Triplet Children in Great Britain and Ireland.

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CONTENTS.

1. *Origin of Material.*

The study of twins is somewhat impeded in Great Britain by the absence of the registration of multiple births; for, contrary to the practice of most civilised countries, the occurrence of twins appears in the registers as two distinct births, occurring to the same parents at an unusually short interval of time. Consequently official data are lacking as to the frequency and sex distribution of twins and triplets. On the other hand, the existence of a Royal Bounty for triplets supplies a potential source of information, of which it is believed scientific use has not previously been made. The records of the Royal Bounty, in the charge of the Secretary of His Majesty's Privy Purse, constitute in effect a special registry of triplet births, including the great majority of the cases in Great Britain and Ireland. With the support of the Medical Research Council the author was kindly allowed access to this material, for which he desires to express his indebtedness to all concerned.

Visits to individual families for the purpose of measuring the surviving children made the enquiry a more expensive one than if the information had been gathered merely by correspondence. During three years the British Association made grants to a Committee, appointed by Section H, under the chairmanship of Dr. Shrubsall, in aid of this work, which together with a generous donation from Major Leonard Darwin covered nearly the whole of the actual expenditure. This would have been much greater had not a number of gentlemen (see below, p. 288), situated in districts distant from London, freely given their assistance in taking measurements.

A study of the conclusions arrived at in different investigations of twin births

reveals two serious disabilities from which existing bodies of data ordinarily suffer. The most important collections of twin measurements, such as those of Thorndike (10), Dahlberg (3), and Lauterbach (4), refer to twins of ages from childhood to adolescence, with a few adult cases. Statistical allowance for age is not easy over a period which includes a well-marked maximum of growth rate, which occurs at considerably different ages for boys and for girls, and doubtless at different ages also for children of the same sex. Attempts have been made to eliminate the effects of varying age by comparison with a larger number of children from single births (10), data which are seldom available, and by the use of empirical growth curves based upon the twin measurements (4), a procedure which is useful only when the data are exceptionally extensive. Both methods, however, are open to the objection that possibly hereditary factors play an important part in the determination of precocity or the reverse, and that, if so, similar genetic variation in children of opposite sex may produce a materially less degree of resemblance between twins (who, of course, are usually at the same age at the time of measurement) than in the case of twins of like sex.

The second disability also affects collections of measurements, but in an even more serious degree appears to influence studies of the inheritance of the twinning tendency. It is that cases are brought to the notice of the investigator on account of their interesting character. The investigation may even have been initiated by some such interesting group of cases, and even if subsequent cases are collected by some sound method which excludes the possibility of unconscious selection, the collection will still in some degree retain its atypical character. Large collections, if not composite, escape this difficulty better than small collections, but with the increased precision with which tests of statistical significance are now carried out, it becomes the more important to emphasise that only data obtained on a carefully planned and uniform basis are capable under such tests of yielding valid conclusions. How far this consideration is capable of explaining the great discrepancies, not only between the conclusions of different investigators, but between the bodies of data they present, can only be known as material free from this suspicion is accumulated.

The material for the present study comprises three consecutive years of the King's Bounty records, with dates of birth ranging from October 8, 1917, to September 28, 1920. The period was chosen so that from the time the investigation was commenced surviving children should be available for measurement at a fixed age, which was selected in advance at 6½ years. If two or more triplet children survived to this age, they were measured. Since the limiting factor of the enquiry was the cost of visiting the children at this time, no attempt was

made to recover at a later date the measurements of cases, which for one reason or another could not be measured at the right time. It would have been scarcely possible to obtain the measurements but for the assistance of Mr. E. M. Somerfield in Ireland, Dr. Alexander Low in Scotland, and Mr. L. H. C. Tippett who measured a large number of cases in the Midlands and North of England. Mr. A. R. Stoney Smith also measured several of the earlier English cases. To the care of these voluntary assistants in procuring accurate and comparable measurements must be ascribed the clear and unambiguous results to which the measurements data point.

All parents, whether the triplet children survived or not, were asked to fill in a relationship form, giving the numbers and sexes of all children, whether by single or multiple births, in certain nearly related families. The importance of obtaining complete data over a uniform range of kinship cannot be over-emphasised. In many families remarkable cases of multiple births from comparatively remote relatives are thrust under the notice of the investigator, but must be ignored, since it is only for the families of near relatives of the father and mother of the triplets that complete and reliable information can ordinarily be obtained. The children born to the father and mother of the triplets and the children born to their parents are normally well known; in addition, the questionnaire covered the children of the brothers and sisters of the parents of the triplets. The latter contain a proportion of incomplete families, and a number of individual families had to be omitted owing to migration. Only cases in which the number and sexes of the children could be listed with confidence were included.

The numerical data, together with the specification of the measurements taken, have been filed at the Natural History Museum at South Kensington, under the arrangements made for the conservation of biological measurements by the Measurements Committee of the British Association.

2. *Survival.*

In all 166 cases of triplet births were available for enquiry; of these, however, no reply could be obtained in 20 cases, either from change of address since the birth of the children, or more rarely from the parents being unwilling to supply information. The data for survival in the remaining 146 cases are given below.

Table I.—Survival of Triplet Children Born Alive.

Born.	3 boys.	2 boys, 1 girl.	1 boy, 2 girls.	3 girls.	Total.
All living	2	4	8	6	20
One dead—					
Boy	7	4	10	—	21
Girl	—	3	12	6	21
One living—					
Boy	6	8	3	—	17
Girl	—	1	11	9	21
Sex unknown	—	2	2	—	4
All dead	7	15	14	6	42
Unknown	8	3	5	4	20
Total	30	40	65	31	166

The proportion surviving differs in the two sexes, but does not seem to differ greatly in the four types of triplet birth. From the table above the following percentages of survival are calculated :—

Tabls II.—Percentages Surviving.

	3 boys.	2 boys, 1 girl.	1 boy, 2 girls.	3 girls.	Total.
Boys	39	37	40	—	39
Girls	—	26	51	48	46

The low proportion of survival among the girls, in sets with two boys and one girl, is noticeable, but this is based on only 35 cases, of which 9 survived.

