1	.	.	.	389
Group IV	30	32	20	16	9	5	2	1	1	.	1	.	.	.	.	.	.	117
Total Finger Print Pairs	68	62	47	46	35	25	10	9	9	3	5	4	.	1	.	.	.	324
Group B_1	42	40	34	21	21	13	4	4	1	.	.	.	.	.	.	.	.	180
M_1	38	37	28	19	16	10	3	1	1	.	.	.	.	.	.	.	.	153
M_2	42	40	28	22	16	10	3	1	2	1	.	.	.	.	.	.	.	165
B_4	40	40	28	23	19	6	3	3	.	.	.	.	.	.	.	.	.	162
B_5	41	39	31	21	21	9	3	2	1	.	.	.	.	.	.	.	.	168
Not B_4	28	22	19	23	16	19	7	6	9	3	5	4	.	1	.	.	.	162
Not B_5	27	23	16	25	14	16	7	7	8	.	.	.	.	.	.	.	.	156
WEIGHT.																		
Total Pairs	59	40	27	18	17	13	6	6	3	1	1	1	1	2	1	1	.	197
Group IV	25	14	5	4	2	2	.	.	.	.	.	.	.	.	.	.	.	52
Total Finger Print Pairs	36	17	21	10	9	7	3	1	1	.	1	1	.	.	.	.	1	108
Group B_1	29	12	9	5	2	3	.	.	.	.	.	.	.	.	.	.	.	60
M_1	25	12	8	4	.	2	.	.	.	.	.	.	.	.	.	.	.	51
M_2	26	12	10	4	.	2	.	.	.	.	1	.	.	.	.	.	.	55
B_4	24	11	9	5	2	2	.	.	.	.	1	.	.	.	.	.	.	54
B_5	28	12	7	5	2	2	.	.	.	.	.	.	.	.	.	.	.	56
Not B_4	12	6	12	5	7	5	3	1	1	.	.	1	.	.	.	.	1	54
Not B_5	8	5	14	5	7	5	3	1	1	.	1	1	.	.	.	.	1	52
FIVE STATIC CHARACTERS.																		
Total Pairs	183	181	102	108	51	55	29	21	14	7	8	11	1	3	1	1	.	776
Group IV	70	66	31	29	11	9	2	1	1	.	1	.	.	.	.	.	.	221
Total Finger Print Pairs	123	121	70	79	42	39	16	12	12	5	7	7	.	2	.	1	.	536
Group B_1	81	79	45	36	25	19	4	5	2	.	.	1	.	.	.	.	.	297
M_1	73	71	36	32	19	14	3	2	2	.	.	.	.	.	.	.	.	252
M_2	78	76	37	37	20	15	3	2	3	1	.	.	.	.	.	.	.	272
B_4	72	78	40	35	23	14	3	3	.	.	.	.	.	.	.	.	.	268
B_5	79	77	41	36	23	15	3	3	1	.	.	.	.	.	.	.	.	278
Not B_4	51	43	30	44	19	25	13	9	12	5	7	7	.	2	.	1	.	268
Not B_5	44	44	29	43	19	24	13	9	11	5	7	7	.	2	.	1	.	258
BLOOD-PRESSURE.																		
Total Pairs	45	36	25	25	33	14	11	6	8	5	2	2	2	.	2	1	1	218
Group IV	15	12	9	7	8	6	3	.	1	2	.	.	.	.	1	1	.	65
Total Finger Print Pairs	40	30	21	21	25	12	8	4	5	3	2	2	1	.	2	1	1	178
Group B_1	24	21	11	9	16	7	5	.	.	1	1	.	1	.	1	1	1	99
M_1	21	19	10	7	14	7	4	.	.	1	.	.	1	.	.	1	1	86
M_2	22	19	10	8	14	8	5	.	1	2	.	.	1	.	.	1	1	92
B_4	22	17	8	10	12	6	3	1	1	2	1	.	1	.	2	1	1	88
B_5	23	20	11	9	14	5	5	.	.	1	1	.	1	.	1	1	1	93
Not B_4	18	13	13	11	13	6	5	3	4	1	1	2	.	.	.	.	.	90
Not B_5	17	10	10	12	11	7	3	4	5	2	1	2	.	.	1	.	.	85
PULSE AND RESPIRATION INTERVALS.																		
Total Pairs	55	42	35	23	22	20	17	9	13	6	11	3	1	3	.	.	2	262
Group IV	19	13	11	6	9	6	5	2	2	3	2	1	.	1	.	.	.	80
Total Finger Print Pairs	42	40	31	20	17	19	14	8	8	4	6	3	1	2	.	.	1	216
Group B_1	23	24	20	11	11	7	6	6	3	4	3	.	.	1	.	.	1	120
M_1	21	19	17	9	10	7	5	5	1	3	3	.	.	1	.	.	1	102
M_2	23	20	17	11	10	9	6	5	1	3	3	.	.	1	.	.	1	110
B_4	24	19	19	9	9	6	6	5	2	4	2	.	.	2	.	.	1	108
B_5	22	21	19	11	11	6	6	5	2	4	3	.	.	1	.	.	1	112
Not B_4	18	21	12	11	8	13	8	3	6	.	4	3	1	.	.	.	.	108
Not B_5	20	19	12	9	6	13	8	3	6	.	3	3	1	1	.	.	.	104

for which $D - D' > S$, since this is easier to apply in practice than any definition requiring the computation of a mean difference. Looking first at Table XXX it is seen that any single head measurement (length, breadth, circumference) rarely gave a difference exceeding $1{\cdot}5S$ in any of the experimental groups of monozygotic twins, but this would not be of much use in diagnosis. The result of analysis according to the number of head measurements giving differences exceeding their standard deviations is shown in Table XXXI.

Table XXXI.

		Like Sexed Twins					Opposite Sexed Twins	Other Siblings	
		Total	Group IV	Total Finger Print Group	M_1	B_4		Like Sexed Pairs	Opposite Sexed Pairs
No. of Pairs having all five Static Measurements		122	39	104	48	53	71	172	158
No. of these in which the Height Difference > S_a		13	1	11	.	1	14	50	47
No. of the *Remainder* with 1, 2, 3 or 4 of the Head Measurements giving Differences exceeding the Standard Deviations	1	29	19	12	12	9	18	37	42
	2	16	2	13	1	4	11	34	32
	3	6	.	5	1	.	3	18	10
	4	2	.	2	.	.	1	2	5

Thus in 15 out of 71, or 21 % of opposite sexed twin pairs, and in 24 out of 122, or 20 % of like sexed twin pairs, two or more of the four characters (length, breadth, horizontal circumference and interpupillary distance) differed by amounts exceeding the standard deviation, but this only occurred in about 5 % of groups IV or M_1. The additional rule was therefore embodied in the definition of the B_5 group that pairs with $a = 6$ and height difference $< S_a$ must also show differences less than the standard deviations in three out of the four head measurements if they were to be regarded as monozygotic.

It remains to apply several *methods to test which of the experimental definitions leads to the best results.*

(1) Test the fit of the various distributions of differences for height against the theoretical distributions for the 99 monozygotic pairs and 95 dizygotic pairs arrived at by an independent method in section 6 and shown in Table XXII, first reducing the theoretical distributions to the total pairs observed for finger prints by multiplying by $\frac{106}{194}$.

Table XXXII.

	Differences in Height in Terms of Standard Deviation											Total
	0–	·2–	·4–	·6–	·8–	1·0–	1·2–	1·4–	1·6–	1·8–	2·0 and over	
Total Pairs of Like Sex	32	29	19	12	3	3	4	1	1	1	1	106
Monozygotic Pairs												
Theoretical*	23	17	8	4	1	1	.	.	.	.	.	54
B_4	21	17	10	3	1	1	.	.	.	.	.	53
M_1	22	16	6	5	1	.	.	.	.	.	.	50
M_2	22	17	7	5	2	1	.	.	.	.	.	54
B_5	24	18	8	4	1	.	.	.	.	.	.	55
B_1	25	18	9	6	1	.	.	.	.	.	.	59
Dizygotic Pairs												
Theoretical*	9	9	8	7	6	4	3	2	2	1	1	52
Not B_4	11	12	9	9	2	2	4	1	1	1	1	53
Not B_5	8	11	11	8	2	3	4	1	1	1	1	51

* By fitting normal curves, see section 6.

The results are shown in Table XXXII and the tests for goodness of fit are as follows:

B_4 group, $n' = 6$, $\chi^2 = \cdot 924$, $P = \cdot 97$.
B_5 group, $n' = 6$, $\chi^2 = 1\cdot 102$, $P = \cdot 95$.
M_2 group, $n' = 6$, $\chi^2 = 1\cdot 418$, $P = \cdot 92$.
Not B_4, $n' = 11$, $\chi^2 = 7\cdot 141$, $P = \cdot 71$.
Not B_5, $n' = 11$, $\chi^2 = 6\cdot 073$, $P = \cdot 81$.

The M_1 and B_1 groups give a much inferior fit with the theoretical, both as regards the totals and the form of the distributions, to B_4 and B_5. The M_2 group also fails to give as good a fit as B_4 or B_5, in addition to its other disadvantages. For B_4 the test gives $P = \cdot 97$, and since the B_4 group has been formed solely by the use of finger print patterns without reference to any other character whatever, this provides strong corroborative evidence that, on the one hand, the assumption made in section 6 that the distribution of differences for height is normal in type for monozygotic as well as for dizygotic pairs is well founded, and, on the other hand, that a finger print method of diagnosis leads to consistent results.

