The Genetic Structure of a Tribal Population, the Yanomama Indians

VII. ANTHROPOMETRIC DIFFERENCES AMONG YANOMAMA VILLAGES[1]

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ABSTRACT Anthropometric data on 12 variables in 19 villages of the Yanomama Indians demonstrate significant heterogeneity in physique among villages of this tribe. Mahalanobis' distances (D^2) calculated from the data lead to the tentative conclusion of a general correspondence between anthropometric and geographic distances separating villages. The mean stature of the Yanomama is smaller than that of most other South American tribes which have been measured, and the Yanomama are genetically distinct from the other small Indians as shown by genetic distances based on allele frequencies for a variety of genetic markers.

Since some subjects were measured more than once by the same and by different observers, it was possible to calculate approximate estimates of variance within and between observers. Univariate analysis indicates that face height and nose height are especially susceptible to systematic differences in technique between observers. The variances obtained in this field study compare favorably with those of some classical laboratory studies described in the literature. It was found that measurement error nevertheless probably makes a substantial contribution to anthropometric distance between villages. The median error variance as a fraction of that of Herskovits ('30) is 0.62 for the seven measurements in common with this study. The median value of the error variance for the 12 variables in this study is between 16% and 17% of the total variance.

The biological differences among human groups are produced by a complex mix of biological and cultural determinants. Within a tribe of relatively undisturbed slash-and-burn agriculturalists, the extent of this biological differentiation of sub-groups may be studied unconfounded with the influence of modern civilization. The Yanomama Indians of southern Venezuela and northern Brazil, who have only recently entered into permanent contact with non-Indians, are one of the largest and least acculturated such tribes in South America (Zerries, '55; Chagnon, '68). Living in 100–150 villages of approximately 40 to 250 individuals, they provide an unusual opportunity to study the social and population structure which probably characterized many human groups for the greater part of human evolution (Neel, '72). An extensive biomedical and genetic study of the Yanomama has already resulted in an examination of the variation

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in genetic traits among villages (Ward, '72). In addition, we have collected anthropometric data on adult men and women in 26 villages for a comparison of genetic and morphological differentiation of villages, and for the study of metric variability in its own right.

For traits determined by alleles at a single locus, the extent of genetic variability among socially and geographically defined subunits of primitive or recently acculturated groups has been documented repeatedly (Workman and Niswander, '70; Ward and Neel, '70; Sinnett et al., '70; Friedlaender et al., '71; Ward, '72). The magnitude of this microdifferentiation (see Neel and Ward, '70) contrasts with the impression, apparently intuitive and anecdotal, of relative homogeneity in some remote tribes (referred to in Neel and Salzano, '67). Despite the demonstration of village heterogeneity in traits determined by single loci, it might be suspected that metric traits, influenced by many genes and susceptible to environmental variation, would be less subject to genetic drift or other dispersive effects (Workman and Niswander, '70: 43) so that differences between villages would not exceed those ascribable to random variation. In this paper we present the data and summarize the evidence for anthropometric differences among Yanomama villages, greatly in excess of random differentiation.

We have also extensively investigated measurement error in our data. The measurements reported here were taken by four observers (identified as A, B, C, and D). It is often necessary to combine measurements made by several observers in large studies carried out over several years of field trips. As Neel et al. ('70) have emphasized, the interpretation of small differences between groups always requires a knowledge of measurement error. When in addition, different observers measure in different groups, the opportunities for systematic errors are particularly great. Although some attempt has been made to specify measurement error in previous anthropometric studies (Herskovits, '30; Davenport et al., '34; Steggerda, '42; Majumdar and Rao, '60: 88–90; Neel et al., '70), the contribution to total difference between groups, based on several variables has not been examined so far as we are aware. We have therefore added to this presentation of the data a detailed treatment of measurement error and an assessment of its contribution to observed village differentiation.

POPULATION AND METHODS

Figure 1 shows the location of villages where measurements were obtained. Sampling within each village was of necessity haphazard, but we tried to include all men of estimated age between 18 and 45 years, and all women between 16 and 45. From an original list of 17 anthropometric measurements obtained in the field, we have reduced the data on each individual to those 12 variables (in addition to age and sex) most easily defined with precision and believed to be least subject to inter-observer variability: stature, sitting height, head circumference, calf circumference, forehead height, face height, nose height, nose breadth, head length, head breadth, bizygomatic breadth, and bigonial breadth. The definitions follow Hertzberg et al. ('63) and Schull and Neel ('65). To reduce the role of non-genetic influences on the anthropometric traits examined, we have excluded weight which we presume to be especially sensitive to nutritional variation.

