THE HEREDITY OF UNILATERAL VARIATIONS IN MAN

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FREQUENCY OF UNILATERAL VARIATIONS

The dissection of even a small series of human bodies always reveals a considerable array of parts which show more or less conspicuous deviation from the normal. In some instances the variations probably represent nothing more than fluctuations in size or position, but not infrequently they are of such a character as to suggest something of a different order. Many of the more common ones are well known, and there is considerable information bearing on the frequency of their occurrence, as well as a certain amount of evidence as to their hereditary nature. The question is somewhat complicated, however, by the fact that, in organs which are ordinarily bilaterally symmetrical, a distinct variation often appears in one member of a pair but not in the other. This fact has suggested to some students that such variations are essentially fortuitous, although it is generally conceded that a hereditary manifestation need not necessarily find a bilateral expression. In view of the existing uncertainty in this regard, the status of unilateral variations with reference to heredity and the factors which influence their appearance, or non-appearance, becomes a matter of genetic interest.

Inasmuch as both sides of the body are developed from the same germ-plasm, it might have been expected that abnormalities which are of germinal origin would almost invariably be symmetrical in their expression, and the question naturally arises as to whether or not uni-

lateral variation ordinarily represents anything other than somatic fluctuation. Two methods of attacking this problem suggest themselves: first, a determination of the relative frequency of the unilateral and the bilateral occurrence of individual variant forms; and, second, the accumulation of evidence of the presence or absence of their hereditary transmission. The first part of the analysis can be undertaken statistically, the second must depend upon the records of individual families. The latter are rarely available in adequate numbers when actual dissection is required to establish the facts.

In order to get some preliminary indication of the amount of unilateral variation to be expected in paired structures taken at random, the upper and lower limbs of twenty unselected subjects were carefully followed through an ordinary course of dissection. Except for occasional unavoidable omissions, 157 pairs of structures (90 muscles, 39 blood vessels and 28 nerves) were examined in each case. The total number of individual parts actually inspected was 5916. Among these there were 530, or approximately 9 percent, which deviated appreciably from the norm as described in standard text-books. The distribution of the abnormalities with reference to sides of the body may be summarized as follows:

Pairs of structures which were normal on both sides.....	2612
Pairs in which the right was aberrant, the left normal.....	79
Pairs in which the left was aberrant, the right normal.....	83
Pairs in which both were aberrant and alike.....	163
Pairs in which both were aberrant but unlike.....	21
<hr/>	
Total number of pairs compared.....	2958

The summary shows that there were 162 instances in which structures were abnormal on one side and normal on the other, and 163 in which they were abnormal in the same manner and to about the same extent on both sides. The 21 pairs which were abnormal and unlike probably belong in two categories: (1) those in which there was only a quantitative difference in the expression of the trait on the two sides, and (2) those in which two really different variations happened to appear on opposite sides of the same individual. In practice it is often difficult to differentiate between these two classes. If the number in group (1) could be determined, it might properly be added to the 163 cases of similar bilateral abnormalities, while twice the number in group (2) should be added to 162 in order to make up the total of unilateral manifestations. The figures indicate approximate equality in the unilateral and bilateral expression of abnormality, the ratio lying between 0.88 : 1 and 1.25 : 1.

TABLE 1

The frequency of unilateral and bilateral occurrence in a series of twenty variations, and a comparison of the observed numbers with the numbers expected on the assumption that the distribution is a random one.