As is to be expected both from the genetical similarity of the children and from the similarity of their experience up to and including birth, the deaths of one or more children in the same set are far from independent. Of 101 pairs of two boys, in 20 cases both survived, in 38 one survived, and in 43 cases neither survived; thus the chance of survival of a boy is raised to 51 per cent, if his brother lives from the value 31 per cent, if his brother dies. Of 188 pairs of opposite sex, in 40 cases both lived, in 32 cases the boy only survived, in 37 cases the girl only survived, and in 79 cases both died; thus the chance of survival of the boy of such a pair is raised from 29 percent to 52 per cent by the survival of his sister ; while the chance of survival of the girl is raised from 32 per cent, to 56 per cent, by the survival of her brother. Finally, of 139 pairs of two girls, in 42 cases both survived, in 53 cases only one survived, and in 44

cases neither survived ; consequently the chance of survival of a girl is raised from 37 per cent. to 61 per cent. by the survival of her sister. The association seems to be just as close between children of opposite sex as between children of the same sex, a fact which suggests that, with the high mortality experienced by triplet children, genetic similarity has little to do with the similarity of the chances of life.

3. *Average Size of Triplet Children.*

The children actually measured numbered 49 boys and 68 girls. The averages of the six measurements taken for each type of triplet births and for the aggregate of all types are given in Tables III and IV.

Table III.—Average Size of Boys.

Type.	Number of individuals.	Stature.	Stem.	Span.	Left cubit.	Head.	
						Length.	Breadth.
		mm.	mm.	mm.	mm.	mm.	mm.
3 boys	18	1102	624	1090	292·0	178·3	143·4
2 boys, 1 girl	16	1127	640	1128	304·5	179·3	140·8
1 boy, 2 girls	15	1092	624	1100	290·8	176·3	140·2
Aggregate	49	1107·0	629·2	1105·6	295·7	178·0	141·6

Table IV.—Average Size of Girls.

Type.	Number of individuals.	Stature.	Stem.	Span.	Left cubit.	Head.	
						Length.	Breadth.
		mm.	mm.	mm.	mm.	mm.	mm.
2 boys, 1 girl	8	1106	628	1084	292·9	170·5	138·3
1 boy, 2 girls	38	1078	610	1071	283·9	172·2	135·5
3 girls	22	1065	608	1060	278·5	168·5	136·6
Aggregate	68	1077·0	616·0	1069·1	283·3	170·8	136·2

It would be of great interest to compare the general averages with those of children by single births of the same age. The growth curve of children is, however, only known for a few special districts, and no general figure is available for the whole country, such as would be comparable with the triplet

material. Dunstan (2) gives valuable figures based on 300 measurements of stature in each trimester for the children of the rural area of E. Sussex. At 6| years of age his boys averaged 1114.4 mm. and his girls 1103.2 mm. Comparison may also be made with the average heights obtained from Miss Elderton's distribution for Glasgow School children (1), Table III, p. 296.

Table V.—Average Stature of Children at 6½ Years.

	Triplets.	E. Sussex, rural.	Glasgow A, poorest district.	Glasgow B, poor district.	Glasgow C, better class.	Glasgow D, still higher class.
	mm.	mm.	mm.	mm.	mm.	mm.
Boys	1107·0	1114·4	1070·6	1093·4	1093·4	1115·0
Girls	1077·0	1103·2	1065·6	1088·4	1087·2	1111·2

The differences between the different districts, though not exceeding 2 inches, are sufficiently great to leave in some uncertainty the comparison of triplet with single children. They are, of course, far too great to be ascribed to random sampling, but neither environmental nor hereditary factors can be excluded. With boys the average stature at this age in E. Sussex agrees with the "still higher class" schools in Glasgow, and only these two give a higher average than the triplets; the triplet girls do not compare so well, being taller only than the Glasgow girls from the lowest class districts. The averages cannot be taken to indicate that triplet children are on the average less tall at 6| years of age than are children from single births. The distinguishing feature of the triplet measurements is not their average values, but the large sex difference. In the collections based on large samples to which the comparison is made, the sex difference is about 11 mm. in E. Sussex and only about 5 mm. in all the Glasgow groups ; the triplets show a difference of 30 mm. If standard errors are calculated for the triplet children regarded as independent samples, the values would be only 6 and 5 mm., and would not suffice to explain the large sex difference.

Actually, the children are drawn in batches of two or three from the same family, a circumstance which tends somewhat to increase the liability to error of the two averages; on the other hand, the fact that many of the pairs of opposite sex are brother and sister will tend to diminish the error of the difference. In order to obtain a strict test the sex difference was obtained for the 23 families in which both boys and girls had been measured, counting each family as only a single observation. The mean sex difference is then found to be 18 mm., with a standard error of nearly 9 mm.; there are, in fact, somewhat

large differences between different families measured in the relative stature of the boys and the girls, but the remarkable sex difference observed in the stature of the triplets is largely due to the boys having come predominantly from the taller families.

The average stature of the two sexes, 1092 mm., is seen to correspond with districts B and C of Glasgow, being about three-quarters of an inch less than that of rural E. Sussex and Glasgow district D, and nearly an inch greater than Glasgow district A. This simple result is one of the most surprising of the enquiry. It is well known that the correlations observed between the measurements of near relatives are only intelligible on the view that at least 90 per cent. of the variance observed in adult stature is due to genetic differences (8). This conclusion does not exclude the induction by environmental causes of an increase or decrease of stature of the order of half an inch, as a frequent occurrence ; nor does it exclude effects of greater magnitude induced by extraordinary circumstances. The pre-natal conditions of triplet children must be exceptionally unfavourable, and the birth is very frequently premature. Perhaps the best measure of the severity of the environment which they have experienced consists in the very large post-natal death-rate. The conditions are sufficiently severe to kill more than half the children, but appear to be almost, if not entirely, inoperative in checking the normal growth of the survivors.