Although a complete comparison (e.g., factorial) design of the four observers' measurements was not possible, data were obtained which permit some treatment of both intra- and inter-observer error for three observers. Observers A and C measured the same series of subjects in one village (11ABC); in another, observer A measured subjects originally measured by B three years earlier. In addition, approximately every tenth subject measured by A or B was measured twice to permit an estimate of intra-observer variability. It was not possible to estimate inter- or intra-observer error with data obtained by observer D. The analysis of measurement error follows the presentation of the results.

Preliminary screening of the data for extremely implausible measurements revealed three men and four women each with a single measurement more than four standard deviations from the mean for that measurement in their sex. These seven "outliers" were removed from the

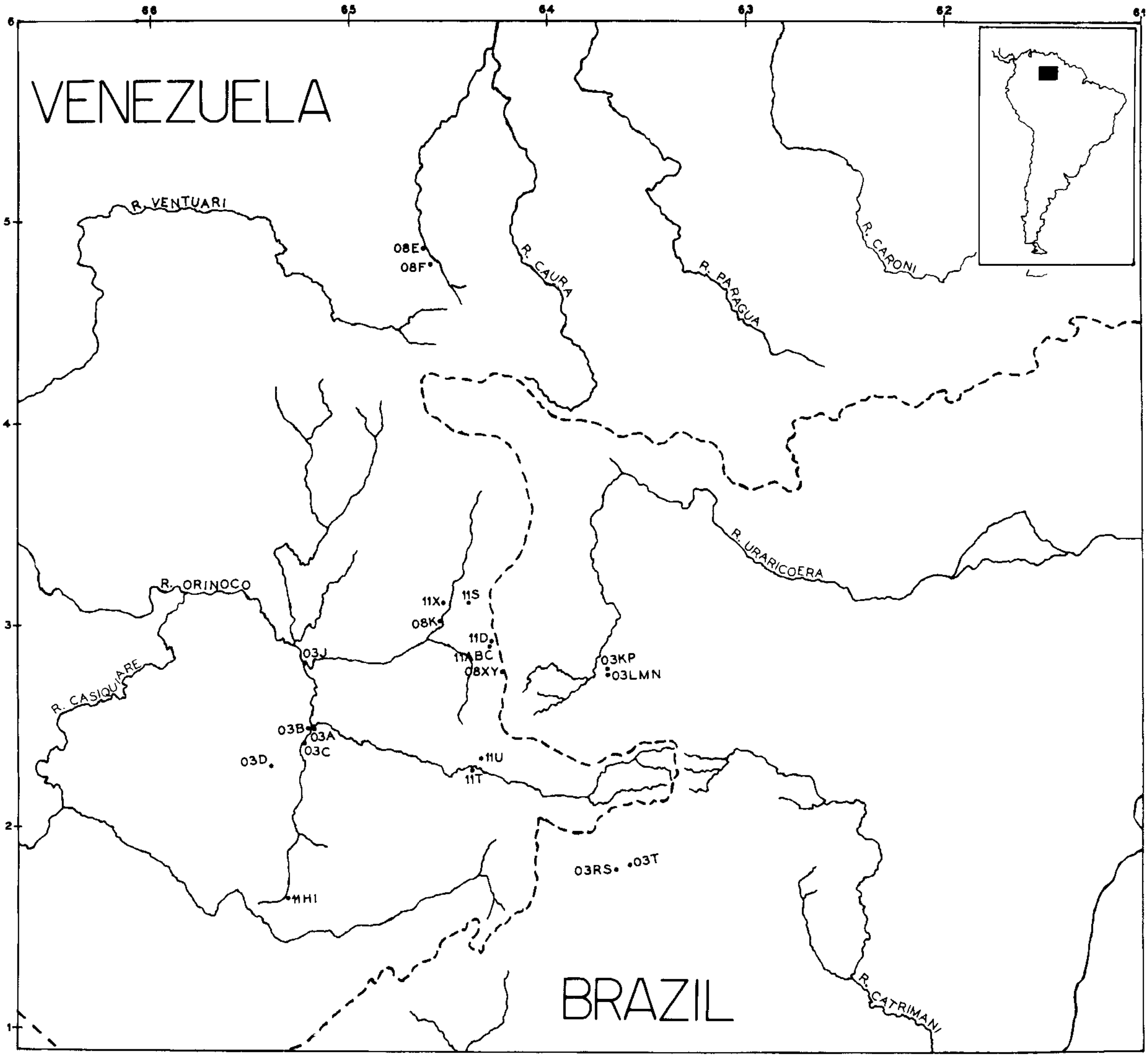

Fig. 1 Location of the 19 Yanomama villages studied.

analysis. After outliers and individuals outside the age limits were eliminated, there remained 316 men and 260 women in the 19 villages with more than 15 measured subjects. Gene frequency data for 14 of these villages have been published (Gershowitz et al., 72; Weitkamp et al., '72; Weitkamp and Neel, '72). In this anthropometric study the closely related villages 03A and 03B of the previous reports have been combined to form the first of the 19 villages, because too few adults were measured in 03B to use it separately. Anthropometric data from five previously unreported villages are included. Gene frequencies for these groups are also available (Layrisse et al., in preparation; Tanis et al., in preparation).