The B_5 distribution also gives an excellent fit with the theoretical, for $P = \cdot 95$, and the correspondence between the two distributions is remarkable. Comparing the fit of the residual "dizygotic" groups we find for "Not B_4" $P = \cdot 71$, and for "Not B_5" $P = \cdot 81$, so that either B_4 or B_5 give satisfactory results when tested by the theory of section 6, and of the two B_5 leads to the better fit when both components are considered.

(2) A second test is to compare the frequency distributions of the resulting dizygotic groups "Not B_4" and "Not B_5" with the opposite sexed group of twins when related to the number of finger patterns alike, as shown graphically in Fig. 4 (a), the totals being taken from Tables XXV and XXVI.

The B_5 grouping gives the best correspondence for the dizygotic residue, and the frequencies of monozygotic pairs on a scale of α show an approximately linear increase from $\alpha = 10$ to $\alpha = 6$, whilst the dizygotic frequencies form a distribution of the usual type with maximum at $\alpha = 4$. On the other hand, the groups resulting from B_4 give somewhat irregular frequency distributions on a β-scale. A further test of correspondence of the dizygotic groups is to compare the means and standard deviations of α or β, and γ, from Tables XXV and XXVI; thus:

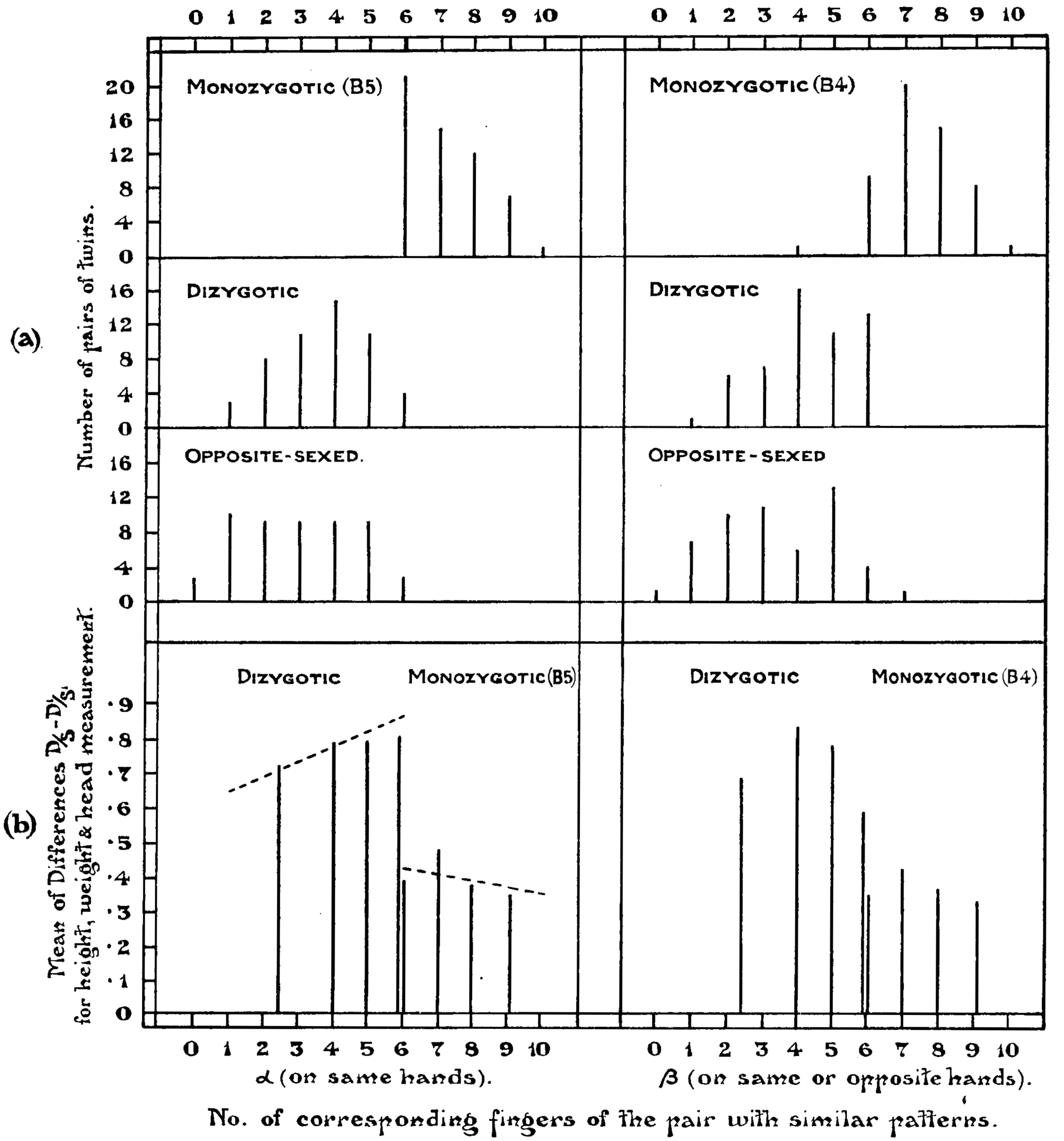
$$\left\{\begin{array}{lllll} \text{Opposite sexed twins} & \bar{\beta} = 3\cdot 365 \pm \cdot 155; & \bar{\gamma} = 5\cdot 712 \pm \cdot 110; & \sigma_\beta = 1\cdot 66; & \sigma_\gamma = 1\cdot 19 \\ \text{“Not } B_4\text{” dizygotic twins} & \bar{\beta} = 4\cdot 278 \pm \cdot 124; & \bar{\gamma} = 6\cdot 222 \pm \cdot 137; & \sigma_\beta = 1\cdot 35; & \sigma_\gamma = 1\cdot 49 \\ B_4 \text{ monozygotic twins} & & \bar{\gamma} = 6\cdot 166 \pm \cdot 187; & & \sigma_\gamma = 2\cdot 05 \end{array}\right.$$

$$\left\{\begin{array}{lllll} \text{Opposite sexed twins} & \bar{\alpha} = 2\cdot 961 \pm \cdot 156; & \bar{\gamma} = 5\cdot 712 \pm \cdot 110; & \sigma_\alpha = 1\cdot 69; & \sigma_\gamma = 1\cdot 19 \\ \text{“Not } B_5\text{” dizygotic twins} & \bar{\alpha} = 3\cdot 673 \pm \cdot 124; & \gamma = 5\cdot 962 \pm \cdot 141; & \sigma_\alpha = 1\cdot 33; & \sigma_\gamma = 1\cdot 51 \\ B_5 \text{ monozygotic twins} & & \bar{\gamma} = 6\cdot 411 \pm \cdot 189; & & \gamma_\gamma = 2\cdot 06 \end{array}\right.$$

In both cases the mean number of finger patterns alike, $\bar{\alpha}$ or $\bar{\beta}$, is greater and the variability of α or β is less for the dizygotic like sexed groups than for the opposite sexed groups, but this arises from differences in the α or β frequencies at the *zero* end of the scale; thus there were 13 out of 52 opposite sexed pairs with less than two fingers alike on the same sided hands as compared with only three out of about the same number of dizygotic like sexed pairs. This may indicate a real sex difference but is in any case independent of the method of division from the monozygotic, which affects the other end of the distribution. When the B_4 criterion was used, the mean β's differed by $\cdot 913$, and when the B_5 grouping was used the mean α's differed by $\cdot 712$. Comparing also the numbers of correspondences in patterns on the opposing hands of the same

Figure 4.

DISTRIBUTIONS OF TWIN PAIRS, AND MEAN DIFFERENCE FOR 6 PHYSICAL CHARACTERS, IN RELATION TO NUMBER OF FINGERS HAVING SIMILAR PATTERNS.



child, there is an indication that the mean value $\bar{\gamma}$ is greater in monozygotic than dizygotic twins, a fact which would not be surprising since symmetry reversal is known to be involved in monozygotism; the differences in $\bar{\gamma}$ between B_5 twins and the residual like sexed group is ·449 ± ·236, and between B_5 twins and the opposite sexed group ·699 ± ·219. The variability in γ is also undoubtedly greater in the monozygotic than in the dizygotic twins. The B_5 criterion again produces a closer correspondence between the two dizygotic groups in regard to γ than does B_4.

(3) A third method of testing the groupings produced by the B_4 and B_5 definitions was to tabulate $\bar{\Delta}$ (the mean of the six corrected differences for the five static characters and weight) in relation to the correspondence in finger patterns measured by α and β respectively and to represent the relation graphically. The advantage of this measure $\bar{\Delta}$ over the difference for any single character is that the modes of the $\bar{\Delta}$ distributions occur at quite different values in the monozygotic and dizygotic twins, as will be seen from the upper part of Table XXXIII (compare also Table XXIV).