It will not be argued that the recovery of these children to normal stature is due to their environmental conditions during infancy and early childhood being in any way above the average ; on the contrary, since the wage system in this country makes no allowance for the burden of offspring, we may be certain that the very existence of the triplet children will ordinarily induce a condition of economic hardship, which will last at least as long as the children remain dependents. An equally important circumstance is that, apart from economic stress, the amount of the care and attention ordinarily bestowed by their mothers upon children at these ages must be much diminished. It would appear that we must conclude that whatever may be the case in animals with a shorter growth period, the long duration of infancy and childhood in man gives ample opportunity for full recovery from the effects of pre-natal conditions, and for the full realisation of the genetic potentialities, even in characters, such as general growth, in which environmental modification would seem to be most readily effected.

4. *Precision of Measurements.*

The precision attainable in different human measurements does not seem to have been at all fully studied. In an investigation like the present in which it is important to determine with accuracy the degree of resemblance between children, many of whom may be of monozygotic origin, it is essential not only that no effort should be spared to attain adequate accuracy, but that objective evidence of the accuracy actually attained should be put on record. It was therefore arranged that for the majority of the cases measured, and especially for those of which the author had the greatest suspicion (namely, his own) that not only should the measurer satisfy himself that an accurate measure had been taken, but also that independent duplicate measures of the same value should be obtained, in order to yield by subsequent comparison an independent estimate of the accuracy of measurement. In doing this the specific purpose of the accuracy aimed at was held in view. The differences between different families of children are comparatively large, and these differences are to be used only in estimating the general variance of triplet children of a given age. The small systematic errors which undoubtedly exist between the measures obtained by different observers using different instruments will be entirely unimportant in estimating this variance, which will, on the contrary, be seriously affected by paucity of material, and should, in the author's opinion, be obtained from such an accurate estimate of the variance of the population as could be made from a carefully planned anthropometric survey based on the sampling method. In the second place, the small fluctuations, which, on the analogy of laboratory determinations would doubtless affect the same observer making the same measurements on different days, have fortunately no relevance to the comparisons between the measurements of different children on the same day and in the same circumstances. The errors in such comparisons should, in fact, be perfectly represented by the discrepancies between duplicate measurements taken at the same sitting.

The variance of a single observation of each measurement is given in Table VI.

If two values for the same measurement showed a marked discrepancy, a third was taken, a procedure which served to exclude gross errors. All measurements left on record were used in the above table, each case contributing 1 or 2 to the number of comparisons according as 2 or 3 measurements were left on record. The standard error of the values adopted will be nearly that calculated from the mean of two measurements, though this will be a slight over-estimate

Table VI. —Variation in Reported Measurements.

	Number of comparisons.	Single measurements.		Mean of 2, standard error.	Per cent. of like-sex variance.
		Variance.	Standard error.		
		mm².	mm.	mm.	
Stature	77	6·171	2·48	1·89	0·57
Stem length	73	12·751	3·57	2·53	2·80
Span	76	40·964	6·40	4·53	3·15
Cubit	77	3·356	1·83	1·30	3·03
Head length	75	0·691	0·831	0·588	3·53
Head breadth	70	0·331	0·575	0·407	2·46

owing to the cases, which include measurements made in the least accurate circumstances, in which the mean of three values was employed. The last column expresses the variance ascribable to errors of measurement as a percentage of the variance ascribable to differences between triplets of like sex, calculated in a similar way. Since in no case this amounts to 4 per cent., it is evident that the estimate of degree of resemblance even between the like-sex pairs, will not be vitiated in the case of any one measurement by the working errors.

Dahlberg (3) gives a most valuable account of the errors of measurement detected in his study of the resemblance between twins. The values given, on p. 199 of his book, for 15 bodily measurements refer to the standard difference between single measurements, and are therefore double the standard errors of the mean of two measurements. For length of head, Dahlberg's figures indicate a higher precision than that attained in this enquiry, for the standard error of the mean of two of his measurements would be only 0.35; for breadth of head, his standard error, 0.415, is about the same as that given by our own data, but for stature his value is 2.69, a larger value than the 1.89 indicated above, though not one which would detract from the value of his observations.

5. *Degrees of Resemblance.*

5.1. *Resemblance of Triplets of Unlike Sex.*—The triplets living to be measured supply 34 cases of pairs of opposite sex. These must be regarded as dizygotic pairs. If they are also biovular, provided the fraction of the variance for which environmental variations is responsible is quite small, they should show the same degree of correlation as that shown by adult brothers and sisters by different births. This test was applied to Lauterbach's data, an attempt being

made to eliminate the age of measurement by fitting a cubic growth curve to the measurements of each sex. The values then found were somewhat low (see Table VIII) compared to well-ascertained fraternal correlations from single births, with the exception of that for cephalic index, which in that body of material showed no appreciable differentiation due to age or sex. It might therefore be supposed that this procedure could not, in view of the marked spurt of growth at puberty, entirely eliminate the disturbance due to varying ages.

As appears from the table, the present material based on measurements at a fixed age does, in fact, yield higher values, comparable with that obtained for cephalic index in Lauterbach's data. The natural supposition that weight, which yields the lowest unlike-sex correlation, is in reality not so highly correlated, even in growing children, as are the skeletal measurements, is not supported by the high values found for this variate between like sex pairs. The difference between the averages of the two series is, therefore, in so far as it is not ascribable to random sampling, probably due to the uniform age of the triplets.

Table VII.—Covariation of Pairs of Opposite Sex.

	Mean.		Sum of squares.		Sum of products.	Correlation.	
	Boys.	Girls.	Boys.	Girls.		r.	z.
Stature	1104	1083	71,540	51,594	32,733	0·539	0·602
Stem length	630	622	17,473	8,984	51,123	0·409	0·435
Span	1111	1073	86,927	62,219	37,946	0·516	0·571
Cubit	296·4	286·5	12,206	8,926	7,032	0·645	0·767
Head length	176·8	170·3	1,899·0	1,059·7	670·0	0·472	0·513
Head breadth	140·0	136·4	1,084·1	709·4	573·4	0·654	0·782

Table VIII.—Correlations between Brother and Sister.

		r.	Mean r.
Single births	Stature	0·553	0·508 ± 0·012
	Span	0·525	
	Cubit	0·440	
Twins	Stature	0·455	0·458 ± 0·053
	Stem length	0·461	
	Weight	0·380	
	Cephalic index	0·537	
Triplets	Stature	0·539	0·545 ± 0·074
	Stem length	0·409	
	Span	0·516	
	Cubit	0·645	
	Head length	0·472	
	Head breadth	0·654	

In view of the sampling errors no significance should be attached to differences between the correlations of the different characters ; comparison of the average correlations obtained from single births (7), twins (4), and triplets leaves no doubt that the correlations are substantially equal. Moreover, if any appreciable part of the correlation observed between brothers and sisters were not of genetic origin, but were due to the general similarity of the environment to which children of the same parents are exposed, the correlation should be appreciably higher with twins or triplets. Since this is not the case the data confirm the view that no appreciable proportion of the resemblance is due to similarity of environment.