The multivariate statistic used to measure and test the significance of differences in this study is Mahalanobis' Generalized Distance, or D^2 (the square of the Euclidean distance in a space obtained by transforming the original variables to uncorrelated standardized variables; Rao, '52). For each pair of villages, this measure combines the contribution of differences in each of the 12 variables, and weights each difference in proportion (inversely) to both its variability within villages, and its correlation with the other 11 variables. A brief consideration of a few statistical properties of this measure will give some feeling for the significance to be attached to the values which follow.

Although the distribution of $\frac{N_1N_2}{N_1 + N_2}D^2$ approaches χ^2 (Chi-squared) with df equal to the number of variables, it is convenient to evaluate a function of D^2 which is distributed as F:

$$F_{p,k} = \frac{(N_1 + N_2 - p - 1)}{(N_1 + N_2 - 2)p} \cdot \frac{N_1N_2}{N_1 + N_2} D^2,$$

where N_1 and N_2 are sample sizes, p is the number of variables, and $k = N_1 + N_2 - p - 1$. To test the statistical significance of a difference between two populations we convert the D^2 between them to F. For example, the F corresponding to D^2 of 6.272 for two independent random samples, each of size 15 on 12 variables, is 2.38. This value is referred to the F distribution with 12 and 17 degrees of freedom, where it is exactly the 5% critical value. All the D^2's to be tested will be referred to the F distribution. The preceding calculation shows that a comparison of the kind specified requires $D^2 > 6.272$ for a difference to be significant at the 5% level. For two samples of 30 each, $D^2 = 1.876$ reaches significance at the 5% level (Morrison, '67).

Ultimately the goal is to use the distances as a *metric* of morphological differences among villages, not to test the statistical significance of such differences. Provided that some differences are large enough to be clearly distinguishable from random variation, and that departures from the statistical assumptions are not so great as to invalidate the use of distance as such a metric, our concern with the statistical significance of the differences may be minimal. A matrix of distances like table 3 (presented later) might consist entirely of non-significant entries, yet still be informative as a metric of relative differences between villages.

Elsewhere (Spielman, in manuscript (a)) we describe a method for combining measurements on men and women from the same village. Within each sex, all measurements are expressed in standard deviation units from the mean for that sex. After the difference in each measurement attributable to mean sex differences is removed in this way, men and women from the same village are in general much more similar than men and women from different villages. The within-village resemblance justifies pooling the data on men and women from the same village after expressing all data (for each sex) as standard deviations from the mean for the appropriate sex. Throughout this paper, data for the calculation of distance were pooled after standardization. Since the adjustment of the data is a linear transformation which does not affect generalized distance within sex groups, the distances remain directly comparable with those based on measurements of a single sex.

RESULTS

The pooled data, adjusted for differences due to sex, are given in table 1, which includes additional information on villages sampled. The entries for means are in standard deviation units, exactly as used in the distance calculations. Approximate village means in original units (centimeters) may be obtained using the tribal means and standard deviations given at the bottom of the table. The variance-covariance matrix for the data is given in two forms in table 2. The correlations derived from the pooled within-group covariance matrix appear above the principal diagonal. The variances and covariances of the sex-adjusted variables as actually used for distance computation are given in the lower triangle and on the principal diagonal; i.e., they represent the dispersion matrix inverted in the multivariate analysis.

Anthropometric distances

Table 3 gives the 171 distances for all possible pairs of 19 villages. The guidelines for statistical hypothesis-testing indicated earlier may be used in a cautious way with this table. Since the sample sizes are all greater than 15, a D^2 value greater than 6.27 may be declared statistically

TABLE 1

Village size and means for 12 anthropometric measurements in 19 Yanomama villages (sexes pooled after standardization — see text)