STRUCTURE AND TYPE OF VARIATION	TOTAL NUMBER OF PAIRS OF STRUCTURES (SUBJECTS) EXAMINED	VARIATION LIMITED TO THE RIGHT SIDE	VARIATION LIMITED TO THE LEFT SIDE	VARIATION PRESENT ON BOTH SIDES OF THE BODY	Observed	Observed
					Expected	Expected
					Number of Bilateral Cases	Ratios of Unilateral to Bilateral Cases
					ad	$e(b+c+2d)-2d$
					$(b+d)(c+d)$	$b+c$
Palate bone articulating with frontal.....	450	11	7	22	10.3	33.0
Malar bone partially subdivided.....	800	2	2	6	7.5	27.0
Medial infraorbital canal present.....	2700	8	7	3	10.1	15.7
Infraorbital canal subdivided.....	3028	86	93	54	7.9	11.8
Supracondylar process of humerus present.....	2929	10	14	3	3.9	4.2
Os centrale carpi lacking.....	143	1	7	38	3.1	23.0
External tibiale element present.....	223	7	10	26	4.9	16.8
Sesamoid bone in peroneus tendon.....	323	4	8	18	10.2	37.8
Sternalis muscle present.....	717	18	13	17	11.6	23.2
Axillary arch present.....	153	1	2	11	10.8	82.6
Biceps muscle with three heads.....	532	26	61	43	3.2	5.3
Palmaris longus muscle suppressed.....	2270	87	98	236	4.9	14.8
Flexor pollicis longus muscle lacking.....	59	8	12	13	1.8	2.8
Psoas minor muscle present.....	406	26	25	175	1.8	7.3
Piriformis muscle divided.....	499	59	57	73	2.1	3.5
Quadratus femoris muscle absent.....	240	8	3	8	10.9	23.3
Peroneus tertius muscle absent.....	538	16	18	20	7.8	15.8
Plantaris muscle absent.....	542	9	21	31	8.1	22.7
Carotid artery with "canalabra" division.....	175	3	6	29	4.5	27.0
Obturator artery arising from epigastric.....	167	20	28	27	1.7	2.5
Totals.....	16,904	410	492	853	8.0	21.2

There is no reason to suppose that the material was particularly unusual in either the number or the distribution of its abnormalities.

The frequency of the unilateral and bilateral appearances of certain particular variations is shown in the accompanying table, the data for which have been drawn largely from the reports listed at the end of this paper. To be available for inclusion in the table it was necessary that the record show in each instance (a) the total number of unselected subjects examined; (b) the number of these in which the particular trait under consideration appeared on the right side but not on the left; (c) the number in which it appeared on the left side only; and (d) the number in which it was present on both sides. This necessary requirement renders unavailable many published records, which do not happen to be presented in such form as to be of use for this particular study, but despite this handicap, the absolute number of usable data is rather extensive. For purposes of the present analysis twenty different structures are considered, and the available figures are combined without reference to sex or race. In this material the incidence of variation is 7.4 percent and the ratio of unilateral to bilateral manifestations is 1.06 : 1, which is in fair agreement with the above-mentioned findings for a larger number of structures in a smaller number of bodies. But when individual types of variation are considered separately there is found to be a considerable range, both in the general incidence and in the ratio of unilateral to bilateral cases.

RELATION OF UNILATERAL TO BILATERAL APPEARANCE OF THE SAME TRAIT

Owing to the high frequency of unilateral variations it might be surmised that they are due to environmental influences, or to somatic fluctuations, and that bilateral cases represent chance simultaneous occurrences of the same variation on both sides. This hypothesis can be tested statistically, although there may be some question as to what are the best criteria to employ for the purpose. In any event, if these occurrences may be classed under the head of chance phenomena, the number of bilateral cases of each type should bear some definite relation to the number of unilateral cases of the same type. When in a given sample, a (see columns a to d in table 1), there are $b+c$ cases of a unilateral variation, the hypothetical total number of right-side cases may be reckoned as $b+d'$ and of left-side cases as $c+d'$. The expected value of d' can then be determined on the basis of a random distribution of the anomaly, and the agreement between observation and expectation tested

by a comparison of d and d' . In the first entry of the table the expected number of bilateral cases according to this procedure is $d' = \frac{(11+d')(7+d')}{(450)^2}$

$\times 450 = 0.178$. The difference between d and d' , in this case about 20, is the excess of observed over expected cases of bilateral manifestation of the anomaly. The ratio between the two is about 123 : 1. While this is an essentially logical procedure it has the defect of ignoring the actual value of d in the first part of the calculation, a matter of importance when the numbers dealt with are small.