Table XXXIII. *Mean Difference $\bar{\Delta}$ for six Physical Characters* in relation to Similarity in Finger Patterns in like sexed Twins.*

			$\bar{\Delta}$																			Total	Means
			0–	·1–	·2–	·3–	·4–	·5–	·6–	·7–	·8–	·9–	1·0–	1·1–	1·2–	1·3–	1·4–	1·5–	1·6–	1·7–	1·8–		
Experimental groups based on Finger Pattern Similarities for the Separation of Monozygotic from Dizygotic Twins	B_5		1	5	12	11	8	13	2	2	2	.	.	.	.	.	.	.	.	.	.	56	·404
	Not B_5		.	1	.	2	5	9	10	5	8	4	1	1	2	1	1	.	1	.	1	52	·762
	B_4		1	5	11	11	6	13	3	1	3	.	.	.	.	.	.	.	.	.	.	54	·424
	Not B_4		.	1	1	2	7	9	9	6	7	4	1	1	2	1	1	.	1	.	1	54	·746
	B_1		1	5	12	11	8	13	2	3	5	.	.	.	.	.	.	.	.	.	.	60	—
	Not B_1		.	1	.	2	5	9	10	4	5	4	1	1	2	1	1	.	1	.	1	48	—
	M_1		1	5	12	10	7	10	2	1	3	.	.	.	.	.	.	.	.	.	.	51	—
	Not M_1		.	1	.	3	6	12	10	6	7	4	1	1	2	1	1	.	1	.	1	57	—
	M_2		1	5	12	10	8	12	2	2	3	.	.	.	.	.	.	.	.	.	.	55	—
	Not M_2		.	1	.	3	5	10	10	5	7	4	1	1	2	1	1	.	1	.	1	53	—
α = Number of Corresponding Fingers having Similar Patterns on the Same Sided Hands of Twin Pairs	Not B_5	1	.	.	.	.	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	3	·727
		2	.	.	.	2	1	.	2	2	1	.	.	.	.	.	.	.	.	.	.	8	
		3	.	.	.	.	.	3	2	.	2	1	1	1	.	.	1	.	.	.	.	11	
		4	.	1	.	.	1	2	5	.	1	2	.	.	2	.	.	.	1	.	.	15	·790
		5	.	.	.	.	3	3	.	1	1	1	.	.	.	1	.	.	.	.	1	11	·795
		6 *a*	.	.	.	.	.	.	.	1	3	.	.	.	.	.	.	.	.	.	.	4	·825
	B_5	6 *b*	1	2	4	3	4	6	.	1	.	.	.	.	.	.	.	.	.	.	.	21	·392
		7	.	1	3	2	2	3	1	1	2	.	.	.	.	.	.	.	.	.	.	15	·483
		8	.	1	4	2	1	3	1	.	.	.	.	.	.	.	.	.	.	.	.	12	·383
		9	.	1	.	4	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	7	·350
		10	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	
β = Number of Corresponding Fingers having Similar Patterns on the Same Sided or Opposite Sided Hands of Twin Pairs	Not B_4	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	·671
		2	.	.	.	2	1	.	2	.	1	.	.	.	.	.	.	.	.	.	.	6	
		3	.	.	.	.	.	2	1	1	1	1	1	.	.	.	.	.	.	.	.	7	
		4	.	1	.	.	1	2 + 1[1]	5	.	1	2	.	.	2	.	1	.	1	.	.	16 + 1[1]	·831[2]
		5	.	.	.	.	2	1	1	1	2	1	.	1	.	1	.	.	.	.	1	11	·795
		6	.	.	1	.	3	4	.	3	2	.	.	.	.	.	.	.	.	.	.	13	·596
	B_4	6	1	2	2	1	.	2	1	.	.	.	.	.	.	.	.	.	.	.	.	9	·350[3]
		7	.	1	1	3	4	6	1	1	3	.	.	.	.	.	.	.	.	.	.	20	·425
		8	.	1	6	3	1	3	1	.	.	.	.	.	.	.	.	.	.	.	.	15	·363
		9	.	1	1	4	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	8	·338
		10	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	

[1] This unit belongs to B_4 group by definition. [2] Excluding unit mentioned in preceding note. [3] Including unit mentioned in preceding note.

From this table it appears that, whichever criterion for monozygotism is used, a value of $\bar{\Delta}$ in excess of ·9 is not to be expected in monozygotic pairs, and a value less than ·3 is very unusual in dizygotic pairs; about three-quarters of the pairs however have values for $\bar{\Delta}$ between these limits, and for these the diagnosis is not much assisted by the computation of $\bar{\Delta}$.

The relation of α to $\bar{\Delta}$ in the second part of Table XXXIII is represented graphically in Fig. 4 (b) on p. 91. The heterogeneity of the distribution is at once evident, and the division by the B_5 criterion, represented as a dotted line in the table, produces two portions which have every appearance of

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* Height, head length, head breadth, head circumference, interpupillary distance and weight.

being independent. Starting from $\alpha = 1$ in the dizygotic portion the mean value of $\bar{\Delta}$ tends to increase slightly in a linear manner with α, the regression line drawn in Fig. 4 (b) indicating a rate of increase in $\bar{\Delta}$ of + ·0424 for each additional finger alike from ·648 at $\alpha = 1$ to ·860 at $\alpha = 6$; the correlation coefficient $r = + \cdot 1705 \pm \cdot 0908$ is not, however, significant. On passing over into the monozygotic B_5 portion there is a sudden drop in $\bar{\Delta}$ from ·860 to about half that value and then a slight tendency to decrease in a linear manner as α increases from 6 to 10, the regression line drawn in Fig. 4 indicating a rate of decrease in $\bar{\Delta}$ of − ·0168 for each additional finger alike from ·423 at $\alpha = 6$ to ·356 at $\alpha = 10$; the correlation coefficient $r = - \cdot 0896 \pm \cdot 0958$ is again insignificant. In view of the insignificance of the r's these regression lines might be represented by two horizontal lines at levels $\bar{\Delta} = \cdot 762$ and $\bar{\Delta} = \cdot 383$, the latter value for B_5 twins being almost exactly half the former for the residual group, and this would mean that the apparent correlation between finger pattern resemblance and physical resemblance in like sexed twins is *solely* due to the heterogeneity of the group, and if so the separation into its two constituents by the B_5 method is satisfactory within the limits of error due to the number of pairs in the data.

The presence or absence of any significant relation between finger pattern resemblance and measured differences in various characters in the homogeneous group of opposite sexed twins was next looked for in order to supply another link in this chain of evidence. The opposite sexed twins having legible finger prints were divided into approximately equal portions in two ways, thus:

C_2 = pairs with $\beta > 3$ (at least four corresponding fingers alike on the same or opposite sided hands);
Not C_2 = pairs with $\beta < 4$;
C_3 = pairs with $\gamma - \beta$ not greater than 2;
Not C_3 = pairs with γ more than 2 in excess of β;

and the root mean-square differences σ_d were compared for each of these four groups as in Table XXXIV, where n = number of pairs of measurements. Comparing C_3 with its complementary group the differences are greater in some characters and less in others and are not significant; and the same applies to C_2 except that there is a significant difference for the physiological characters. This apparent relation of finger pattern resemblance to blood-pressure, pulse and respiration differences in opposite sexed twins may be worth further investigation; both the C_2 and C_3 methods of division seem to indicate a greater divergence in these characters when the finger prints are least alike, but by the second method the difference is insignificant.

Table XXXIV.

	C_2		Not C_2		C_3		Not C_3	
	n	σ_d	n	σ_d	n	σ_d	n	σ_d
Height	24	·881 ± ·086	27	·633 ± ·059	27	·842 ± ·076	24	·654 ± ·064
Head Dimensions	69	1·000 ± ·084	84	·970 ± ·073	81	1·020 ± ·079	72	·941 ± ·077
Static Characters	117	·967 ± ·065	131	·925 ± ·059	136	1·001 ± ·063	112	·856 ± ·059
Weight	24	·763 ± ·074	27	·974 ± ·089	28	·859 ± ·077	23	·907 ± ·090
Physiological Characters	83	1·007 ± ·050	99	1·345 ± ·061	98	1·060 ± ·049	100	1·237 ± ·056
Aggregate of Ten Characters	224	·963 ± ·058	259	1·109 ± ·062	262	1·010 ± ·056	221	1·082 ± ·065

When the "Not B_5" like sexed twins are divided in a similar way however, a group of 30 pairs having $\alpha > 3$ gives a mean value of the mean difference for the four physiological characters ·859 ± ·080 as compared with ·754 ± ·082 for 22 pairs having $\alpha < 4$, values which differ insignificantly and in the opposite sense to the relation found above.

The static measurements present, if anything, greater differences when more finger patterns are alike than when less are alike in opposite sexed twins, and since $\bar{\beta} = 5$ approximately in group C_2, and $\bar{\beta} = 2$ approximately in the complementary group the regressions of σ_d on β are roughly given by dividing the differences between the respective values of σ_d by 3. Thus the mean of the six regressions for the five static characters and weight amounts to ·042 per finger which is the same as the regression of $\bar{\Delta}$ on α of ·042 per finger for like sexed dizygotic twins (not B_5). The correlation coefficient for the five static characters is $r = \cdot 5716 \pm \cdot 0637$ within the C_2 group as compared with $r = \cdot 5602 \pm \cdot 0369$ in all opposite sexed twins. It is therefore evident that there is no appreciable relation between finger pattern resemblance and likeness in the static measurements so long as we are dealing with homogeneous groups of dizygotic twins, and hence it seems to follow from Fig. 4 (b) that (i) the separation of the heterogeneous group of like sexed twins by use of the B_5 definition produces a dizygotic group which agrees in almost every respect with the opposite sexed group, and (ii) there is a similar absence of relation between finger patterns and differences in static characters in the monozygotic twins.

Returning to Table XXXIII, the lowest section of the table shows the relation of $\bar{\Delta}$ to β and the division effected by using the criterion B_4. When the mean values of $\bar{\Delta}$ are plotted as in Fig. 4 (b), the two distributions are not so clearly separated as by use of the α scale and B_5, and there is no doubt that the B_5 grouping produces here, as in the previous tests, more consistent results than the B_4 method.

(4) A final test is to compute, for the static characters and weight, the mean and root mean-square differences m_d and σ_d in pairs of monozygotic and dizygotic twins of like sex and compare the values for the latter with those expected from the values for opposite sexed pairs. The values of m_d and σ_d, as previously defined, were obtained from the distributions in Table XXX, and the mean corrected deviate m_0 and total variability σ_0 of each group were separately calculated and r obtained by the formula $r = 1 - \sigma_d^2/2\sigma_0^2$. These are given in Table XXXV for all the groups of characters, n being the number of pairs of measurements. The values of $\sigma_0 \sqrt{1 - r^2}$ are also given for certain groups.