Village	Observer	Number measured: Men	Women	Variable[1] 1	2	3	4	5	6	7	8	9	10	11	12
1. 03AB	B	27	35	0.24	0.40	−0.07	0.27	−0.14	0.38	0.81	−0.09	−0.35	−0.20	−0.20	−0.46
2. 03C	B	17	17	0.55	0.63	0.11	0.49	−0.36	0.61	0.80	−0.25	−0.11	−0.31	0.17	−0.47
3. 03D	B	14	19	0.53	0.55	0.23	−0.01	−0.59	0.51	0.49	−0.28	0.11	−0.34	0.14	−0.58
4. 03KP	D	14	13	0.38	0.12	0.84	−0.04	0.69	−0.29	−0.33	0.90	0.40	1.08	1.04	0.21
5. 03LMN	D	11	15	0.01	−0.39	−0.03	−0.16	0.89	−0.42	−0.32	0.96	−0.30	0.39	0.05	−0.03
6. 03RS	D	15	14	0.95	0.37	0.84	0.46	0.58	0.09	−0.13	0.06	0.44	−0.03	0.25	0.67
7. 03T	D	10	12	0.59	0.07	0.81	0.78	1.12	−0.17	−0.09	0.24	0.48	−0.37	0.16	0.51
8. 08E	C	12	5	−0.33	−0.95	1.00	0.54	0.06	−1.19	−0.60	0.04	0.02	1.11	−1.72	0.34
9. 08F	C	8	9	−0.55	−0.63	0.78	0.03	0.38	−0.47	−0.22	−0.01	0.30	1.07	−2.34	−0.81
10. 08K	A	20	0	0.05	0.29	−0.32	0.15	0.06	−0.10	−0.15	0.12	0.15	−0.23	0.11	0.29
11. 08XY	A	25	0	−0.68	−0.87	−0.38	−0.22	−0.25	−0.08	−0.17	−0.28	−0.19	0.07	−0.29	−0.03
12. 11ABC	A	33	35	−0.84	−0.86	−0.48	−0.63	−1.07	−0.37	−0.60	−0.15	−0.34	−0.06	0.17	0.01
13. 11D	A	10	11	−1.11	−0.94	−0.72	−0.47	−0.80	−0.31	−0.48	−0.27	−0.29	−0.29	−0.48	0.12
14. 11HI	A	33	11	0.33	0.75	−0.20	0.60	0.30	0.23	0.03	−0.20	0.24	−0.12	0.31	−0.21
15. 11LQ[2]	A	19	19	−0.13	0.40	−0.17	−0.12	0.14	0.26	0.41	−0.20	0.07	−0.27	0.08	−0.13
16. 11S	A	10	6	0.15	−0.04	−0.15	−0.16	−0.08	0.15	0.24	−0.37	0.07	−0.09	0.17	0.11
17. 11T	A	12	17	0.07	−0.10	−0.43	−0.26	0.33	0.45	−0.05	−0.05	0.01	−0.15	0.24	0.90
18. 11U	A	14	11	0.06	0.22	−0.22	−0.71	0.49	−0.22	−0.83	0.16	0.34	−0.11	−0.01	0.14
19. 11X	A	12	11	−0.27	0.04	−0.08	−0.32	0.23	−0.33	0.13	0.29	−0.05	0.15	0.37	0.46
		316	260												
	Men		Mean	153.20	81.32	53.78	29.25	6.53	11.47	4.76	4.02	18.36	14.77	14.02	10.05
			S.D.	4.94	2.90	1.29	1.59	0.72	0.60	0.34	0.26	0.47	0.41	0.52	0.58
	Women		Mean	142.29	75.76	51.33	27.03	6.07	10.33	4.26	3.60	17.42	14.21	13.20	9.43
			S.D.	4.36	2.75	1.31	1.60	0.73	0.53	0.33	0.24	0.49	0.44	0.48	0.52

[1] Units: standard deviations from the mean (for each sex). Variables: 1. Stat. 2. Sit. hght. 3. Head circ. 4. Calf circ. 5. Fohd hght. 6. Face hght. 7. Nose hght. 8. Nose bdth. 9. Head lngth. 10. Head bdth. 11. Bizygmtc bdth. 12. Bgnl bdth.

[2] Village 11LQ appears as 03J in other studies.

significant. There are 100 such values among the 171 distances. Note however that the sampling is not strictly random, and the observations (individuals) are not independent in the statistical sense, so that the significance level is at best a very rough approximation. The effect of non-independence of observations within a village, the result of including related individuals, is to inflate the significance of the F test by exaggerating the degrees of freedom in the denominator; but even if the degrees of freedom are reduced to only 10 or 11, the largest distances in table 3 remain highly significant.

Generalized distance (D^2) is a summary statistic which conceals the relative importance of the component variables. To identify the measurements which make the largest contribution to overall discrimination, we have used the multiple stepwise discriminant analysis program BMD07M (in the Biomed series, distributed by the Health Sciences Computing Facility, U.C.L.A.), described briefly by Rightmire ('70). Of the 12 measurements, the six which are jointly most important for discriminating among villages are, in order of decreasing contribution: head breadth, bigonial breadth, forehead height, face height, nose breadth, and sitting height.