An alternative method which does not have this defect is to take the true incidence of right-side and left-side cases as $\frac{b+d}{a}$ and $\frac{c+d}{a}$, respectively. Then the expected number of bilateral cases (d') becomes $a \times \frac{(b+d)(c+d)}{a^2} = \frac{(b+d)(c+d)}{a}$. Dividing the observed number by the

expected number gives $\frac{ad}{(b+d)(c+d)}$, the ratio of the observed to the expected number of bilateral cases. This ratio, e , is recorded in the sixth column of the table and gives an index of the tendency to bilaterality exhibited by each anomaly. In all cases investigated this value is more than one. If presence of a variation on one side were to inhibit its appearance on the other, e would take a fractional form. The reliability of the index depends on the total number of subjects and the likelihood of a "normal" distribution of the observed number of cases. When the probable error of the observed number of anomalies ($b+c+2d$) in a total of $2a$ parts (considering both sides) is determined, two values are obtained which differ from the observed value by $-x$ and $+x$, respectively. The most probable values of d' on the basis of these figures lie between $\frac{(b+c+2d-x)^2}{a}$ and $\frac{(b+c+2d+x)^2}{a}$, being grouped asymmetrically

around the value obtained directly from the observed figures. In this grouping the chances are slightly over 3 : 1 that the true value does not lie above the upper figure, which may be called d'' , and about 10 : 1 against its being $2(d''-d')$. It seems unnecessary to compute these values in each case, and the summary in table 2 will suffice to indicate the figures which may be regarded as statistically significant to the extent that the chances are 10 : 1 against a value of e as large as or larger than the one indicated.

TABLE 2

INCIDENCE OF THE ANOMALY IN PERCENT OF TOTAL NUMBER OF PARTS (2a)	VALUES OF e WHICH THEORETICALLY SHOULD NOT BE EQUALED OR EXCEEDED OFTENER THAN ONE TIME IN TEN		
	When a=100	When a=500	When a=1000
0.1	11.5	4.6	3.2
1.0	3.3	1.9	1.6
5.0	1.9	1.4	1.3
10.0	1.6	1.3	1.2
20.0	1.4	1.2	1.1

For some purposes the value e might not be the most satisfactory one' since it tends to give more weight to the number of abnormalities than to their observed distribution. Given a certain number of variations in $2a$ parts it may be desirable to compare the observed ratio of bilateral to unilateral cases with the expected ratio between these two classes. This can be done readily when e has been determined. For, the expected number of bilateral cases being $\frac{d}{e}$, the ratio between bilateral and unilateral instances should be (except when b and c differ greatly in value) $\frac{d}{e} : (b+c+2d) - \frac{2d}{e} = \frac{d}{e(b+c+2d) - 2d}$. But the observed ratio is $\frac{d}{b+d}$, and this divided by the expected ratio gives $\frac{e(b+c+2d) - 2d}{b+c}$, an expression which would seem to allow proper weight for each factor in the empirical data. This ratio, f , is entered in the last column of table 1.

Tested in this manner the twenty traits listed in table 1 all show what may be regarded as a statistically significant excess of bilateral occurrences. In this respect there is an agreement between the two sets of data, one derived from an investigation of a few traits in many subjects, the other from the study of a much larger number of traits in a small number of bodies. This is probably not a coincidence, but may be assumed to indicate the usual situation in reference to the frequent deviations from normal which are listed in text-books of anatomy under the head of "variations." Stated in other terms, it appears that an index of symmetry¹ is generally considerably higher than an index of modality, whether

¹ In an unpublished paper read before Section H of the A.A.A.S., in 1920, the writer proposed the following indices as useful in dealing with certain data relating to human variation: index of modality (translated into terms of the table), $\frac{100(a-b-c-d)}{a}$; index of symmetry, $\frac{100(a-b-c)}{a}$.

it be organs or whole individuals that are considered. This can only mean that the causal factors tend to be effective on both sides of the body at once, more often than can be accounted for on the basis of chance.