The measures of resemblance in Table XXXV for like sexed twins divided by the B_5 criterion, and from Table V for opposite sexed twins may first be summarised as below.

Table XXXV A.

		m_d	σ_d	r	$\sigma_0 \sqrt{1-r^2}$
Height	Monozygotic (B_5)	·28	·34	·95	·11
	Dizygotic Like Sexed	·66	·86	·49	·74
	,, Opposite Sexed	·72	·90	·63	·81
Weight	Monozygotic (B_5)	·31	·40	·93	·43
	Dizygotic Like Sexed	·75	·97	·44	·82
	,, Opposite Sexed	·78	·96	·48	·87
Head Size	Monozygotic (B_5)	·50	·61	·82	·58
	Dizygotic Like Sexed	·81	1·01	·32	·82
	,, Opposite Sexed	·79	·96	·55	·84
Blood-pressure	Monozygotic (B_5)	·65	·91	·69	·84
	Dizygotic Like Sexed	·79	1·00	·32	·82
	,, Opposite Sexed	·84	1·11	·26	·88
Pulse and Respiration	Monozygotic (B_5)	·72	·95	·51	·82
	Dizygotic Like Sexed	·80	1·03	·42	·87
	,, Opposite Sexed	·97	1·20	·26	·88

Table XXXV. *Degrees of Resemblance in monozygotic and dizygotic Twins of like Sex.*

	n	m_0	σ_0	m_d	$\sigma_d \pm$p.e.	r	$\sigma_0 \sqrt{1-r^2}$
HEIGHT.							
All Twin Pairs of Like Sex	194	+·0567	·9497	·4830	·6565 ±·0225	·7611	—
Facially "identical" Group IV	52	+·3635	·9804	·2841	·3577 ±·0237	·9334	—
Monozygotic Pairs. B_5	55	+·2291	1·1198	·2815	·3421 ±·0220	·9531	·1072
B_4	53	+·2849	1·1540	·3070	·3771 ±·0247	·9466	·1175
M_1	50	+·2900	1·0775	·2875	·3532 ±·0238	·9463	—
Dizygotic Pairs. Not B_5	51	−·0118	·8502	·6603	·8621 ±·0576	·4858	·7432
Not B_4	53	−·0585	·8203	·6203	·8338 ±·0546	·4840	·7179
Not M_1	56	−·0893	·9099	·6209	·8248 ±·0526	·5881	—
HEAD MEASUREMENTS.							
All Twin Pairs of Like Sex	389	+·0185	·9397	·6532	·8346 ±·0294	·6056	—
Facially "identical" Group IV	117	+·1838	1·0337	·4721	·5980 ±·0384	·8326	—
Monozygotic Pairs. B_5	168	+·1619	1·0121	·4959	·6059 ±·0325	·8208	·5781
B_4	162	+·0981	·9897	·4822	·5886 ±·0321	·8232	·5619
M_1	153	+·2111	1·0146	·4877	·5980 ±·0336	·8263	—
Dizygotic Pairs. Not B_5	156	−·1070	·8711	·8110	1·0144 ±·0564	·3220	·8247
Not B_4	162	−·0333	·9170	·8131	1·0125 ±·0552	·3904	·8442
Not M_1	171	−·1275	·8704	·7907	·9897 ±·0513	·3536	—
STATIC CHARACTERS.							
All Twin Pairs of Like Sex	776	+·0055	·9468	·6059	·8051 ±·0209	·6385	—
Facially "identical" Group IV	221	+·1552	1·0290	·4190	·5392 ±·0263	·8627	—
Monozygotic Pairs. B_5	278	+·1122	1·0343	·4455	·5564 ±·0242	·8553	·5358
B_4	268	+·0821	1·0264	·4458	·5507 ±·0244	·8561	·5312
M_1	252	+·1591	1·0411	·4431	·5582 ±·0255	·8563	—
Dizygotic Pairs. Not B_5	258	−·0783	·8807	·7886	1·0058 ±·0454	·3479	·8256
Not B_4	268	−·0410	·9008	·7756	·9944 ±·0440	·3907	·8290
Not M_1	284	−·1025	·8802	·7594	·9710 ±·0418	·3916	—
WEIGHT.							
All Twin Pairs of Like Sex	197	−·0868	·9332	·5868	·8215 ±·0279	·6034	—
Facially "identical" Group IV	52	+·1077	·9820	·3072	·4060 ±·0268	·9145	—
Monozygotic Pairs. B_5	56	−·0357	1·0649	·3102	·4008 ±·0255	·9292	·4325
B_4	54	−·0315	1·0659	·3662	·5124 ±·0333	·8844	·3893
M_1	51	+·0255	·9412	·2956	·3841 ±·0256	·9167	—
Dizygotic Pairs. Not B_5	52	−·1711	·9149	·7572	·9702 ±·0642	·4377	·8226
Not B_4	54	−·1704	·9195	·6847	·9043 ±·0587	·5163	·7875
Not M_1	57	−·2140	1·0328	·7311	·9442 ±·0596	·5821	—
BLOOD-PRESSURE.							
All Twin Pairs of Like Sex	218	+·0876	1·0130	·7463	·9710 ±·0382	·5406	—
Facially "identical" Group IV	65	+·1354	1·1703	·6695	·9062 ±·0654	·7002	—
Monozygotic Pairs. B_5	93	+·1311	1·1686	·6500	·9149 ±·0552	·6935	·8420
B_4	88	+·1693	1·1462	·7199	1·0151 ±·0629	·6078	·9102
M_1	86	+·1477	1·1601	·6274	·8382 ±·0526	·7390	—
Dizygotic Pairs. Not B_5	85	−·0071	·8615	·7936	1·0036 ±·0633	·3199	·8164
Not B_4	90	−·0378	·9038	·7173	·8992 ±·0551	·5043	·7788
Not M_1	92	−·0130	·8971	·8082	1·0623 ±·0644	·2989	—
PULSE AND RESPIRATION INTERVALS.							
All Twin Pairs of Like Sex	262	−·0912	·9954	·8071	1·0533 ±·0330	·4402	—
Facially "identical" Group IV	80	−·0600	·9778	·7245	·9502 ±·0540	·5278	—
Monozygotic Pairs. B_5	112	−·1241	·9601	·7209	·9496 ±·0456	·5109	·8244
B_4	108	−·1833	·9767	·7199	·9676 ±·0473	·5036	·8438
M_1	102	−·1275	·9742	·7152	·9474 ±·0476	·5270	—
Dizygotic Pairs. Not B_5	104	−·0315	·9547	·7995	1·0272 ±·0511	·4213	·8658
Not B_4	108	+·0250	·9287	·7976	1·0073 ±·0492	·4117	·8463
Not M_1	114	−·0351	·9425	·7977	1·0223 ±·0486	·4117	—
PHYSIOLOGICAL CHARACTERS.							
All Twin Pairs of Like Sex	480	−·1000	1·0024	·7757	1·0157 ±·0210	·4867	—
Facially "identical" Group IV	145	+·0276	1·0735	·7009	·9315 ±·0351	·6235	—
Monozygotic Pairs. B_5	205	−·0088	1·0673	·6888	·9340 ±·0296	·6171	·8397
B_4	196	−·0250	1·0706	·7199	·9892 ±·0236	·5731	·8774
M_1	188	−·0016	1·0721	·6750	·9109 ±·0301	·6390	—
Dizygotic Pairs. Not B_5	189	−·0201	·9141	·7988	1·0182 ±·0336	·3796	·8456
Not B_4	198	−·0035	·9177	·7611	·9597 ±·0310	·4532	·8181
Not M_1	206	−·0257	·9225	·8005	1·0291 ±·0325	·3778	—
AGGREGATE OF TEN CHARACTERS.							
All Twin Pairs of Like Sex	1453	−·0121	·9645	·6595	·8906 ±·0182	·5738	—
Facially "identical" Group IV	418	+·1050	1·0406	·5028	·6894 ±·0263	·7838	—
Monozygotic Pairs. B_5	539	+·0508	1·0521	·5240	·7133 ±·0240	·7701	·6712
B_4	518	+·0297	1·0489	·5412	·7447 ±·0256	·7480	·6962
M_1	491	+·0837	1·0462	·5166	·7021 ±·0247	·7748	—
Dizygotic Pairs. Not B_5	499	−·0659	·8982	·7885	1·0055 ±·0352	·3734	·8332
Not B_4	520	−·0402	·9100	·7606	·9723 ±·0333	·4305	·8214
Not M_1	547	−·0852	·9171	·7719	·9906 ±·0331	·4167	—

For height, weight and head measurements there is a great contrast by all the four measures of resemblance between monozygotic and dizygotic pairs. For the physiological characters this is less pronounced, and the standard errors of estimate, $\sigma_0 \sqrt{1 - r^2}$, are not appreciably different in the two types of twins for these characters, although the correlation coefficients differ considerably, thus indicating that if large groups of twin children were formed in which one twin of every pair had always a standard age, sex and blood-pressure (or pulse or respiration rate), the variability in the other twins of the pairs would be the same amongst monozygotic as amongst dizygotic pairs. This would not be true for groups of twins who had passed adolescence.

The expected values of m_d and σ_d may be found by equations (5) and (6) of section 6, and are as follows:

Table XXXVI.