It should be noted that the range of home environment in the case of triplets was extremely high. In not a few cases the support of the triplets, in addition to previous children, sufficed to lower the subsistence level to one of extreme hardship during the childhood of the triplets. Other cases were comparatively well-to-do. In somewhat less degree it is probable that the same is true of the American twins in Lauterbach's record. The point is one of some importance, since it may reasonably be argued that Pearson's data, predominantly from the families of University students, do not represent such extreme environments as would be sufficient to produce permanent retardation of growth ; and that the conclusion drawn (8) by comparison of these values with expectation on the assumption of Mendelian inheritance, that no appreciable fraction of the variance can be ascribed to environmental differences, though true for the class sampled by Pearson, ought not to be extended to classes in which child life is attended by real and severe hardships. The data presented do not suggest appreciable environmental effects in any class for children born from 1917-1920 ; nevertheless, on a point of such importance it may be worth while to call attention to the possibility of making a crucial test of the matter with more precision than the present enquiry attempts, by consistently accumulating the evidence supplied by triplets, as in this country it is possible to do, taking as control an adequate number of children by single births of the same age, but of superior class.

5.2. *Resemblance between Triplets of Like Sex.*—The correlation between pairs of triplets of like sex may best be found by taking the mean measurements of two or more such children in the same way as have been treated the two or more measurements of a single child. In this way not only is the constant negative bias of intra-class correlations derived from a symmetrical table avoided, but no undue weighting is given to the sets of three as opposed to the sets of two ; moreover, the accuracy of the determination corresponds to that of a number of simple pairs providing an equal number of comparisons. The

measurements comprise six cases of all three children of the same sex living to be measured, and 32 pairs of the same sex, the material being thus equivalent in respect of the estimation of the variance within such a trio to 44 pairs.

The value thus obtained, for the variance within a trio, is shown below (Table IX), for the six characters measured. It is interesting to compare them with the results obtained by Dahlberg (3). Dahlberg expresses his results as a mean difference between pairs of twins; his figures have therefore been squared and multiplied by p/4. Mean values for boys and girls have been used, and since Dahlberg's material consists of persons of very different ages, the comparison may best be made on the basis of the average actual measurement at each age. The unit is thus one-thousandth of the mean measurement in each case. Comparisons are possible for three characters. By a careful examination of the facial resemblance, and especially of the character of the ears, Dahlberg has diagnosed his material as monozygotic and dizygotic respectively, ignoring for this purpose the measurements actually obtained. The comparison thus provides a rough means of estimating what percentage of the triplets of like sex are of these two types of origin, assuming the accuracy and comparability of Dahlberg's figures.

Table IX.—Like-Sex Variance within Twinship or Trio.

	Triplets.	Dahlberg dizygotic.	Triplets.	Dahlberg monozygotic.	Triplets monozygotic.
	mm².	per mille.	per mille.	per mille.	per cent.
Stature	541·7	914·6	454·2	100·3	56·5
Stem length	227·4				
Span	651·0				
Cubit	55·38				
Head length	9·789	647·8	321·8	157·9	66·5
Head breadth	6·729	557·0	348·7	113·5	47·0

The mean percentage monozygotic is about 57 by this method. This estimate agrees well with one based on the sex proportions of the group of triplets concerned, for of the 44 cases, 10 belong to sets of 3 boys, 6 to sets of 2 boys and 1 girl, 15 to sets of 1 boy and 2 girls, and 13 to sets of 3 girls. The number of cases in which all the children are of like sex is thus 23, against 21 of mixed sex. The proportion of monozygotic like-sex pairs may be estimated as 3 X 23 — 21 = 48, against 2 X 21 — 42 dizygotic ; a method of estimation which yields 53.3 per cent. monozygotic. Such a close agreement doubtless owes something to chance, while, on the other hand, it undoubtedly strengthens both estimates.

To obtain correlations between triplets of like-sex, comparable with those obtained for triplets of unlike sex, the individual variance for members of such pairs must be compared with the general variance of the population from which they were drawn. It was no part of the design of this research to obtain final figures for this variance, which, as was pointed out above, would be better based upon a comprehensive anthropometric survey; the data do, however, supply a tolerable basis for estimation, in the variance found among all children of like-sex who were measured. There were of these 49 boys and 68 girls. Since the girls also preponderate (28 pairs to 16) in the like-sex pairs, the variance obtained from these two groups may be pooled as they stand, giving an estimated variance with precision appropriate to 115 degrees of freedom. This does not preclude large sampling errors, but the results can be little affected at most by any real difference in variability which may exist between the two sexes. The like-sex correlation is then found by subtracting from unity the ratio of the individual variance of a member of a like-sex pair to the individual variance of a member of the general population.

The correlations thus obtained between triplets of like sex agree closely with those obtained by the author for the like-sex twins of Lauterbach's data.

Table X.—Correlations between Pairs of Like-Sex.