In order to assess the possible genetic significance of the observed anthropometric differentiation, we need estimates of the heritability of the traits involved. Although in principle, heritabilities calculated for one population from twins need not apply to another, we have followed McHenry and Giles ('71) and used as a measure of heritability the ratio of dizygotic to monozygotic twin pair variances, calculated by Osborne and DeGeorge ('59) for a sample of U. S. twins. Of the measurements reported here for the Yanomama, only forehead height is absent from the twin study; only the 11 measurements in common are considered for heritability. Head breadth, which contributes most to discrimination in the Yanomama, has the highest DZ:MZ variance ratio for the twin sample, and hence presumably the highest heritability. The ranks in DZ:MZ variance ratio of the other measurements important for the discrimination are: fifth (bigonial breadth), seventh (face height), eighth (nose breadth), third (sitting height). To the extent that inference from heritabilities based on U.S. twins are applicable to the Yanomama, it appears that at least one major discriminating trait is highly heritable, but that evidence from the literature for the heritability of the other major discriminating variables is ambiguous.

Measurement error

We have not been able to find in the literature analyses of measurement error for field data like ours, or using a multivariate approach. For this reason, and because the results from this error study will be important for a later comparison of village differences in genetic markers, anthropometrics, and dermatoglyphics, we devote considerable attention here to such an analysis. The errors made in an anthropometric study may be conveniently divided into two kinds. Random error, which increases the variance of a set of observations without affecting the mean, is the less serious type, in the sense that it may reduce apparent significance but does not introduce bias. Systematic errors, on the other hand, occur when the same measurements taken on different occasions differ consistently. Random errors contribute to both intra- and inter-observer differences, and set an absolute lower limit for each; systematic errors are presumably more likely of the inter-observer than the intra-observer variety in this study.

The error study is based throughout on measurements of the same individual made twice, which we call "repeats" when made by the same observer, and "duplicates" when made by different observers. After a preliminary check for heterogeneity among observers, repeats by observers A, B, and C were combined and duplicate measurements made by A and B, or by A and C, were combined. Although eight apparent outliers were found, (pairs of measurements differing by more than four times the standard deviation of the difference between pairs), none was excluded from the repeats or the duplicates by A and C; it was thought self-defeating to eliminate the worst errors from an error study. The A–B duplicates are a special

TABLE 2

Variance-covariance matrix (on diagonal and below) for 12 anthropometric measurements on Yanomama Indians (cf. table 1). Correlation matrix, above diagonal. (See text)

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1	0.7420	0.7251	0.3293	0.3138	0.0546	0.3596	0.3054	0.2167	0.3144	0.2334	0.3663	0.3037
2	0.5213	0.6965	0.3351	0.3488	0.0599	0.3113	0.2431	0.2267	0.3245	0.2745	0.3980	0.2497
3	0.2545	0.2508	0.8045	0.3348	0.2347	0.3049	0.1246	0.2355	0.7859	0.6820	0.5293	0.2181
4	0.2482	0.2673	0.2757	0.8430	0.0340	0.2250	0.0860	0.2621	0.2331	0.2452	0.4093	0.2171
5	0.0387	0.0411	0.1729	0.0257	0.6751	0.0926	0.0149	0.0582	0.2541	0.1848	0.0980	−0.0178
6	0.2881	0.2416	0.2543	0.1921	0.0707	0.8648	0.5717	0.1861	0.3051	0.1861	0.2313	0.1858
7	0.2324	0.1792	0.0988	0.0698	0.0108	0.4697	0.7807	0.1793	0.1120	0.0931	0.1528	0.1370
8	0.1783	0.1808	0.2018	0.2299	0.0457	0.1654	0.1514	0.9127	0.2430	0.1794	0.3590	0.1247
9	0.2642	0.2641	0.6876	0.2088	0.2037	0.2767	0.0965	0.2265	0.9515	0.4344	0.3718	0.2233
10	0.1862	0.2121	0.5664	0.2085	0.1406	0.1603	0.0762	0.1587	0.3924	0.8576	0.5720	0.1434
11	0.2592	0.2729	0.3900	0.3087	0.0662	0.1767	0.1109	0.2817	0.2980	0.4351	0.6748	0.3331
12	0.2417	0.1925	0.1807	0.1842	−0.0135	0.1596	0.1118	0.1101	0.2012	0.1227	0.2527	0.8533

Variables are listed by name in table 4.

TABLE 3

Anthropometric distances between Yanomama villages. Mahalanobis' D^2 below diagonal, $\sqrt{D^2}$ above. See text for guide to approximate significance of D^2.