		Expected	"Not B_5"	"Not B_4"	"Not M_1"
Height	m_d	·6931	·6603 ±·0471	·6203 ±·0434	·6209 ±·0423
	σ_d	·8642	·8621 ±·0576	·8338 ±·0546	·8248 ±·0526
Head Dimensions	m_d	·8409	·8110 ±·0481	·8131 ±·0474	·7907 ±·0448
	σ_d	1·0410	1·0144 ±·0564	1·0125 ±·0552	·9897 ±·0513
Static Characters	m_d	·7914	·7886 ±·0380	·7756 ±·0367	·7594 ±·0349
	σ_d	1·0410	1·0058 ±·0454	·9944 ±·0440	·9710 ±·0418
Weight	m_d	·7597	·7572 ±·0535	·6847 ±·0475	·7311 ±·0493
	σ_d	·9059	·9702 ±·0642	·9043 ±·0587	·9442 ±·0596

None of the alternative dizygotic values differ significantly from those expected, but of the three criteria B_5 produces the closest approximation to the expected value in every case except σ_d for weight.

From the cumulative evidence above it can be concluded that the B_5 criterion provides the best method of separating monozygotic from dizygotic twins, but B_4 has the advantage of requiring no measurements and also of eliminating to some extent the personal equation in comparing finger patterns, though this is not believed to be of much importance. The M_1 criterion, which involves a judgment of facial resemblance, offers no advantages and may be discarded.

The two alternative methods are therefore set out below in a form for practical use. It is not claimed that either of these will lead to a correct diagnosis in every case but the errors will not be frequent enough to invalidate conclusions arrived at by using the methods in statistical researches on groups of twins.

Method of Diagnosis by Finger Prints, Height and four simple Measurements of the Head (B_5). The *apparatus* required is a finger print pad and ink, white paper, a height standard, a steel measuring tape for the horizontal head circumference, a millimetre scale for interpupillary distance and a Flower's craniometer or other form of head spanner for taking the maximum length and breadth of the head. The *procedure* is as follows:

(*a*) Take the finger prints of each child of the pair and repeat any fingers for which the patterns are not clear.

(*b*) Compare the corresponding finger patterns on the same sided hands of the two sets and note in how many the patterns are similar, meaning by "similar" that they are not only of the same class (arch, whorl, loop) but are so much alike as regards general configuration, inclination of axes, position of deltas and number of ridges as to make them appear the same to a casual examination, without actually counting the ridges or looking for minutiae.

(*c*) If seven or more fingers have similar patterns the pair may be regarded as monozygotic, and if five or less as dizygotic.

(*d*) If six fingers have similar patterns or if there is a doubt between five and six or between six and seven, measure each child for height and compare the difference in centimetres with the standard deviation figure in the table below (Table XXXVII) appropriate to the sex and age of the pair; if the difference is equal to or greater than this figure the pair may be classed as dizygotic.

(*e*) If the height difference is less than the limit tabulated, measure in each child the maximum head length and breadth with the craniometer, the horizontal circumference with the steel tape, and the interpupillary distance with the millimetre scale whilst the child is looking at a distant object, and compare the differences in millimetres with the values given in the table; if more than one of these differences exceed the tabulated figures, regard the pair as dizygotic, otherwise as monozygotic.

In only about one pair out of four will it be necessary to proceed beyond (*c*).

Table XXXVII. *Limiting Differences for Diagnosis of like sexed Twins.*

Age Last Birthday

	3	4	5	6	7	8	9	10	11	12	13	14
Height (cm.) Boys	3·7	4·1	4·5	4·8	5·2	5·5	5·9	6·3	6·7	7·0	7·4	7·8
Height (cm.) Girls	3·0	3·6	4·1	4·7	5·2	5·7	6·3	6·9	7·4	8·0	8·5	9·1
Head Length	5·5 mm.											
Head Breadth	4·5 mm.											
Horizontal Circumference	13 mm.											
Interpupillary Distance	3 mm.											

Alternative method of Diagnosis by Finger Prints alone, if the B_5 method is not applicable (B_4).

(*a*) Take the finger prints of each child and repeat any fingers for which the patterns are not clear.

(*b*) Compare the corresponding finger patterns on the same-sided hands of the two sets and mark off those which are similar (as defined in (*b*) above), giving a total of α similar pairs.

(*c*) Examine the remainder one by one for similarity with the corresponding finger of the opposite sided hand of the other child, provided that that finger has not already been marked, and add the number of similar pairs of fingers so found to α, giving the total β; in looking for crossed similarity one pattern must of course be the mirror image of the other.

(*d*) Compare the corresponding finger patterns of each child separately, left with right, and count the total pairs, γ, of similar pattern, allowing as in (*c*) for reversal of the pattern.

(*e*) If $\beta = 7$ or more, *or* alternatively if β is greater than γ, the twins may be regarded as monozygotic; if $\beta = 6$ or less *and* β is equal to or less than γ, they may be regarded as dizygotic.

Note regarding recent Japanese work on the Finger Prints of Twins. After I had reached the conclusions set out above, a very interesting paper came to my notice by Komai (16) in the *Quarterly Review of Biology*, September 1928, in which he not only reviewed the various methods employed for distinguishing identical from fraternal twins, with a useful summary of the most important papers on the subject, but also gave an account of the work of three Japanese investigators which had been published in journals not accessible to me, and concluded with a brief summary of results which he had reached from a study of palm, sole and finger patterns of 73 pairs of twins. In view of the close relation of this work to my own I give a brief account of it which I have extracted from his paper.

Kuragami (17) in 1926 examined finger prints of 15 pairs of like sexed twins and 5 pairs of opposite sex and found that in two pairs of the former group a ridge count of the finger patterns gave exactly the same value in each child*. Obonai (18) in the same year examined the finger prints of 196 pairs of twins in conjunction with some physical and psychical characters and concluded that some like sexed pairs, who would be regarded as identical from their facial resemblance and from physical and psychical tests, may have very unlike finger patterns. Kishi (19) in 1927 collected finger prints from 60 pairs of twins and found that finger patterns of opposite sexed twins are more variable than those of like sexed twins.

Komai used a method of classification of finger patterns involving the number of ridges, ratio of height and breadth of loops, tendency towards twisting and length of each ridge, and concluded that the finger, palm and sole prints of the twins whose monozygosity is evident on various grounds such as facial similarity, body build and school standing, resemble each other much more closely than prints of dizygotic twins of like or opposite sex. Thus he says "finger prints of monozygotic twins very seldom show differences in type of pattern† in more than 2 pairs of corresponding fingers, whereas in dizygotic the difference is met with in more than 2 pairs of corresponding fingers." He also states that in monozygotic twins the hands or feet of the same side of different individuals often resemble each other more closely than the two hands or feet of the same individual (which agrees with the observation of Bonnevie) and goes on to say, "such a condition, so far as I have ascertained, is met with in no case of different sex twins, nor of same sex twins whose dizygosity is undisputed‡, so that this may serve as a criterion for identifying many monozygotic twins. It cannot be disputed however that certain same sex twins who are known to have been born with a common placenta and who resemble each other very closely in physiognomy and body build, have dissimilar patterns† on more than two fingers or on palms or soles...*thus the method of distinguishing the two kinds of twins by means of such* patterns has its limitations."

(*e*) *Diagnosis by Anthropometric Measurements alone.*

Muller (20) has suggested a method by which the joint probability of a pair of twins, whether monozygotic or dizygotic, falling within the same qualitative or quantitative class in respect of a series of uncorrelated traits, may be computed and used for purposes of diagnosis. The formula which Muller arrives at is open to criticism, but the general idea underlying his suggestion might be developed in a different way and put to practical use. It is not possible in this paper to do more than outline such a method, but it seems to me that the *differences* between pairs in respect of several characters might be used instead of the actual measures of the characters themselves, somewhat as follows.

Let the proportion of all monozygotic twins who differ in character (1) by an amount falling into category $A_1 = m_1$ and for all dizygotic like sexed twins let this proportion $= d_1$, and let suffixes 2, 3 ... refer to other characters; and let the proportion of monozygotic pairs in a population of like sexed twins $= p$, and the proportion of dizygotic pairs $= q$, so that $p + q = 1$. If a like sexed twin pair be found to give a difference falling within category A_1 for the first character,

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* Presumably this did not apply to every finger, since identity even in the general form of the patterns in all 10 fingers is somewhat rare and only occurred in one pair out of 108 like sexed pairs in my data.

† It must be noted that Komai's definition of identity of patterns is not the same as mine.

‡ This is also true in my data (see Table XXVI) but would not suffice as a criterion to separate the like sexed twins unless some other condition is added. Thus there were 9 pairs with 8, 9 or 10 finger patterns alike which did not fulfil the condition $\alpha > \gamma$, and there was every reason to regard most if not all of these as monozygotic; see Table XXVI.

the probability that it is of monozygotic origin $= pm_1/(pm_1 + qd_1)$, for the distribution of differences in the whole like sexed twin population is given by

	A_1	Not A_1	
Monozygotic Pairs	pm_1	$p(1-m_1)$	p
Dizygotic Pairs	qd_1	$q(1-d_1)$	q
All Like Sexed Pairs	pm_1+qd_1	$p(1-m_1)+q(1-d_1)$	1

For two uncorrelated characters the probability of a monozygotic pair giving differences in categories A_1 and A_2 respectively $= m_1m_2$, and for a dizygotic pair $= d_1d_2$, so that if a twin pair is found to give differences in categories A_1 and A_2 the probability that it is monozygotic is $pm_1m_2/(pm_1m_2 + qd_1d_2)$, or for any number of uncorrelated characters

$$pm_1m_2m_3 \ldots /(pm_1m_2m_3 \ldots + qd_1d_2d_3 \ldots).$$

Since only an approximation to the probability is required, the expression can be simplified by putting $p = q = \frac{1}{2}$, which is almost true, giving the probability of monozygotism as

$$m_1m_2m_3 \ldots /(m_1m_2m_3 \ldots + d_1d_2d_3 \ldots).$$

If the two characters are correlated with each other, the joint probabilities m_1m_2 and d_1d_2 become $K_1m_1m_2$ and $K_2d_1d_2$, where the factors K_1 and K_2 are approximately equal and therefore disappear provided that r is small or alternatively that the differences are not large*. The values of K_1, K_2 can be calculated if necessary for any particular case on the assumption of normal distributions of differences, and the complete formula can be used without reservation.