Triplets.			Twins (Lauterbach).		
	r.	*z.*		*r.*	*z.*
Stature	0·720	0·908	Stature	0·735	0·940
Stem	0·498	0·547	Stem	0·575	0·655
Span	0·735	0·938	Weight	0·735	0·938
Cubit	0·803	1·107	Cephalic index	0·731	0·931
Head length	0·766	1·010			
Head breadth	0·764	1·006			
Mean	0·726	0·914	Mean	0·699	0·866

In both series stem length shows a surprising departure in the direction of low correlation. In Lauterbach's data the effect could merely be noted as an anomaly ; in the triplet data, though not in the twin data, it is also the lowest correlation for children of unlike sex. It was noticed early in the measurements that the values obtained for stem length were very sensitive to the posture in which the child was placed. Care was therefore taken to eliminate as far as possible such variations ; the children were seated on a firm horizontal surface, usually a kitchen table, with their knees projecting as little as possible beyond the edge. I have, however, still suspected that the clothing, and especially the

habitual sitting posture, of the child might considerably affect the measurements. In view of the slight discrepancies between duplicate measurements taken at about half an hour's interval, which only account for a depression of the value of the correlation by 0.014, the conclusion that difficulties of measurement are alone responsible cannot be regarded as established, and it may be that this measurement, unlike others, admits, at least in the growing child, an appreciable amount of environmental modification. Such a view is not free from difficulty, in view of the fact that with pairs of unlike sex the triplet data show little, and Lauterbach's data no effect, and, in addition, the effect with twins of like sex in Lauterbach's data is much more pronounced with boys than with girls. The discrepancies obtained from Lauterbach's measurements and my own should in any case be sufficient to put investigators on their guard against basing important conclusions on this particular character, without a thorough scrutiny of the reliability of the measurement technique to be employed.

If stem length is set aside as of doubtful reliability, the mean correlation from the triplets, obtained as usual from the values of z ($=\tanh^{-1}r$), is 0.759, while that from Lauterbach's twins is 0.734. Neither with nor without stem length are the values significantly different. This agreement supplies a further confirmation of the estimates made above of the proportion of monozygotic pairs, for this proportion was estimated in Lauterbach's data to be about 59 per cent.

Further and concordant evidence of the proportion of pairs to be regarded as monozygotic may be obtained from the values of the correlations themselves. Even if it were assumed that monozygotic twins were identical in their physical measurements, then if the dizygotic like-sex pairs were no more highly correlated than pairs of unlike-sex, it would require 47 per cent. monozygotic to raise the correlation from 0.545 to 0.759. This percentage may therefore be regarded as a minimum. If, on the contrary, we take the proportion as estimated by comparison with Dahlberg's data for the relative variance, and from the sex distribution (namely, 57 per cent.), then the correlation between monozygotic twins should be 0.920 in order to reproduce our correlations. A similar estimate made from Lauterbach's data gave values between 0.92 and 0.93 for all three characters other than stem length. In the values from the triplet data also we have omitted stem length from the average, and have also, on the other hand, made no allowance for the known errors of measurement which will have depressed all the other correlations by about 0.008.

Since an intra-class correlation measures the fraction of the variance ascribable to differences between the classes compared, a correlation of 0.93 between mono-

zygotic twins may be interpreted as meaning that 93 per cent. of the human variance in physical measurements is to be ascribed to hereditary factors, leaving 7 per cent. for other causes of variation. Exactly what these other causes of variation are, it is extremely difficult to indicate. Gross factors, such as the supply of nutrients, facilities for exercise, and all other conditions open to inspection and regulation, may have very little influence ; these would certainly cause smaller variations between twins than between unrelated children. Other causes, such as the onset, and age of onset, of infectious diseases, depend from less obvious environmental differences, and their effects will in consequence have a more accidental character. If, as seems probable from the mutual interaction of the parts in development, very minute initial variations of growth of particular organs may in some cases lead to appreciable ultimate difference in the measurements, these will be as great for twins as for unrelated children. Indeed it may be suspected that they will be greater, for the great differences in weight at birth show that the pre-natal condition of children born together must in some respects be strikingly different.

An exact estimate of the average correlation in metrical characters between identical twins should evidently combine a critical diagnosis based upon Dahlberg's methods, carried out independently by two different judges, without knowledge of the measurements ; an equally necessary factor in such an estimation, and one which is unfortunately wanting from Dahlberg's data, is the value of the variance at a given age of the general population sampled. Experts differ profoundly as to the correct diagnosis of monozygotic and dizygotic twins (11, 12) ; nevertheless, the concordant results obtained by comparing the triplet data with Dahlberg's averages have convinced the writer that his method of diagnosis, which was published during the progress of the triplet enquiry, has gone far to solve the problem of discriminating the two types of twins. Such discrimination can, however, never be absolute, if only because genetic identity itself is not impossible for dizygotic twins.

The question whether all three triplet children can ever be regarded as monozygotic should evidently be answered confidently only on a larger basis of observation than the six cases for which measurements were obtained. A rough criterion based on the measurements may be made by excluding all cases which differed in any measurement by more than a fixed maximum difference. Taking arbitrary standards proportional to the standard differences between like-sex pairs, namely, for stature 40 mm., for stem length 26 mm., for span 44 mm., for cubit 13 mm., for head length 5.4 mm., and for head breadth 4.5 mm., only 22 pairs remain sufficiently alike in all measurements. These will doubtless

be predominantly monozygotic pairs, but the criterion is far from decisive, and some overlap will doubtless have occurred. In no case do all three triplets fulfil the conditions. In three cases, numbers 1, 59 and 61, one child is considerably larger than the other two. In cases number 1 and 61 the two smaller children are alike in their measurements, in case number 59 they differ by 8 mm. in head breadth; this case is probably trizygotic. In the three other cases monozygotism cannot be confidently denied. In case 52, *(c)* is in most respects the smallest child, but only differs distinctly from her sisters in being shorter (by 5.6 and 7.2 mm.) in the head. In case 2 all three girls agree closely save that (c) is narrower (by 5 and 7 mm.) in the head. In case 40, *(a)* is both shorter in sitting height and narrower in the head than her two sisters. Since the standard difference in head length between monozygotic pairs, as judged either from Dahlberg's data or from the triplet measurements, cannot differ much from 3.1 mm., the case for regarding case 52 as monozygotic is particularly strong.

6. *Inheritance of Tendencies favouring Multiple Births.*

Much confused controversy has turned upon the inheritance of tendencies favouring twin births, and especially upon the influence of the father upon the production of twins. The most self-consistent view seems to be that developed by Weinberg, namely, that there is no paternal influence, and that the production of monozygotic twins is not inherited. This view is not only self-consistent but is supported by a considerable quantity of genealogical statistics; it appears indeed, without critical scrutiny, to be the only view consistent with the figures which Weinberg presents. Unfortunately, it has not been borne out by any other substantial body of data. The situation involves a definite conflict of evidence, and it is undesirable that this prime fact should be obscured, although it must necessarily be complicated by the conflict of inferences drawn from the evidence. The best hope of progress evidently lies in obtaining data from entirely fresh sources, taking every care to eliminate those causes of error which seem most likely to have produced the existing discrepancies.