THE CAUSAL FACTORS INVOLVED IN UNILATERAL VARIATIONS

There would seem to be several possibilities as to the nature of these causal factors. They might be environmental, in the sense that they are due to extrinsic influences affecting development either before or after birth; they might represent somatic mutations, as SUMNER and HUESTES (1921) have suggested in the case of certain variations in *Peromyscus*; or they might be germinal in the ordinary sense. It is also conceivable that the same phenotype may be produced independently by several different causes. In regard to the first possibility: while it is evident that in postnatal life the environment often plays an important rôle in influencing anatomical structure, it is unlikely that anything outside the embryo itself could directly produce the small but distinct deviations which represent the vast majority of congenital variations, and still less probable that such external factors would so frequently be confined in their effect to a small region on only one side of the body. SUMNER and HUESTES argue to the same effect when they suggest something comparable to bud variation in plants as an explanation of asymmetries in *Peromyscus*. In the case of some gross malformations there is a certain amount of evidence for pathological causation, but there is no indication that the variations under consideration belong to that class.

Scarcely more probable would seem to be the idea of somatic mutation as a general cause of these small variations, at least in human material. The strong tendency for the traits to be bilateral would indicate that the supposed mutations frequently occur as far back as the fertilized ovum and these cases might be expected to be hereditary. This idea leads to the hypothesis that there are two classes of such variations, those due to mutations in the oöperm, which tend to be bilateral and hereditary, and those due to late mutations, which are unilateral and non-hereditary. But if this were the case the high mutation rate as indicated by unilateral cases would lead to the expectation of a rapid increase in the frequency of the trait due to the mutations that occur early enough to involve the germ-plasm. Such traits as have been studied properly show no indications of such an increase. In short, data from the dissecting room do not, so far as can be ascertained, afford any positive evidence in support of the view that the large number of variations ordinarily met with are due to a series of mutations which occurred during the develop-

ment of each particular individual. It is the study of the heredity of one of these variations, however, which throws the most light on the situation and seems to indicate a class of problems of especial interest to the student of human genetics.

The palmaris longus muscle will serve as an illustration, since it represents a type of variable structure commonly encountered in human anatomy and one which has attracted the attention of anatomists in many countries. The total of recorded data in relation to this muscle is greatly in excess of what could be utilized in table 1 and is adequate to show beyond any reasonable doubt that one of its frequent variations, namely, complete suppression, has a different frequency (a) in different races, (b) in the two sexes of the same race, and (c) on the two sides of the body. It is more often suppressed in the white race than in colored races, in women than in men, and in the left than in the right arm. This variation resembles many others that have been extensively studied in showing a difference of incidence with reference to race, sex and side of the body. Such a peculiarity might incline one against the idea of heredity as a factor in its causation. Nevertheless, suppression of the palmaris longus muscle proves to be hereditary (THOMPSON, BATTS and DANFORTH 1921) with no excess of cases left over to be accounted for by environmental factors or somatic mutation. Moreover, family histories show that parents in whom the muscle is suppressed on one side only, may produce children with it suppressed on the same side, on the opposite side, or on both sides, and parents in whom the trait is bilateral produce some children in whom it is unilateral. The evidence in this case seems to make it perfectly clear that a strictly hereditary trait may show all of the characteristics mentioned above; it may be unilateral or bilateral, and it may show a differential frequency in the two sexes and on the two sides of the body.