As an example of the application of this method I have chosen a pair of like sexed twins in which the diagnosis was in doubt, namely no. 33 shown in Table XXIX, and calculated the probability of the pair being monozygotic on the basis of five characters, none of which were highly correlated. The differences were as follows, and since none of them were large the approximate formula was used.

	Eye Colour	Height	Head Breadth	Systolic Pressure	Pulse Time
No. 33	1	·270	1·119	·239	·406

If we assume the B_5 criterion to give a correct diagnosis of monozygotism, Table XXVIII shows that 16 out of 56 monozygotic pairs and 19 out of 52 dizygotic pairs gave an eye colour difference of 1, and hence for no. 33 pair $m_1 = 16/56$ and $d_1 = 19/52$; from Table XXX it appears that 18 out of 55 monozygotic pairs and 11 out of 51 dizygotic pairs gave a height difference between ·2 and ·4, so that $m_2 = 18/55$ and $d_2 = 11/51$; and for head measurements 9 out of 168 monozygotic and 16 out of 156 dizygotic pairs gave a difference between 1·0 and 1·2, so that $m_3 = 9/168$ and $d_3 = 16/156$, and similarly for blood-pressure $m_4 = 20/93$, $d_4 = 10/85$ and for pulse interval $m_5 = 19/112$, $d_5 = 12/104$. Thus for pair no. 33 the probability of monozygotism is given by the formula to be ·94 or about 16 to 1. Actually this pair had only three pairs of fingers with similar patterns and was classified dizygotic by the B_5 criterion and monozygotic by the B_4 rule. Clearly a 16 to 1 chance is not conclusive enough to enable us to decide in favour of monozygotism; all that can be said is that the probability is in favour of this diagnosis.

There is no reason why this method could not be extended to a large number of characters and the differences tabulated in a convenient form for use, but the labour of computing the

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* The approximate formula cannot be usefully applied to any two characters correlated to a greater extent than $r = {\cdot}3$, and in cases where r exceeds ·1 neither difference should much exceed the standard deviation of the character measured nor should the product of the two differences exceed a quarter of the product of the two standard deviations.

probability for a given case would be considerable, and since the initial tabulation must depend at present on the assumption that some other criterion such as finger prints is fairly reliable, it is simpler to examine the finger patterns in most cases. For cases where a doubt remains the method is, I think, capable of being developed so as to give useful assistance.

8. Correction for Experimental Errors and Evaluation of True Degrees of Resemblance.

All anthropometric measurements are subject to varying amounts of *experimental error* due to imperfections in the instrument itself, inconstant technique in applying the instrument to the part measured, or mistakes in reading the scale or recording the reading. When a character is measured throughout by the same observer using the same instrument, this true experimental error is reduced to such small proportions in the ordinary physical measurements as to have little effect in increasing the apparent variability and reducing the correlation coefficients. This condition was fulfilled in the present research except for height and weight where the measuring scale was different in each school, but since the same scale was always used for all the children in a family the differences would scarcely be affected though σ_0 would be very slightly increased. In the physiological measurements the experimental error may be of more importance.

In addition to these experimental errors there is another source of variation tending to weaken the apparent correlations between measurements in pairs, which may be called *individual variability*, by which is meant real changes in the character measured due to (*a*) posture, (*b*) emotional factors, (*c*) variations due to time of day or temperature, (*d*) variations from day to day and accidental changes which are truly individual. In the present research all the children in a family were, except in a few instances, measured on the same day and within an hour or so of each other, so that (*c*) would not appreciably affect the differences; as far as possible the posture and external conditions whilst the measurements were being made were kept the same so that (*a*) and (*b*) were reduced to a minimum. As regards the last category (*d*), it is well known that if a person's blood-pressure or pulse rate is measured at 5 minute intervals for an hour, or at the same hour on a series of days, a large amount of variation is found however constant the technique, a phenomenon which can be only partly explained by the experimental error, and this must have an important influence in reducing the correlation coefficients between twins or siblings. The best way of getting rid of this effect would be to take a large number of measurements of each person, find the mean for each and use these means to compute the differences and correlation coefficients instead of using single measurements. This was not practicable, but a series of experiments was carried out in the Anthropometric Laboratory on five individuals over a period of 50 days, using the same instruments and technique as for the twins, in order to determine the combined effect of experimental error *plus* individual variation. As in the observations on twins, the time of day did not vary more than an hour, and posture and external conditions were almost constant, so the variability met with in each individual was partly due to experimental error and partly to factor (*d*).

Let σ_d = root mean square of corrected differences in pairs of twins or siblings as defined in section 3.

σ_0 = standard deviation of the corrected single measurements on all persons in the group.

σ_ϵ = standard deviation of corrected multiple measurements made on any one person (i.e. the average value of this for individuals).

r = correlation coefficient in pairs of twins or siblings.

r' = true correlation coefficient after allowing for the effect of σ_ϵ.

Then if the individual variations and experimental errors to be eliminated may be regarded as occurring independently in the two members of every pair, so that there is zero correlation between the pairs of "errors," the mean square difference between all pairs of these errors is $2\sigma_\epsilon^2$, and the mean square of the real differences in the group of pairs becomes $\sigma_d^2 - 2\sigma_\epsilon^2$, whilst the total variance in the group of children comprising the pairs is reduced from σ_0^2 to $\sigma_0^2 - \sigma_\epsilon^2$. Hence the true correlation coefficient between the pairs is $r' = 1 - \dfrac{\sigma_d^2 - 2\sigma_\epsilon^2}{2(\sigma_0^2 - \sigma_\epsilon^2)}$, and since $r = 1 - \dfrac{\sigma_d^2}{2\sigma_0^2}$ we obtain by substitution $r' = \dfrac{r}{1 - \dfrac{\sigma_\epsilon^2}{\sigma_0^2}}$, and since σ_0 has been computed for every group it is only necessary to obtain a measure of σ_ϵ for each character.

This was done by measuring the same person at the same hour on 50 consecutive weekdays, several persons being subjected to this process for each character in order to obtain a mean variability, duplicate measurements being also taken 5 or 10 minutes apart in order to separate the accidental from the day-to-day changes. For the present purpose this separation is not necessary, and only the *first* measurements taken on each day were used to evaluate the variability σ_0.

We want the variability in the average child when measured at different times, and this is no doubt a function of age. In the absence of any measure of the effect of age upon it we can only make the assumption that the values of σ_ϵ obtained in these experiments on young adults may be applied also to children; the results of doing this can of course only be regarded as rough approximations.

Since σ_0 has been hitherto evaluated in terms of the standard deviation S of each character as unit (see section 3) it must be converted into actual units of measurement before calculating $\sigma_\epsilon^2/\sigma_0^2$. This can be done approximately by multiplying σ_0 (or alternatively dividing σ_ϵ) by a factor σ' which is the root mean square of the deviations from the curves of means in all the children measured. The values of σ' and σ'^2 and of σ_ϵ^2 and $\sigma_\epsilon^2/\sigma'^2$ are shown in Table XXXVIII.

Table XXXVIII. *Calculation of Correction Factors for Correlation Coefficients.*

	σ'	σ'^2	σ_ϵ^2	$\sigma_\epsilon^2/\sigma'^2$	Total Measurements	Weighted Mean σ_ϵ^2	$\frac{r'}{r}$ for $\sigma_0 = 1$
Height	6·010 cm.	36·121	·08546	·00237	754	·00237	1·0024
Head Length	5·623 mm.	31·618	·56788	·01796	546	—	1·0183
Head Breadth	4·485 ,,	20·115	·08370	·00416	548	—	1·0042
Horizontal Circumference	13·208 ,,	174·451	2·92667	·01678	548	—	1·0171
Three Head Measurements	—	—	—	—	1642	·01297	1·0131
Interpupillary Distance	2·924 ,,	8·548	·14187	·01660	731	—	1·0169
Five Static Characters	—	—	—	—	3127	·01124	1·0114
Weight	3·610 kg.	13·030	·13645	·01047	763	·01047	1·0106
Systolic Pressure	11·659 mm.	135·936	23·9796	·17640	564	—	1·2139
Diastolic Pressure	8·204 ,,	67·300	15·6713	·23286	356	—	1·3035
Blood-pressure	—	—	—	—	920	·19825	1·2473
Pulse interval (30 beats)	2·844 sec.	8·091	3·6795	·45476	572	—	1·8768
Respiration Time (10)	4·284 ,,	18·353	5·2817	·28778	527	—	1·4041
Pulse and Respiration	—	—	—	—	1099	·37469	1·5992
Physiological Characters	—	—	—	—	2019	·29429	1·4170
Aggregate of ten Characters	—	—	—	—	5909	·10782	1·1208

Where it is required to correct r for a number of grouped characters such as the three head dimensions, the weighted mean value of $\sigma_\epsilon^2/\sigma'^2$ has been used. The value of σ_0 approximates to unity in large groups, and in the last column is given the value of r'/r when $\sigma_0 = 1$. In correcting the individual values of r, however, the actual value of σ_0^2 for the group in question has always been used in the formula. The figures for $\sigma_0 = 1$ indicate that the effect of correction on the correlation coefficients for pairs is roughly to increase them by the following amounts: height 1 in 400, head length* 1 in 50, head breadth* 1 in 250, horizontal circumference of head 1 in 60, interpupillary distance 1 in 60, weight 1 in 100, systolic pressure 1 in 5, diastolic pressure 3 in 10, pulse interval 9 in 10, respiration interval 4 in 10.

