ANNALS OF HUMAN BIOLOGY, 1994, VOL. 21, NO. 2, 155–169

# Geographical and ethnic variability of finger ridge-counts: biplots of male and female Indian samples

T. KRISHNAN and B. MOHAN REDDY

Indian Statistical Institute

**Summary.** The graphical technique of *biplot* due to Gabriel and others is explained, and is applied to ten finger ridge-count means of 239 populations, mostly Indian. The biplots, together with *concentration ellipses* based on them, are used to study geographical, gender and ethnic/social group variability, to compare Indian populations with other populations and to study relations between individual counts and populations. The correlation structure of ridge-counts exhibits a tripartite division of digits demonstrated by many other studies, but with a somewhat different combination of digits. Comparisons are also made with the results of Leguebe and Vrydagh, who used principal components, discriminant functions, Andrews functions, etc., to study geographical and gender variations. There is a great deal of homogeneity in Indian populations when compared to populations from the rest of the world. Although broad geographical contiguity is reflected in the biplots, local (states within India) level contiguity is not maintained. Monogoloids and Caucasoids have distinct ridge-count structures. The higher level of homogeneity in females and on the left side observed by Leguebe and Vrydagh is also observed in the biplots. A comparison with principal component plots indicates that biplots yield a graphical representation similar to component plots, and convey more information than component plots.

## 1. Introduction

Variability of finger ridge-counts among populations representing various geographic, ethnic and racial groups has been engaging the attention of researchers in dermatoglyphics for the past decade or two. It has been realized that summary measures such as TFRC/ATFRC are not adequate in tracing population relationships, and that a multivariate approach is needed to study finger ridge-counts. Following this realization, many authors have carried out multivariate analysis of finger ridge-count data (see, for example, Knussmann 1967, Chopra 1971, Jantz and Owsley 1977, Jantz and Hawkinson 1979, 1980, Jantz, Hawkinson, Brehme and Hitzeroth 1982, Krishnan and Reddy 1992). One of the most interesting and useful results of these studies has been the demonstration of the universality of a fairly clear tripartite division of digits observed by Siervogel, Roche and Roche (1978), Reed, Norton and Christian (1978), Meier (1981), Santos, Meier and Vieira-Filho (1990) and others. This division consists of digit 1, digits 2 and 3, and digits 4 and 5; digit 4 is unstable, sometimes appearing with 5 and sometimes with 2 and 3.

In a series of papers, Leguebe and Vrydagh (1979, 1981, 1982) investigated the diversity of finger ridge-counts of males and females across the world, and showed that the structure of diversity of ridge-counts on separate fingers differs in the population groups; there is similarity between males and females; however, females are more homogeneous. They also found that the left hand is more homogeneous than the right. They used such multivariate techniques as principal component analysis and discriminant analysis, and such graphical techniques as Andrews functions and canonical variate plots. In a recent paper Jantz, Brehme and Eriksson (1992) have shown that finger variables and palmar main lines are most closely related to language distances after controlling for geography. Correlations with geography generally disappear after controlling for language. Barbujani and Sokal (1991) have reviewed the evidence that there is a general parallelism of linguistic and genetic variation.

Our study here is in the spirit of Leguebe and Vrydagh (1979, 1981, 1982), making use of multivariate and graphical techniques to analyse and represent finger ridge-count data to bring out striking population differences and patterns. There have been many recent developments in the field of exploratory data analysis and graphical representation of multidimensional data, which exploit the power of modern computers. Many of these techniques aim to represent multidimensional data on a graph in such a way that there is as little loss of information as possible in having a two-dimensional representation of much higher dimensional data. For a discussion of these technqiues see, for instance, Wang (1978), Barnett (1981), Greenacre (1984) and du Toit, Steyn and Stumpf (1986). Our aim in this article is to point out the use of one such technique—the technique of *biplot* (Gabriel 1981)—in representing finger ridge-count data of a collection of populations and in interpreting the graphs to study differences in the populations, the variance and correlation structures of the ridge-counts and the relationship between these two aspects. We wish to point out that Hanihara (1993) has recently used the biplot, among other techniques, in an anthropometric study.