Village nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		0.96	1.47	2.95	2.84	2.53	2.89	5.07	4.88	2.03	2.40	3.09	2.93	1.96	1.48	1.75	2.81	2.97	2.18
2	0.91		0.88	3.18	3.39	2.58	3.01	5.71	5.60	2.25	2.77	3.15	3.24	1.92	1.65	1.81	3.00	3.18	2.57
3	2.17	0.78		3.09	3.48	2.60	3.21	5.83	5.70	2.32	2.78	2.86	3.13	2.18	1.79	1.80	3.02	2.93	2.63
4	8.71	10.12	9.57		1.58	2.35	2.77	5.19	5.51	2.47	2.69	2.95	3.33	2.94	2.76	2.37	2.60	2.33	1.94
5	8.08	11.52	12.09	2.49		2.53	2.70	4.55	4.75	2.42	2.40	3.19	3.11	3.05	2.87	2.53	2.49	2.35	2.09
6	6.42	6.66	6.78	5.51	6.41		1.20	4.72	5.21	2.58	3.05	3.64	3.69	2.89	2.78	2.36	2.78	2.82	2.64
7	8.37	9.09	10.27	7.70	7.27	1.44		4.87	5.38	2.94	3.44	4.18	4.10	3.17	3.09	2.88	3.24	3.32	2.95
8	25.74	32.65	34.00	26.97	20.74	22.28	23.69		2.17	5.43	4.79	5.73	5.19	5.98	5.76	5.43	5.77	5.71	5.32
9	23.82	31.35	32.43	30.34	22.56	27.13	28.93	4.71		5.40	4.82	5.90	5.19	5.76	5.52	5.47	5.87	5.56	5.44
10	4.13	5.05	5.37	6.11	5.86	6.64	8.67	29.50	29.21		1.76	2.26	1.99	1.21	1.22	1.21	1.47	1.51	1.33
11	5.77	7.68	7.74	7.26	5.77	9.29	11.84	22.94	23.26	3.10		1.59	1.11	2.46	2.14	1.47	1.82	2.35	1.92
12	9.52	9.94	8.17	8.70	10.17	13.22	17.51	32.86	34.80	5.11	2.52		1.27	2.99	2.59	2.02	2.35	2.58	2.28
13	8.60	10.49	9.80	11.12	9.69	13.65	16.83	26.96	26.93	3.96	1.24	1.61		2.83	2.42	2.06	2.18	2.52	2.23
14	3.84	3.67	4.74	8.67	9.27	8.33	10.07	35.72	33.14	1.47	6.05	8.96	7.99		1.26	1.63	2.20	2.16	2.13
15	2.18	2.73	3.19	7.63	8.26	7.70	9.54	33.17	30.51	1.49	4.59	6.72	5.86	1.59		1.29	2.03	2.09	1.45
16	3.07	3.29	3.25	5.60	6.38	5.55	8.30	29.45	29.88	1.47	2.15	4.07	4.26	2.67	1.67		1.52	2.00	1.51
17	7.91	8.99	9.11	6.76	6.19	7.71	10.52	33.33	34.40	2.15	3.33	5.52	4.75	4.85	4.14	2.32		1.69	1.75
18	8.80	10.08	8.60	5.45	5.53	7.95	10.99	32.55	30.94	2.28	5.54	6.66	6.36	4.65	4.36	3.98	2.84		1.91
19	4.74	6.61	6.90	3.75	4.38	6.99	8.73	28.28	29.62	1.77	3.70	5.18	4.98	4.52	2.10	2.27	3.05	3.65	

case, however. The remeasuring for these was done three years after the initial measuring, with attendant opportunities for change of the true measurement by aging, or even mis-identification of the subject. Among the A-B duplicates, we have therefore excluded from the error study two individuals, each with a duplicate measurement five or more standard deviations from the mean difference between duplicates, on the grounds that these differences represent a kind of variation not due to measurement error. (The removal of the two outliers reduced the A-B distance, which will appear later in table 5, by 14% — from 3.185 to 2.668.) There remains a total of 42 repeats (20 by A, 17 by B, and five by C) and 17 duplicates (six by A and B, 11 by A and C).

Table 4 presents a partition of the total (not the within-group) variances. This must be considered a rather crude approximation, since to make inferences applicable to the entire sample of Indians, we must assume that each of the error-study samples, repeats and duplicates, is strictly representative of the larger group. This assumption is embodied in the estimation procedure (see table 4): the variance between repeats has been subtracted from the variance for duplicates to give an estimate of true variance between observers. Similarly, the sum of variance between repeats and variance between observers has been subtracted from the total variance to give an estimate of true variance between subjects. For these purposes, the total variance is based on all 576 subjects in 19 villages, not just on those included in the error study. The median value for the error variance (due to repeats and duplicates) as a fraction of the total is about 17%. The component of the variance due to duplicates (third and fourth columns, table 4) indicates that only two variables, face height and nose height, are highly susceptible to systematic error.