NON-APPEARANCE OF A TRAIT THAT MIGHT HAVE BEEN EXPECTED
TO BE PRESENT

In the variation just mentioned the trait finds only a unilateral expression in about 44 percent of the cases in which it appears at all, and yet, as indicated above, there is no reason to believe that the unilateral cases are genetically in any way different from those in which the trait is bilateral. It would seem rather that the capacity of the gene to reveal its presence through somatic manifestation is so slight and the balance between the influences that make for the appearance of the trait and those which lead to its non-appearance is so even that in about two-

fifths of the cases the actual manifestation is limited to one side of the body. Since the trait fails now on one side, now on the other, it is to be expected that it will occasionally fail on both sides at once. The expected number of such bilateral failures can be calculated if it is assumed that occurrence or failure on one side does not prejudice the chances for occurrence or failure on the other side. If there is not such prejudice, and there is no indication that there is, the expected number of failures should be the probable number on the basis of a chance distribution. Proceeding on this basis x may represent the total number of individuals in a population, a , who are of such genotypical constitution as ordinarily to manifest a trait. Then b represents the empirically determined number in which the trait fails to manifest itself on the left side only; c , the corresponding number for the right side; and d , the number in which it does not fail on either side. In addition to these there is the unknown group in which the trait fails of manifestation on both sides. This may be represented by y . Then

$$b + c + d + y = x \dots\dots\dots (1)$$

The incidence of failures on the right side is $\frac{c+y}{x}$ and on the left $\frac{b+y}{x}$.

The incidence of bilateral failures should then be the product of these two values, which by definition equals $\frac{y}{x}$ and this equation may be written

$$(b+y)(c+y) = xy \dots\dots\dots (2)$$

From (1) and (2) it follows that $y = \frac{bc}{d}$, which indicates the theoretical

number of individuals in a given group, a , which genotypically belong to the aberrant class but phenotypically appear to be in the normal group. In the case of the palmaris longus data presented in table 1, $y = 36$ and $x = 457$. This would mean that about 8 percent of the individuals who might show the trait fail to do so. The unilateral cases computed with reference to the value of x is 40 percent and the bilateral cases are 52 percent. It might be expected that if this hypothetical 8 percent (1.6 percent of all individuals) who should fail to show the trait really exist, their presence would be revealed in some instances by the character of the offspring. Two cases which agree with such an expectation have been encountered thus far.

Similar non-appearance of a trait, either unilaterally or bilaterally, is not uncommon in hyperdactyly² (e.g., unilateral 25 times in one series

² BARFURTH (1914) studying hyperdactyly in the feet and wings of the fowl, records similar results and employs a somewhat similar method of analysis.

of 132 subjects in which the condition of the hands are recorded), zygodactyly and some other ordinary anomalies. The value y , which is easily found by dividing bc by d , or which in terms of percent may be indicated as $\frac{100\ bc}{ad}$, should give a clue to the number of cases of non-appearance

which ought to be allowed for in either genetic or statistical studies. Thus, if all cases of hare-lip were hereditary, a failure of appearance should be expected, on the basis of RISHBIETH'S (1912) data, in 18 percent of the cases which would have been genetically capable of showing it. These might erroneously be classed with heterozygous dominants. In the case of the supracondylar process of the humerus, another variation in which there is some evidence of heredity (TERRY 1921), non-appearance might be expected, on the basis of the available figures, to be as frequent as 63 percent of the genotypes. It will be apparent that this non-appearance of a trait is wholly different from recessiveness and needs to be taken into account in dealing with hereditary bilateral conditions whether they be genetically dominant or recessive. Consideration of this factor may help to elucidate some of the numerically aberrant results that are often obtained in certain classes of human pedigrees.

The non-appearance of a trait where it might be expected amounts to "failure of dominance" in some instances and in others to the failure of recessive genes to produce the expected result. This suggests that in this group of traits the factors that are actually being studied are "modifiers." It is possible that all individuals are homozygous for the palmaris longus muscle, the normal presence and arrangement of digits and the ordinary type of most anatomical structures but that some have in addition modifying factors which tend to produce the commonly observed anomalies. Some of these modifying factors, if they may be regarded as such, are relatively potent while others are weak. When a particular type of variation owes its existence to a strong modifier, y will be small and the observed occurrence of the trait close to expectation; when it is due to a weak one, y will be large and difficulty of establishing the presence or absence of heredity greatly increased. Thus, SUMNER and HUESTES (1921) conclude that shifting in the point of attachment of the pelvic arch in *Peromyscus* is not an hereditary trait; but their figures show some excess of bilateral cases, and when tested on the assumption that the condition might be hereditary, a value is obtained for y such as to indicate that between 17 and 18 percent of "normal" mice may potentially represent the abnormal form. When there is a chance that cases of non-appearance are four times as frequent as those in which the trait does

appear the likelihood of getting good Mendelian pedigrees is tremendously reduced and the elimination of heredity as a factor becomes correspondingly difficult.