In Table XXXIX are given the uncorrected r, the value of σ_0 for the group, the number of pairs of measurements n, and the approximate corrected r' for the more important groups dealt with in the preceding sections.

Table XXXIX. *Corrected Coefficients of Correlation in Twins and Siblings.*

			n	σ_0	r	r'	n	σ_0	r	r'	n	σ_0	r	r'	n	σ_0	r	r'
			HEIGHT				HEAD MEASUREMENTS				STATIC CHARACTERS				WEIGHT			
Opposite Sexed Pairs	Twins		87	1·0524	·6350	·64	189	1·0138	·5548	·56	363	1·0177	·5602	·57	88	·9914	·4821	·49
	Others		225	1·0026	·4944	·50	492	·9877	·4415	·45	944	1·0040	·4342	·44	227	·9476	·3278	·33
Like Sexed Pairs	Other than Twins		261	·9492	·4794	·48	543	1·0135	·4385	·44	1048	·9981	·4350	·44	260	·9706	·4331	·44
	All Twins		194	·9497	·7611	·76	389	·9397	·6056	·61	776	·9468	·6385	·65	197	·9332	·6034	·61
	Monozygotic B_5		55	1·1198	·9531	·95	168	1·0121	·8208	·83	278	1·0343	·8553	·86	56	1·0649	·9292	·94
	Dizygotic. Not B_5		51	·8502	·4858	·49	156	·8711	·3220	·33	258	·8807	·3479	·35	52	·9149	·4377	·44
	Special Groups	B_1	59	1·0909	·9455	·95	180	1·0035	·7983	·81	297	1·0247	·8268	·84	60	1·0204	·9112	·92
		B_4	53	1·1540	·9466	·95	162	·9897	·8232	·83	268	1·0264	·8561	·87	54	1·0659	·8844	·89
		Not B_4	53	·8203	·4840	·49	162	·9170	·3904	·40	268	·9008	·3907	·39	54	·9195	·5163	·52
		IV	52	·9804	·9334	·94	117	1·0337	·8326	·84	221	1·0290	·8627	·87	52	·9820	·9145	·92
		M_1	50	1·0775	·9463	·95	153	1·0146	·8263	·84	252	1·0411	·8563	·87	51	·9412	·9167	·93
		Not M_1	56	·9099	·5881	·59	171	·8704	·3536	·36	284	·8802	·3916	·40	57	1·0328	·5821	·59
			BLOOD-PRESSURE				PULSE AND RESPIRATION				PHYSIOLOGICAL CHARACTERS				AGGREGATE OF TEN CHARACTERS			
Opposite Sexed Pairs	Twins		101	·9105	·2582	·34	119	·9598	·2157	·36	220	·9375	·2341	·35	671	·9889	·4458	·50
	Others		248	·9024	·3599	·48	318	·9877	·1938	·31	566	·9687	·2852	·42	1737	·9870	·3766	·42
Like Sexed Pairs	Other than Twins		286	1·0419	·3717	·45	370	1·0086	·1464	·23	656	1·0129	·2328	·33	1964	1·0001	·3660	·41
	All Twins		218	1·0130	·5406	·67	262	·9954	·4402	·71	480	1·0024	·4867	·69	1463	·9645	·5738	·65
	Monozygotic B_5		93	1·1686	·6935	·81	112	·9601	·5109	·86	205	1·0673	·6171	·83	539	1·0521	·7701	·85
	Dizygotic. Not B_5		85	·8615	·3199	·44	104	·9547	·4212	·72	189	·9141	·3796	·59	499	·8982	·3734	·43
	Special Groups	B_1	99	1·1492	·6866	·81	120	·9711	·5236	·87	219	1·0605	·6147	·83	576	1·0397	·7519	·84
		B_4	88	1·1462	·6078	·72	108	·9767	·5036	·83	196	1·0706	·5731	·77	518	1·0489	·7480	·83
		Not B_4	90	·9038	·5043	·67	108	·9287	·4117	·73	198	·9177	·4532	·70	520	·9100	·4305	·49
		IV	65	1·1703	·7002	·82	80	·9778	·5278	·87	145	1·0735	·6235	·84	418	1·0406	·7838	·87
		M_1	86	1·1601	·7390	·87	102	·9742	·5270	·87	188	1·0721	·6390	·86	491	1·0462	·7748	·86
		Not M_1	92	·8971	·2989	·40	114	·9425	·4117	·71	206	·9225	·3778	·58	547	·9171	·4167	·48

Examination of these corrected coefficients leads to the following conclusions:

The true correlation between brother and sister born at different times is of the order of ·50 for height, ·45 for head length, breadth and girth, ·33 for weight, ·48 for blood-pressure, ·31 for pulse and respiration rates, or ·42 for all these characters taken together. Between brother and brother or sister and sister of differing ages the coefficients are ·48 for height, ·44 for head measurements and weight, ·45 for blood-pressure, ·23 for pulse and respiration rates, or ·41 for all the characters combined. It is noteworthy that blood-pressure, after correction for the large accidental and experimental variations, gives values of the same order as static measurements in fraternal pairs. The low value of ·33 for weight is anomalous, for in like sexed pairs weight gives ·44. Pulse and respiration rates give coefficients definitely lower than the other characters, being of the order ·2 to ·3 after the large correction for individual variability has been made.

Turning now to twins, the true correlation in opposite sexed pairs is of the order ·64 for height,

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* For measurements taken with Flower's craniometer; another form of head spanner proved to be less variable.

·56 for head measurements, ·49 for weight, ·34 for blood-pressure, ·36 for pulse and respiration rates, or for all the characters combined almost exactly ·52. Here it is to be noted that all the four physiological factors give coefficients of the order ·35, whilst the static characters give values apparently higher (·57) than in siblings other than twins (·44).

Dizygotic twins of like sex (not B_5) give values of r' approximating to ·49 for height, ·33 for head measurements, ·44 for weight and blood-pressure, ·72 for pulse and respiration rates, or ·43 for all the characters combined. These values are somewhat lower than for opposite sexed dizygotic twins for the static characters but are higher for the physiological characters, especially for pulse and respiration. The high value ·72 for pulse and respiration suggests that the correction made for "experimental error" has been excessive for these characters; probably children are subject to a smaller variability from time to time than young adults in pulse and respiration rates. It has already been noticed however that the value of r' is only of the order ·2 or ·3 for fraternal pairs other than twins, so this may not be the explanation.

The B_4 criterion gives a dizygotic group for which r' approximates to ·40 for head measurements and ·52 for weight which are in closer accord with the values for opposite sexed dizygotic twins. If the probable errors of r are taken as roughly measuring those of r', there are no significant differences between the coefficients of correlation for the alternative like sexed dizygotic groups nor between these and the coefficients for dizygotic opposite sexed twins, and these coefficients may therefore be averaged as follows and compared with those for monozygotic twins.

Table XL.

	Height	Head Dimensions	Weight	Blood-pressure	Pulse and Respiration	Aggregate of 10
Mean corrected Coefficient for Pairs Differing in Age, of Like and Opposite Sex	·49	·45	·38	·46	·27	·42
Mean corrected Coefficient for Dizygotic Twins of Like[1] and Opposite Sex	·56	·45	·46	·39	·39	·47
Corrected Coefficient for Monozygotic Twins (B_5)	·95	·83	·94	·81	·86	·85

[1] Using B_5 method as criterion in the Like Sexed Twins.

When the B_4 criterion is used, the coefficients for the monozygotic twins are somewhat lower for weight and physiological factors, but not sensibly different for height and head dimensions, which are the characters introduced for diagnostic purposes into the B_5 definition. It cannot be said therefore that the high value of ·95 for height is due to the elimination by definition of pairs with large height differences; thus by using finger prints alone (B_4) $r' = ·95$, or using facial resemblance alone (IV) $r' = ·94$, or using facial resemblance plus finger prints (M_1) $r' = ·95$.*

9. Estimation of the Relative Effects of Constitution and Environment.

Holzinger (21), in a recent paper, has devised formulae by which he considers it is possible to obtain ratios measuring the relative potency of nature influences to nurture influences in producing differentiation between twins in respect of any character. The first of these formulae is based on the mean differences in pairs in regard to any measurement, and may be written

Ratio of nature to nurture influence in producing differentiation

$$(T) = \frac{\text{Mean difference in dizygotic like sexed twins } \textit{minus} \text{ mean difference in monozygotic twins}}{\text{Mean difference in monozygotic twins}}.$$

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* Using B_5 method as criterion in the like sexed twins.

In regard to this formula it must first be noted that only a portion of the "nature" effect is being measured by the numerator of the fraction, for a pair of dizygotic twins maintains on the average a greater resemblance than would be found if an unrelated pair of children were substituted for them at birth. To obtain the full measure of the nature influence it would be more reasonable to write the numerator "mean difference in unrelated pairs treated from birth as though they were twin children *minus* mean difference in monozygotic twins," which would largely increase the numerical value of T. This of course could not be evaluated, but apart from this fundamental objection the formula evidently involves three assumptions: (1) if a pair of monozygotic twins could be reared in absolutely identical environment, the difference between them should be zero since they are presumed to arise by division of a single ovum after fertilisation, and hence the observed difference must have been caused by differences in nurture alone; (2) the mean difference in dizygotic twins arises partly from differences in inherited constitution, due to variation in the paternal and maternal cells from which they originated, and partly from differences in nurture; (3) nurture has had the same opportunities of producing differentiation in like sexed dizygotic pairs chosen at random as in monozygotic pairs chosen at random. In regard to the first of these assumptions it may be observed that it is doubtful whether fertilised cells or their genes or chromosomes divide with such mathematical exactitude in nature as to lead to an expectation of zero difference, after development, in all characters under identical environmental influences, and that it is quite possible that a small but appreciable mean difference is to be looked for. If this is so, this amount of difference would have to be allowed for both in numerator and denominator of the formula in order to obtain T, and since it would have to be added to the numerator and subtracted from the denominator, this correction would have the effect of increasing T to an unknown extent, and from this point of view T must be regarded as a *minimal* value of the nature/nurture ratio.