The size of the component of variance ascribable to differences between observers led us to recompute the pairwise distances tentatively excluding face height and nose height. If systematic differences between observers for these two variables make an important contribution to differences between villages, we should expect to find that excluding them would reduce the variability among villages measured by different observers more than it reduces that among villages measured by the same observer. There is, fortunately, a rigorous formulation of this question. The sum of squares of deviations (distances) of n villages from the overall mean is exactly the sum of the $n \times (n - 1)/2$ pairwise squared distances divided by n (Edwards and Cavalli-Sforza, '65). We may calculate the fractional reduction in variance among groups measured by a single observer (pooling over observers) due to removal of the two variables; it is about 13%. Compare this with the reduction in variance among groups measured by two different observers (pooling again over observer-pairs): 9%. Since the two questionable variables apparently contribute less variance to groups measured by different observers than to those measured by the same observer, there is no support for the inference that inter-group distances are spuriously inflated by this kind of observer variance in the data.

It is also desirable to combine such univariate results into composite figures which incorporate variability in all variables at once. The distinction between intra- and inter-observer variability is easily maintained when the analysis is thus shifted to a multivariable setting. Treating a set of individuals measured on one occasion (or by one observer) as a different "village" from the same set measured on another occasion, we can find the distance between repeats or between duplicates, and compare its magnitude with the inter-village distances obtained earlier. The 19-village pooled within-group covariance matrix based on deviations from each sex-mean was used. Table 5 gives such distances, now using $\sqrt{D^2}$ derived from comparisons with six or more cases available. While the distance between repeats is smaller than any inter-village distance in table 3 (upper triangle), the inter-observer D's, especially those between A's and B's measurements of the same six subjects, are large in comparison with the inter-village D's.

If the large inter-observer distances are due to the systematic error in face height and nose height identified in table 4, recalculation excluding those variables

TABLE 4

Measurement error: components of variance (in cm²) for twelve anthropometric measurements in the Yanomama

	N = 42		N = 17		N = 576		
	V_R	Fraction	V_D	Fraction	V_B	Fraction	V_T
1. Stature	0.44	0.02	N.C.[1]	—	21.49	0.98	21.93
2. Sitting height	0.48	0.06	0.75	0.09	6.76	0.85	7.99
3. Head circumference	0.08	0.05	0.32	0.19	1.29	0.76	1.69
4. Calf circumference	0.04	0.02	0.35	0.14	2.15	0.84	2.55
5. Forehead height	0.05	0.09	0.04	0.08	0.44	0.83	0.53
6. Face height	0.05	0.15	0.10	0.32	0.17	0.53	0.32
7. Nose height	0.02	0.16	0.06	0.50	0.04	0.34	0.11
8. Nose breadth	0.01	0.09	0.01	0.17	0.05	0.74	0.07
9. Head length	0.01	0.03	0.01	0.05	0.21	0.93	0.23
10. Head breadth	0.00	0.02	0.00	0.02	0.17	0.97	0.18
11. Bizygomatic breadth	0.03	0.14	N.C.[1]	—	0.22	0.86	0.25
12. Bigonial breadth	0.03	0.10	0.04	0.14	0.23	0.76	0.30

[1] V_D not calculated when $MS_R > MS_D$. MS_R is used as an estimate of $V_D + V_R$.

Definitions: V, variance; MS, mean square; B, between subjects (Indians); D, between duplicates; R, between repeats; T, total.

$V_T = MS_B = V_B + V_D + V_R$

$V_R = MS_R$

$V_D = MS_D - V_R = MS_D - MS_R$

$V_B = MS_B - V_D - V_R = MS_B - MS_D$

should reduce the off-diagonal entries in table 5 appreciably. These supplementary values, given in parentheses (table 5), provide only partial support for such an explanation. Exclusion of the two face measurements reduces the A-C distance by almost 50%, but the reduction of the A-B distance is only about 16%, just what we expect after eliminating two out of twelve approximately equally variable measurements.

We have been able to locate in the literature only two studies in which observer error has been evaluated as in this study. Seven of our twelve measurements were also used by Herskovits ('30) in a sample of 100 individuals measured by the same two observers. The median value of our error variance as a fraction of theirs is 0.62. Using the sum of duplicate and repeat variances in the present study for comparison with the "mean square deviation" of Herskovits, we find that in only one of the seven measurements does our error variance exceed theirs.

Steggerda ('42) asked 21 professional anthropometrists to measure Mrs. Steggerda, as she accompanied him on visits to other laboratories. The resulting data are not quite so comparable with our own as those of Herskovits, but we present a comparison for the sake of completeness. Eight of our measurements were used. In four, the error variance reported by Steggerda is larger than ours, and the median ratio of our error variance to theirs is between 0.87 and 1.01. Unlike Herskovits' subjects and Mrs. Steggerda, the Yanomama were relatively uncooperative subjects, measured under field conditions, greatly increasing the probability of various clerical errors.