THE INFLUENCE OF THE TWO SIDES

Less easily brought into line with current genetic ideas is the observed differential incidence of some hereditary traits with reference to the two sides of the body. The factors that influence symmetry are on the whole so little understood that it is hardly expedient to discuss this question beyond emphasizing again that many traits do show a tendency to appear prevailingly on one side. The vast literature on human variation makes this evident. Not only do certain individual variations affecting paired structures show this characteristic, but also some groupings, particularly of vascular arrangement (BEAN 1904, LIPSCHUTZ 1918). Since several of these variations with a bias for one side have been shown to be hereditary, it is difficult to escape the conclusion that in some way the sides of the body, *per se*, exert an influence in determining whether or not a factor represented in the germ-plasm will succeed in producing its full effect. In the case of unpaired and typically asymmetrical organs, what may be an expression of the same influence is so constant as to have been very little appreciated. The mechanism by which such an influence can be exerted is difficult to understand, but the mere existence of the phenomenon as it is revealed differentially by the two sides suggests caution in attributing modifying, intensifying or diluting effects to specific genes until genetic tests have given evidence of the independent existence of such genes.

THE INFLUENCE OF SEX

In differential sex incidence the situation is probably essentially the same, although the difference in the incidence of many variations is greater between the two sexes than between the two sides in the same sex. Thus, to again cite suppression of the palmaris longus muscle, while the trait is only slightly more frequent on the left side, it is about 50 percent more frequent in the female than in the male. The effect of these influences is cumulative, the greatest frequency being on the left side in women, the least on the right side in men. Yet it may be recalled that there is good evidence that the fundamental cause is a factor which is regularly transmitted by heredity. Other traits show differential sex incidences varying through a wide range of values, which indicates that maleness or femaleness of the zygote is by itself a factor which

influences the appearance or non-appearance of certain traits represented in the germ-plasm. These observations suggest that there may be a fallacy in some of the attempts to explain differences in the sex incidence of certain traits (e.g., club-foot?) on the basis of sex-linkage in the ordinary sense. In any event it is clear that sex also is, *per se*, a factor in determining the relative frequency of the appearance or non-appearance of a trait.

Differences in the racial incidence of particular variations are probably chiefly due to the differential distribution of genes with reference to race. But since there is good evidence that sex, and even side of the body, plays a rôle in determining whether or not a trait shall appear, it is easily conceivable that in a similar way the complex which determines race may also act as a factor. Detailed genetic study of favorable traits, among which hyperdactyly is probably one of the best, should ultimately supply an answer to this question.

SUMMARY

Definite variations are found to occur with an average frequency of from 7 to 9 percent in a series of individual anatomical structures which are ordinarily classed as bilaterally symmetrical. Most of these variations find a bilateral expression in some individuals and only a unilateral expression in others.

Several lines of evidence indicate that both the bilateral and the unilateral cases are commonly germinal in origin, and in some cases their heredity has been established. So far as the evidence goes there is no indication that the unilateral appearance of a variation differs genetically from the bilateral.

There is some evidence that most of these traits may best be considered as due to modifying factors that interact with more fundamental determiners for which the species may be homozygous.

Each type of gene has its peculiar degree of potency, which in most cases is such as to admit of certain failures of the trait to appear. This is of considerable importance in genetic analysis, since not infrequently the non-appearance class may be of appreciable size.

The sides of the body and the sex of the individual act as definite influences in favoring or tending to inhibit the appearance of various traits represented in the germ-plasm.

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