A further point of importance is that conclusions should be based whenever possible upon comparisons made within a homogeneous body of data, rather than with data obtained by a different method, for apart from the potent influence of unconscious selection, differences in the completeness with which cases of twinning involving one or more still-births are recorded will much affect the frequency of twinning observed. That this precaution is not unnecessary may be seen from the great differences in absolute frequencies obtained by different observers in districts in which the official statistics show no comparable discrepancies.

The triplet data were entirely unselected save for the fact of the occurrence of triplets. Of the 148 families asked for information concerning related births, 98 provided complete and satisfactory information. It will he preferable to use only this unquestionable portion of the data; only one case of those omitted need be mentioned separately, namely, a family of 11 births, of which 2 were of triplets and 5 of twins, yielding in all 20 children. The inclusion of the case would evidently have much raised the observed percentage of twins in the families containing triplets, and possibly also in related families. Its omission, however, cannot invalidate the conclusions to be drawn from unquestionably correct information, for it is omitted not because the information was exceptional in character but because it was confused and very incomplete. A number of such cases of exceptional fecundity have been reported from time to time, and may represent a phenomenon distinct from the normal, though rare and scattered, occurrence of multiple births.

Full data for related multiple births are shown in Tables XI, XII and XIII. Among the families in which the triplets occurred, 493 other births are recorded, of which 14 were of twins and 4 of triplets. Counting triplets as equivalent to the production of twins twice (for, in addition to the production of twins, a second fission or additional ovulation must have occurred), the percentage of twinning in these families is 4.5 per cent. The ratio of triplets to twins is high, but this may be no more than a coincidence. It is to be presumed that the proportion of twins in Great Britain and Ireland is not greatly different from 1 per cent., and the other data of this enquiry show that it cannot be much more. Consequently a rate of 4.5 per cent, represents a very considerable concentration of multiple births, and shows that whether the tendency is inherited or not, certain parents are definitely characterised by higher twinning rates than are others.

Table XI.—Other Children of Parents.

Type of triplets.	Families.	Single births.		Twins.			Triplets.			
		Boys.	Girls.	2 boys.	1 boy, 1 girl.	2 girls.	3 boys.	2 boys, 1 girl.	1 boy, 2 girls.	3 girls.
3 boys	13	33	29	—	4	1	—	—	—	—
2 boys, 1 girl	27	79	73	—	1	—	—	—	1	1
1 boy, 2 girls	39	82	81	2	3	1	—	1	—	—
3 girls	21	45	53	1	1	—	—	1	—	—
Total	100	239	236	3	9	2	—	2	1	1
		475		14			4			

Table XII.—Children of Mother's Parents.

Type of triplets.	Families.	Single births.		Twins.			Triplets.
		Boys.	Girls.	2 boys.	1 boy, 1 girl.	2 girls.	3 boys.
3 boys	13	45	48	1	3	—	—
2 boys, 1 girl	27	80	102	—	1	2	1
1 boy, 2 girls	39	125	161	3	4	1	—
3 girls	21	76	89	—	1	2	—
Total	100	326	400	4	9	5	1
		726		18			

Table XIII.—Children of Father's Parents.

Types of triplets.	Families.	Single births.		Twins.			Triplets.
		Boys.	Girls.	2 boys.	1 boy, 1 girl.	2 girls.	
3 boys	13	62	41	1	—	—	—
2 boys, 1 girl	27	114	85	3	—	2	—
1 boy, 2 girls	39	151	120	3	1	2	—
3 girls	21	85	59	1	1	1	—
Total	100	412	305	8	2	5	0
		717		15			

Evidence of heredity must, of course, be drawn from the corresponding data for related families. Of 745 births to parents of the mother, 18 were of twins and 1 was of triplets; calculated as before, this gives 2.7 per cent. twins in these families. Similarly of 732 births to parents of the father, 15 were of twins; this is 2.0 per cent. The statistical significance of both results may be gauged by the fact that in a Poisson series with mean 7.3 a value as high as 15 will only occur eight times in a thousand trials.

The data for the families of the parents of triplets thus give definite support to the view that the production of multiple births is influenced to an important extent by the hereditary qualities of the father. Of the similar evidence from the relatives of the parents of twins, perhaps the most comparable is that given by Danforth (6) from St. Louis. It is stated that "the investigator had no knowledge of any of these families until in each case the birth of twins was

reported to the bureau of vital statistics." Fifty families were investigated; of 181 births in the same families 10 were of twins (5.5 per cent.), of 328 births to parents of the mothers 10 were of twins (3.0 per cent.), while of 297 births to parents of the father 8 were of twins (2.7 per cent.). The twin data are smaller in volume, being based upon 50 families against 98 available for the triplet enquiry ; the twinning percentages are distinctly higher in each case, although the families were selected merely by a single occurrence of twins, instead of by the occurrence of triplets ; but the main conclusion that the selected families show the highest twin frequency, and that their relations on both sides show the same effect to a diluted extent, appears clearly from both enquiries.

Davenport (5) gives figures for a somewhat more highly selected group of families who have had twins twice. Of 355 births to the parents of twin-repeating mothers 16, or 4.5 per cent., were of twins ; of 289 births to the parents of twin-repeating fathers 12, or 4-2 per cent., were of twins. The discrepancy in the actual percentages is here more striking than in those of Danforth, and we have in this case no assurance that cases of special interest do not find their way, more readily than cases showing no heredity, into the archives of the Eugenics Record Office. That a somewhat severe concentration of interesting cases may have occurred in this material is suggested by the percentage of twin births obtained for the brothers and sisters of repeating fathers and mothers. These are father's sisters' children, 8.2 per cent. ; mother's sisters' children, 5.5 per cent. ; father's brothers' children, 6-5 per cent. ; mother's brothers' children, 4.5 per cent.