TABLE 5

Inter- and intra-observer anthropometric distances, expressed as $\sqrt{D^2}$. Main entries are calculated on all 12 variables; entries in parentheses are calculated with face height and nose height excluded, as described in text.

Observer	A		B	
A	0.329	(0.250)		
B	3.185	(2.681)	0.285	(0.254)
C	1.421	(0.726)		

The analysis of inter- and intra-observer error shows that differences between observers and imperfect replication by a single observer contribute an appreciable error to studies of this type, especially when several observers participate, and they are unable to compare techniques. To the extent that this study is representative, one must conclude that morphological differences found in large bodies of anthropometric data collected by workers trained in completely independent traditions should be evaluated relative to measurement error.

DISCUSSION

Even the approximate significance test used here shows clearly that some of the differences between villages are highly significant; the differentiation in morphology is not merely random variation. It would be desirable to establish whether the Yanomama villages are unusually highly differentiated morphologically, as has been shown for allele frequencies (Neel and Ward, in press). Unfortunately, comparable data from similarly undisturbed groups are not available.

When the relative magnitudes of the anthropometric distances in table 3 are compared with the geographic location and distances (see map), the general correspondence of geographic separation with anthropometric distance is apparent. Two villages (08E and 08F; see figure 1) are very remote geographically and linguistically (Migliazza, in preparation) from the rest of the 19 represented here. They are also clearly the most different from the rest anthropometrically (cf. rows and columns 8 and 9, table 3). Villages in close geographic proximity, like 03AB, 03C, and 03D (villages 1, 2, and 3) are also "close" anthropometrically. With a technique developed for use with multivariate data (Spielman, in manuscript (b)), the comparison of the patterns of geographic and anthropometric differentiation of villages has been extended to all 19 villages. Underlying the method of comparison is a measure of similarity of between sets of data usually represented by dendrograms or trees of relationship. The complete analysis, which includes a comparison of anthropometric and genetic distances, indicates that there is highly significant agreement among geographic, genetic, and anthropometric relationships of villages (Spielman, in manuscript (b)).

Because of their small stature, the Yanomama are distinctive in physique when compared with other South American Indians (see also Zerries, '59; Díaz Ungría, '60). Among 28 tribes represented in Comas' compilation ('71), the Yanomama males are smaller in mean height than all but three, the Irapá, Motilon and Kuaiker. Of these three, the Irapá and the Motilon are subdivisions of the Yupa of East Zulia in northwest Venezuela (Layrisse and Wilbert, '66). As a result of substantial differences in allele frequency at several loci (Rh, MN, Jk, Fy, Di, Hp were used), the Yupa and Yanomama are placed on different branches at the first split of the phylogenetic trees for Indian tribes constructed by Fitch and Neel ('69). The genetic distance between these two groups calculated by the method of Cavalli-Sforza and Edwards ('67) is 0.406 distance units. The third group in Comas ('71) smaller than the Yanomama in mean stature is the Kuaiker of southwest Colombia. Their frequencies of I^A and I^B (close to 0.01 for each) suggest non-Indian admixture, but frequencies for other alleles seem not to be available. Another tribe of small Indians of South America for whom both anthropometric and genetic data are available is the Cashinahua of eastern Peru. Johnston et al. ('71) give the mean height of a group of 38 adult men as 154.7 cm. Using allele frequency data from Johnston et al. ('68) and Johnston et al. ('69) for the six loci listed above, we find that the genetic distance of the Cashinahua from the Yanomama is 0.496, almost 25% greater than that for the Yupa. There are thus at present no data to suggest an especially close relationship of the Yanomama to these other small-statured Indians of South America. Furthermore, we do not find in the distributions of the 12 metric traits used in this study, any indication of the four physical types recognized by Zerries ('59) in some of the same villages where our data were obtained. Consequently, we find no evidence for his inference that the Yanomama are the descendants of several distinct tribes.

We have illustrated the use of the present body of anthropometric data for comparisons of pattern in geographic, genetic, and anthropometric differentiation. We might also ask: "Is inter-village anthropometric differentiation reflected in men and women of a village in similar ways?" The approach to this question has been to partition total anthropometric D^2 into components which correspond to differences in size and differences in shape. It can then be shown that in spite of substantial differences in size between the sexes, men and women from the same village are more similar in shape than men and women of different villages. This finding is interpreted as an indication of fundamental genetic homogeneity within villages, corresponding to genetic microdifferentiation *between* villages (Spielman, in manuscript (a)).

We have documented the anthropometric microdifferentiation of Yanomama villages and suggested the distinctiveness of the tribe. The data presented here also provide direct access to issues in population genetics and anthropology. In conjunction with additional data from the Yanomama, the anthropometric measurements may be used to investigate in detail the character of village differentiation in a tribal population.

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