The second assumption is not open to question but the third is dependent on the proviso that there is no more tendency to subject dizygotic twins of like sex to differences in nurture than monozygotic twins. I think this may involve a fallacy in that many dizygotic twins are very different in general body build, healthiness, tastes and temperament so that they naturally tend to subject themselves, or be subjected, to differences in nurture to a greater degree than monozygotic twins who have usually the same needs, tastes and inclinations and are rarely seen apart during childhood. To take one example, it is known that the amount of food required by a growing child varies greatly from one individual to another and might be quite different in a pair of dizygotic twins, so that in a poor home one would tend to suffer from insufficient nourishment more than the other. This would mean in general that in a random group of like sexed dizygotic twins the mean effect of nurture in producing differentiation will be greater than in a random group of monozygotic twins, and hence the mean difference in any measurable factor due to nurture alone may be greater in the dizygotic than in the monozygotic.

Another grave difficulty in the reasoning which underlies this formula is that the ratio it measures is between the influence of constitutional factors and the influence of *such environmental factors as are usually at work tending to differentiate pairs of like sexed twins*, and everything conspires to keep these last factors at their minimal potency. By this I mean that almost all the pairs measured by me, and by most other observers, were brought up in the same homes and attended the same school, and therefore we are getting no measure of what a widely different or even moderately different environment is capable of effecting during growth, but merely of what a very slight difference of environment can do. Apart from careful reports of a few individual pairs, such as one by Muller (20), of identical twins reared in different surroundings, the only collective evidence which can help in estimating the possible influence of a really different environment during growth seems to be a separation of the data given by von Verschuer (4) in his Table 9 into two groups according to whether the environment had been similar throughout or not. Many adults, however, were included and it is not clear in how many cases the twins were separated in early life, nor are the numbers in each group stated, but from the standard errors it appears that although no significant effect of environment is proved for height or cephalic index, the weight difference was greater in the group subjected to differing environment than in the group with similar environment.

Enough has been said to make clear the difficulties in interpretation of the formula. It seems that a ratio of this kind cannot tell us very much until more extensive data have been collected relating to twins who have been reared apart. Such pairs are not easily found, but until many have been observed it does not seem practicable to determine the extent of the possible influence of nurture in comparison with nurture in producing differentiation. Nevertheless, Holzinger's formulae can give an indication of the *relative* values of the nature/nurture ratios for different characters, though as to their absolute values they tell us little.

These considerations apply equally to the second formula, which may be written:

$$\text{Ratio of nature to nurture influence } (t^2) = \frac{\text{Monozygotic } r - \text{dizygotic } r}{1 - \text{monozygotic } r}.$$

With these reservations I have calculated the values of T and t^2 for the characters dealt with in this paper, using the B_5 and "Not B_5" values of m_d from Table XXXV and of r' from Table XXXIX; the results are given in Table XLI. I have also given Holzinger's values of T and t^2 for the same characters, and have computed T from von Verschuer's mean percentage differences given in his Tables 6 and 7 and from Dahlberg's mean differences given in his Table 15, and t^2 from Fisher's calculated values of r for monozygotic and opposite sexed dizygotic twins in Lauterbach's data (3). It is evident that the t^2 formula gives much higher estimates of the ratio then the T formula.

Table XLI.

	Author's Data		Holzinger		von Verschuer	Dahlberg	Fisher and Lauterbach
	T	t^2	T	t^2	T	T	t^2
Height	1·3	10·4	1·7	4·0	1·7	2·1	6·6
Head Dimensions	·6	3·0	—	—	—	—	—
Length	—	—	—	3·7	·9	1·1	—
Breadth	—	—	—	—	·7	1·3	—
Horizontal Circumference	—	—	—	—	1·3	—	—
Cephalic Index	—	—	—	—	·7	—	4·8
Weight	1·4	7·0	—	3·6	·8	—	7·5
Blood-pressure	·2	2·0	—	—	—	—	—
Pulse and Respiration Rates	·1	1·0	—	—	—	—	—

Without paying much regard to the actual, but only to the relative values of these ratios, the general conclusion seems to be that constitution is most important in comparison with environment in regard to height and weight, rather less so in regard to head dimensions, still less in regard to blood-pressure, and least of all in pulse and respiration rates.

10. SUMMARY OF CONCLUSIONS OF PART I.

(1) Facial resemblance is not a reliable criterion by itself for diagnosing monozygotic from dizygotic twins. A pronounced difference in eye colour almost certainly excludes monozygotism but differences in colour of the hair are of little use for diagnosis.

(2) Finger print resemblances between corresponding fingers are found to furnish the best means of separating monozygotic from dizygotic twins, and after testing various systems and checking the resulting groups in every possible way by other methods, a simple method of diagnosis has been drawn up, by means of which it is believed that errors will be sufficiently rare to enable sound conclusions to be drawn from its use in collective investigations on twins. This depends on the criterion that monozygotic twins have six or more patterns alike on corresponding fingers of the same sided hands, whilst dizygotic have six or less alike; in the ambiguous case when six are alike the diagnosis is completed by comparing the differences in height and four simple head measurements with tabulated values (Table XXXVII).

(3) A difference in height exceeding the standard deviation of height appropriate to the age of the pair almost certainly excludes monozygotism, and a difference exceeding the standard deviation in more than one of the four head dimensions, length, breadth, horizontal circumference and distance between the pupils is not often to be expected in a monozygotic pair. These facts can be put to practical use in the diagnosis for pairs where the finger print method proves ambiguous.

(4) No evidence of correlation between finger pattern resemblance and likeness in static characters was found within the monozygotic or the dizygotic groups, although there was some suggestion of a relation to likeness in the physiological characters of blood-pressure, and pulse rate in opposite sexed twins.

(5) An alternative method of diagnosis employing finger prints alone has also been devised, which is believed to lead to fairly reliable results, though inferior to the other. It is shown that, although it would be possible to devise a method of diagnosis based on differences by utilising a large number of measurements without resort to finger prints, this would be so laborious in application as to be of little practical use.

(6) Monozygotic twins tend to be taller and heavier, during childhood at least, than dizygotic twins of the same ages; their brothers and sisters occupy an intermediate position as regards height, but are superior in weight to both types of twins. Dizygotic twins tend to have a smaller head length than their brothers and sisters, and a smaller size of head generally than monozygotic twins. The distance between the pupils tends to be smaller in twins than in their siblings. Dizygotic twins are therefore on the whole inferior to their brothers and sisters in these physical measurements, but this is certainly not the case with monozygotic twins, except perhaps as regards weight.

(7) Monozygotic twins to a pronounced extent, and dizygotic twins to a slight extent, tend to exhibit higher blood-pressure and quicker pulse and respiration rates than their brothers and sisters at the same ages, the explanation being possibly psychological rather than organic, but none the less noteworthy. Variability in most characters is considerably greater in monozygotic than dizygotic twins, a phenomenon which awaits explanation.

(8) After adequate correction of all measurements for age and sex, the degree of resemblance between brother and sister born at different times is the same as in pairs of like sex born at different times. When one member of a pair is a twin the degree of resemblance in certain

characters tends to be slightly less than when neither is a twin; thus for the aggregate of ten measured characters the coefficient of correlation was ·34 instead of ·44.

(9) The degree of resemblance in dizygotic twins of like or opposite sex is not appreciably different from that met with in all pairs of children born to the same parents at different times, regardless of the intervals between the births. There is no definite evidence that the interval between births has any influence on the degree of resemblance, though in some characters there is a suggestion of a slightly increased divergence between children born at short intervals apart.

(10) The degrees of resemblance in height and head dimensions are not appreciably influenced by age in either type of twins between the 3rd and 15th years. Although the mean difference in monozygotic twins has been shown to be about the same as that in dizygotic twins at birth, before the school age is reached the former is approximately half the latter in static characters and weight. In the case of blood-pressure this differentiation does not seem to occur until the approach of adolescence, which suggests that the hereditary factors concerned in controlling the basic level of blood-pressure do not come into operation until the sex characters begin to develop. The degree of resemblance in blood-pressure increases in monozygotic but not in dizygotic twins during the school period. Pulse and respiration rates do not show any well defined change in resemblance with age, though there is a suggestion that opposite sexed twins tend to become less alike in these respects as adolescence approaches.

(11) When corrected for the effect of experimental errors and day to day individual variations, coefficients of correlation in pairs of siblings are increased to the extent of about 90 % for pulse rate, 40 % for respiration rate, 30 % for diastolic pressure, 20 % for systolic pressure, 2 % for head length and distance between the pupils, 1 % for weight, 1 in 250 for head breadth and 1 in 400 for height. The corrected coefficients found in monozygotic twins were ·95 for height, ·94 for weight, ·86 for pulse and respiration rates, ·83 for head dimensions and ·81 for blood-pressure, whilst in dizygotic twins and other siblings they approximated to ·5 in each case.

(12) It must be concluded that blood-pressure, pulse and respiration rates, at any rate from adolescence onwards, are governed by hereditary factors to almost the same extent as static characters. An attempt to arrange the characters in order of the relative potency of constitutional to environmental influences results in the following descending scale: height, weight, head dimensions, blood-pressure, pulse and respiration rates.

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