These high percentages, while apparently supporting, in reality introduce a difficulty to the theory developed by Davenport, for he infers from them equal paternal and maternal influence. Now if we select a person specially characterised, such as a twin-repeating father, or a twin-repeating mother, we may infer on this theory that both the parents of this person will (in less degree) be similarly characterised, and the children of the marriage between two such parents will therefore be twins with nearly double the frequency which would have been realised if only one of the parents had been so characterised; although, therefore, a brother or sister is genetically as close a relative as a father or mother, the theory is not compatible with the view that the sister or brother, married to some quite unselected person, will have twins as frequently as will the father and mother married to each other.

If 6 per cent. twins is correct for the brothers and sisters of the chosen parents, we might reasonably expect 11 per cent. twins from their fathers and mothers ; on the other hand, if 4.4 per cent. is correct for the fathers and mothers, we

might reasonably estimate the percentage for the brothers and sisters at 2.7 per cent. If heredity is at work it should, in fact, be made manifest not only by the contrast between the selected families and the general population, but equally by the contrast between different degrees of affinity to the *præpositus*, or selected centre, of each pedigree. The latter type of contrast is indeed the more important, since, as in England, the general population may be almost unknown, and, in other cases, as the divergences between different enquiries indicate, discrepancies of unknown origin have certainly been introduced between the official and the genealogical data ; consequently, in view of these, the comparison of different groups of relatives in the same material provides undoubtedly the best controlled tests available of the hypotheses to be considered.

One probable reason why this contrast, to be expected between different groups of relatives, has not been realised, or at least utilised, lies in the fact that the groups of relatives appropriate for comparison will be different, according to whether paternal influence is admitted or not. If paternal influence were absent, not only would the relatives of the father and the mother's brothers show no excess of twins, but the sisters and daughters of the mother should show no less effect than the mother's mother. This contrast between the twin-frequency of the mother's sisters on the one hand with the mother's brothers, the father's sisters and the father's brothers on the other, seems to provide a well-controlled method of determining if any important group of the causes of multiple births are limited, as Weinberg suggests, to action through the mother. Equally, however, the contrast between the twin-frequency exhibited by the parents and that of the brothers and sisters must be manifest if to any important extent twinning is inherited through both parents alike. Neither contrast appears in Davenport's figures in spite of the high percentages of twinning observed, a circumstance which makes it impossible to use these results with confidence as a means of discriminating between the two opposed views.

Much lower percentages of twins are found among the relatives of twin-bearing parents by Weinberg and Dahlberg. From Wurtemburg Weinberg finds 101 fathers of twins from families with 901 children in all, among whom 6 pairs are twins, thus showing no indication of paternal influence. More extensive data for the relatives of mothers are given for Stuttgart (3, p. 107).

Table XIV.—Related Births to Mothers of Twins.

	Relatives of mothers of twins of like sex.			Relatives of mothers of twins of unlike sex.		
	Mother.	Sister.	Daughter.	Mother.	Sister.	Daughter.
Multiple births	61	55	44	45	24	27
Single births	3909	2524	3386	1803	998	1437
Total	3970	2579	3430	1848	1022	1464
Percentage	1·53	2·13	1·28	2·50	2·35	1·84

The percentage of twinning is seen to be much lower than in either of the American groups of data discussed, that for the mothers being more comparable with the values obtained from the triplet data. For each degree of relationship the relations of twins of unlike sex have the higher percentage, and Weinberg concludes that only the tendency to dizygotism is inherited, that for diembryony showing no hereditary tendency. It should be noted that in Weinberg's material this difference is only statistically significant in the case of the mothers, though the daughters, and even to a very slight extent the sisters, show a tendency in the same direction. If the above figures are examined critically, it appears that the three classes of relatives do not give, within the limits of reasonable sampling errors, the same percentage of twins. This effect seems to be wholly due to the larger material on the relations of twins of like sex. In these the sisters show much the higher percentage. It is possible to give a plausible, though tentative, explanation of these discrepancies.

Dahlberg (3, p. 113) has criticised the material on the ground that incompleteness of registration may have considerably reduced the twin percentage. If this is so the sisters, which show the highest twin frequency, would seem to represent the generation in which the data are most complete, and it constitutes a serious *caveat* against Weinberg's conclusions—that all hereditary effects should be ascribed to dizygotism—that it is precisely in the sisters that no appreciable difference exists between the relations of twins of like and of unlike sex. Dahlberg has shown (3, p. 47) that the omission of still-births diminishes especially the percentage of monozygotic twins.

Upon the question of the inheritance of diembryony the triplet data appear to supply evidence of a decisive character. For of the 15 twin births of the parents of the father of the triplets only 2 are of opposite sex, whereas of the 18 twin births of parents of the mother 9 are of opposite sex. The whole

of the twins, in excess of expectation for ordinary families, born to the parents of the fathers, are thus of like sex, and presumably therefore all monozygotic. It is not that every one of the 13 pairs found need be monozygotic, for two or three like-sex dizygotic pairs might well occur in 700 births taken at random. That 13 such pairs should occur is beyond reasonable probability, and since there is no evidence of any excess of dizygotic pairs, the plain inference from the data is that the paternal influence upon twinning is confined to the production of diembryony. Since in such cases fission occurs after the union with the egg of the paternal gamete, it is only natural that for this process developmental tendencies inherited from the father should be of equal importance with those from the mother. Whether the tendency to diembryony is also inherited through the mother, as seems *a priori* probable, could only be decided upon larger data, for the presence of an excess of dizygotic twins among the relations of the mother must much increase the sampling errors of any estimate of diembryony.

It is to be noted that all the groups of relationship data cited agree in giving a slightly higher twin percentage to the relations of the mother, though in no case, save that of Weinberg, is this excess statistically significant. It does, however, accord with the view that, while paternal influence only affects the one type of twinning, maternal influence may act upon both. If, further, it is assumed that the maternal influence in diembryony is equally potent with that of the father, the smallness of the differences usually found between the relations of the two parents makes it probable that heredity is less influential in inducing dizygotism than it is in inducing diembryony.

