

SHORT REPORTS

The distribution of skull asymmetry in man

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Summary. The distribution of human skull asymmetry has been examined by means of a maximum likelihood method and found to be most compatible with a symmetric bimodal distribution.

There is good evidence that in man the two sides of the skull are not equal in size; thus Woo (1930) found that the frontal and parietal bones were longer on the right, while the malar bone was longer on the left. Inglessis (1925) found that the falx tended to be shifted to the right, and Hoadley and Pearson (1929) found the internal length of the skull was greater on the right than the left. It is of some theoretical interest to ask whether such asymmetries relate to other anatomical and/or functional asymmetries. While it would be possible to carry this out directly, for example by assessing skull asymmetry in individuals with *situs inversus*, or left-handedness, this has not, to my knowledge, been done. In this paper I will suggest, on the basis of an analysis of the distribution of skull asymmetry that it might well relate to left-handedness or cerebral speech dominance.

Hoadley and Pearson (1929) examined the right and left internal skull lengths of 729 adult male skulls from the 26th-30th Egyptian Dynasties. The right and left internal lengths were the "internal maximum lengths measured right and left of the median ridges and parallel to the median sagittal plane" (p. 87) using a specially designed pair of calipers obtained from Dr Hans Weinert. Figure 1(a) shows the distribution they describe of $R - L$, the difference in length of right and left sides. This distribution has a mean of 0.994 mm and standard deviation of 1.66. The question of interest is whether this simple normal distribution provides an adequate description of the data. If skull asymmetry is related to either handedness or cerebral dominance, we might expect that about 10% of individuals would show a reversed asymmetry, and that a bimodal normal distribution would be a better fit to the data. A similar argument would apply if skull asymmetry related to *situs inversus*, except that we would expect only 1 in 10 000 individuals to show reversed asymmetry. Since $n = 729$ in the data, the hypothesis in the case of *situs inversus* may be reduced to the proposition that the data are normally distributed. We may distinguish the models by finding their likelihoods (or better, their log likelihoods, or supports) and determining which is the better fit. Table 1 shows the results of this process, maximum likelihood estimates of the parameters in the models being found by a quasi-Newtonian numerical method, since analytic solutions to the equations are not readily available. Model II (a bimodal normal distribution) has a better fit by 6.99 support units than Model I (a single normal distribution). Since Model II also has one more parameter than Model I we may test

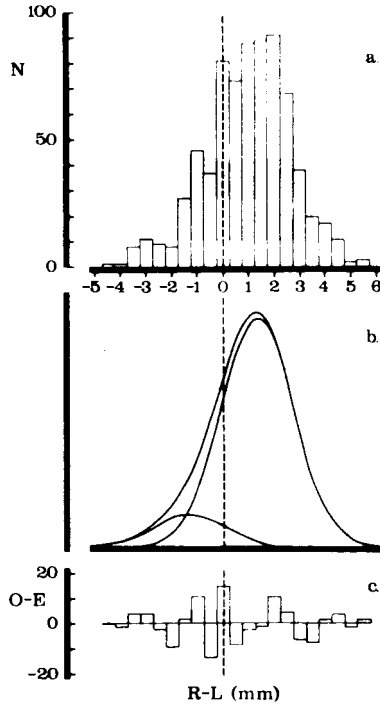


Figure 1. (a) The distribution of skull asymmetry found by Hoadley and Pearson (1929). (b) The fitted distributions for Model II (see text). (c) The differences (observed - expected) between Model II and the data.

Table 1.