This view is the direct contrary of that held by Weinberg; on the other hand, it tallies with Davenport's finding even higher twin-frequencies among the relatives of monozygotic twins than among those of twins in general. It may, in addition, be supported by facts other than the twin-frequency of relatives. It is well known that the percentage of twins increases greatly with the age of the mother. Knibbs (9, p. 309) shows a threefold increase between 20 and 38. Comparisons of the sex distribution at each age, of which the most thorough is that of Dahlberg (3, pp. 21-28), shows that this increase is certainly largely and probably wholly due to a change in the frequency of dizygotic pairs. Evidently, then, dizygotism is much influenced by an environmental factor, age of mother, upon which hereditary influences can have but little effect. Diembryony, on the other hand, is apparently not influenced at all by this factor. In consequence, it is possible to hold that the probability of monozygotic twins depends wholly upon the hereditary nature of the parents, while in the case of

dizygotism any evidence for heredity is bound to be much obscured by the mere effect of variations in the age at childbirth.

If a strongly heritable maternal tendency towards dizygotic twinning existed, it would appear in contrasting the twin-frequency of mother's sisters with those of mother's brothers, father's brothers and father's sisters. No such effect appears in Davenport's data, and the comparison cannot be made in Weinberg's. The triplet data are as follows :—

Table XV.—Frequency of Multiple Births born to Brothers and Sisters of the Parents of Triplets.

	Mother's sisters.	Mother's brothers.	Father's sisters.	Father's brothers.
Single	504	501	626	532
Twin	5	6	7	7
Triplet	1	—	1	—
Total	510	507	634	539
Percentage	1·4	1·2	1·4	1·3

No significant differences exist between the four classes, and it may be doubted if any of them differ significantly from the twin percentage of the general population. For this reason the sex distribution of the related twins is of no special interest. The actual types are, however, given below :—

Table XVI.—Sex Distribution of Related Multiple Births.

	2 boys.	1 boy, 1 girl.	2 girls.	3 boys.	2 boys, 1 girl.
Mother's sisters	—	2	3	—	1
Mother's brothers	2	1	3	—	—
Father's sisters	1	3	3	1	—
Father's brothers	—	4	3	—	—
Total	3	10	12	1	1

Among the relatives of triplets the frequency of triplets compared to that of twins is somewhat high. Among children of the same parents we have 4 triplets to 14 twins, among the children of their parents, 1 triplet set to 33 pairs of twins, and among the children of their brothers and sisters 2 sets of triplets to 25 pairs of twins. The numbers are too small to give more than an indication, but they suggest that in addition to the factors favouring multiple births in general,

there may be others which favour the particular sequence of events, such as double ovulation followed by fission of one zygote, which gives rise to triplets.

It will be noticed that a perfectly clear contrast exists between the frequency of twins born to mothers (2.8 per cent.) and that born to sisters (1.4 per cent.) of mothers of triplets, in accordance with the other clear evidence which these data provide of paternal influence. There is, however, one factor which should be mentioned, not as probably producing the whole effect, but as possibly contributing to it. The strong age association of dizygotic twinning renders the frequency of this phenomenon open to interference by artificial contraceptive methods. If these are employed after the production of a few children, a proportion of the married women concerned will only be "exposed to risk" during the earlier parts of the reproductive period. Such a tendency would certainly reduce the proportion of dizygotic, though probably not of monozygotic twins, and it is only in dizygotic twins that any excess is to be looked for of the mother's sisters against the mother's brothers, and the father's brothers and sisters. If, as there is ample reason to believe, contraceptive practices were more widely employed in the generation represented by mother's sisters than in the previous generation of mothers' mothers, we might reasonably put down some part of the contrast to this cause. It should perhaps be mentioned in this connection that the frequency of triplets, or at least of applications for the King's Bounty, has fallen off in the last 25 years more rapidly than would be expected from the decrease in the annual number of single births registered.

7. *Summary.*

Measurements taken at a fixed age of 115 surviving triplet children show no distinct difference in stature from children by single birth. The precision of the comparison is, however, limited by our scanty knowledge of the average bodily growth in the general population of Great Britain and Ireland.

The average degree of resemblance between triplet children of opposite sex does not differ appreciably from that of twins of opposite sex, or of fully grown brothers and sisters by different births.

The differences between triplets of like sex are intermediate in magnitude between those found by Dahlberg in groups of like-sex twins classified as monozygotic and dizygotic respectively. The comparison indicates that about 57 per cent. of the like-sex triplets pairs measured were monozygotic. The correlation between triplet children of like sex, the estimate of which could be improved by a better knowledge of the general population, agrees well with that

found for like-sex twins in Lauterbach's measurements, and indicates a correlation between monozygotic pairs of about 0.92.

The material is not sufficient to establish definitely that in any set all three triplets were monozygotic, though this is a probable explanation of the resemblance in at least one set. The discrepancies between the data provided by different investigators upon the inheritance of tendencies favouring multiple births have prevented any substantial agreement on this subject. An examination of the material suggests that these discrepancies are due (a) to the accumulation of interesting cases showing apparent heredity in pedigree collections ; (*b*) inequality in the completeness with which still-births are recorded in the different sources of material compared.

To avoid these discrepancies it is important to spare no pains to ensure that a strictly valid statistical technique is employed in the collection of data, a consideration which is of equal importance in the statistical study of rare occurrences of all kinds ; and to utilise, as the best controlled evidence of inheritance, the contrast in twin-frequency between different groups of relatives in the same collection. When allowance is made for these two sources of discrepancy, existing data upon twins may be brought into harmony with the results of the triplet enquiry.

The triplet pedigrees show a significant excess of multiple births in the families of both the father and the mother of the triplets. In the case of the father the excess consists wholly of like-sex twins. In other material the sex distribution of the related twins seems not to have been recorded, in spite of evident importance for the classification of heritable tendencies affecting dizygotism and diembryony respectively. The triplet data indicate that the paternal influence is only exerted in the production of diembryony. It is probable *a priori* that the heritable constitution of the mother exerts an equal influence in this respect, but more extensive data would be required to demonstrate this.

Since, in these and other data, the maternal inheritance is not much stronger than the paternal, it is probable that dizygotism is less strongly inherited than is diembryony. This view is supported by the well-established increase in multiple births with increasing age of mother, which effect appears to be confined to dizygotism.

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