Model	Free parameters	Equation of curve†	Maximum likelihood estimates of parameters	Support (log likelihood)	N parameters
I					
Single normal distribution	μ, σ	$y = N(\mu, \sigma)$	$\mu = 0.995, \sigma = 1.664$	-1913.805	2
II					
Bimodal normal distribution	μ, σ, π	$y = (1 - \pi)N(\mu, \sigma) + \pi N(-\mu, \sigma)$	$\mu = 1.321, \sigma = 1.420, \pi = 0.1223$	-1906.818	3
III					
Annett model	μ, σ, π	$y = (1 - \pi)N(\mu, \sigma) + \pi N(0, \sigma)$	$\mu = 1.398, \sigma = 1.533, \pi = 0.2777$	-1912.111	3
IV					
Modified Annett model	$\mu, \sigma_1, \sigma_2, \pi$	$y = (1 - \pi)N(\mu, \sigma_1) + \pi N(0, \sigma_2)$	$\mu = 1.453, \sigma_1 = 1.369, \sigma_2 = 1.806, \pi = 0.3154$	-1907.238	4
V					
Bimodal normal distribution with different means	$\mu_1, \mu_2, \sigma, \pi$	$y = (1 - \pi)N(\mu_1, \sigma) + \pi N(-\mu_2, \sigma)$	$\mu_1 = 1.292, \mu_2 = 1.458, \sigma = 1.428, \pi = 0.1082$	-1906.773	4
VI					
Bimodal normal distribution with different variances	$\mu, \sigma_1, \sigma_2, \pi$	$y = (1 - \pi)N(\mu, \sigma_1) + \pi N(-\mu, \sigma_2)$	$\mu = 1.319, \sigma_1 = 1.420, \sigma_2 = 1.429, \pi = 0.1220$	-1906.817	4

† y = the ordinate of the curve. $N(a, b)$ represents the ordinate of a normal distribution with mean a and standard deviation b .

the significance of this improvement in fit by the conventional method of treating twice the support difference as a chi-squared variate. Hence $\chi_1^2 = 13.97$, $P < 0.001$, a highly significant improvement in fit.

The present data are of some interest since they have also been discussed by Annett (1976), who has proposed that the slight skewness in them may be due to the presence of a second mode with mean zero (and hence consonant with a genetic model of handedness that she has proposed). Model III tests the support for this model (assuming that the distributions have equal variances). Model III does not show a significantly better fit over a single normal distribution ($\chi_1^2 = 3.388$, NS) and is a worse fit than Model II, which has the same number of parameters (support difference = 5.29, likelihood ratio = 198.6). Model III cannot therefore be regarded as fitting the data well. It could, however, be argued that while Annett explicitly states that the variances in the two distributions should be equal, this is not a necessary requirement of her model. Model IV therefore consists of a modification to the Annett model in which the variances are not equal. The model shows a significantly better fit than a single normal distribution ($\chi_2^2 = 13.13$, $P < 0.005$), but despite one extra parameter still shows a slightly worse fit than Model II (support difference = 0.42). Model IV cannot therefore be regarded as an improvement over Model II, unless there were strong theoretical grounds for believing in it. It could be argued that Model II would fit better still if either the means or the variances of the two distributions were allowed to vary (despite any obvious theoretical justification for this). Table 1 shows that Models V and IV do not show a significantly better fit than Model II.

In the interests of parsimony we may therefore regard these skull data as being drawn from a bimodal normal distribution in which the two distributions are mirror-images of one another, and present in different proportions (figures 1(b) and (c)). The maximum likelihood estimate of the proportion in the minor distribution is 12.12%, which is sufficiently close to population estimates of the incidence of left-handedness and of right-hemisphere language dominance to suggest that one or other of these groups may well show reversed skull asymmetry, although obviously only a direct study could demonstrate this convincingly.

Considering Model II only, we may estimate the confidence limits of the proportions of the minor type by using the estimate of the second differential of the likelihood function. This gives 95% confidence limits of 8.7% to 16.9%.

The present method, in the absence of data concerning handedness, is unable to distinguish between the hypotheses that the two modes in the distribution are related to handedness, speech dominance (or perhaps some third factor). However, the work of LeMay (1977) on cerebral asymmetries, as assessed by computerized tomography (CT), and handedness shows that reversed asymmetry (i.e. total mirror-reversed) does not occur in left-handers, although the mean degree of asymmetry is less in left-handers, albeit in the same direction as in right-handers. The implication is that the asymmetry found in the present study, as also in LeMay's study, is not directly related to handedness *per se*. It is recommended that future studies of CT asymmetry use a full metric rather than just a categorical description of the asymmetry.

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Zusammenfassung. Die Verteilung der Asymmetrie des menschlichen Schädels wurde mit Hilfe der Maximum-Likelihood-Methode geprüft und als sehr gut verträglich mit einer symmetrischen, bimodalen Verteilung gefunden.

Résumé. La distribution de l'asymétrie du crâne humain a été examinée au moyen d'une méthode de vraisemblance maximum et a été trouvée la plus compatible avec une distribution bimodale symétrique.