## 2. The data set

The data set for the present study was obtained from published as well as unpublished sources. It consists of mean ridge-count (larger of radial and ulnar) of each of the 10 fingers from samples of 117 male and 59 female Indian populations and 36 male and 27 female non-Indian populations. Excepting for a couple of populations the sample sizes are generally 50 or more, and, in most cases, above 100. The Indian populations inhabit different regions, although certain states are disproportionately represented; since the data are from secondary sources there is no way a balance could be achieved. The data set is dominated by two states—Andhra Pradesh in Southern India and Maharashtra in Western India—and these states contribute to about 50% of the total samples. This is due to the fact that a large number of investigations have been carried out in these states. However, the western region is represented by only one female sample. Except for Europe, all the other regions provide less than 10 male samples and less than five female samples each. Nevertheless, the data set does provide a vast canvas covering most areas of India and the rest of the world.

These Indian populations represent all strata of the Indian society, from tribes to upper-caste Brahmins, encompassing different social hierarchies in between, such as the middle-ranking agricultural castes and low-ranking castes ranging from shepherds to the traditionally untouchable Harijan castes.

Although Leguebe and Vrydagh (1981) included only about 10% of the number of Indian samples that we have covered, their data set represents the world more comprehensively. The data set that we could assemble, mainly from published material, contains only a few samples outside India. We thus set our objective in this study as the understanding of the variation within Indian populations of finger ridge-counts, with a few non-Indian populations included for comparison; a secondary aim of our study is to compare this variation with the nature of the world variation exhibited in the studies of Leguebe and Vrydagh (1981). There is another aspect that restricted our attempts to collate published data: since the late 1970s the convention has been to present ridge-count data separately for radial and ulnar sides, instead of the larger of the two, which is what we have taken for the present study. It appears that an analysis of 20 counts, radial and ulnar separately, might have been more informative. But such an attempt would have restricted the data set to very few populations; such a study has already been carried out by one of us (Krishnan 1991) for a small homogeneous group of subsaharan African populations. Our attempts to obtain unpublished data relating to non-Indian populations from individual authors were not successful; however, we were able to obtain a large number of data sets on Indian populations from Indian sources.

We classified our populations into regions within India and outside; the numbers of male and female populations in our data set from these regions are given in table 1. We also classified the populations by ethnic and social groups, and this classification, with the numbers of male and female populations in our data set from these classes, is given in table 2. The complete data set, together with these classifications and the reference of the source, can be obtained from the authors; besides the mean, it also contains sample sizes and standard deviations. However, the data we use here are the

Table 1. Number of male and female populations in various regions†.

| Region | Number of populations | |
|---|---|---|
| | Male | Female |
| Southern Andhra | 29 | 22 |
| Northern Andhra | 20 | 20 |
| Maharashtra | 36 | 1 |
| Madhya Pradesh | 4 | 4 |
| Uttar Pradesh | 7 | 3 |
| Rajasthan & Punjab | 6 | 1 |
| Bengal | 9 | 5 |
| Assam | 6 | 4 |
| Tibet & Bhutan | 3 | 2 |
| Europe | 14 | 14 |
| America | 3 | 3 |
| Australia | 6 | 2 |
| Africa | 3 | 3 |
| Middle East | 7 | 2 |
| Total | 153 | 86 |

†Southern Andhra consists of Krishna district and southwards, the rest of Andhra Pradesh falling in Northern Andhra. 'Bengal' also includes a sample of Nicobarese. 'Australia' includes whites and aborigines of Australia as well as Papua New Guinea and Indonesia.

Table 2. Number of male and female populations in various ethnic/social groups†.

| Ethnic/social groups | Number of populations | |
|---|---|---|
| | Male | Female |
| Upper castes | 21 | 11 |
| Middle castes | 17 | 6 |
| Lower castes | 45 | 19 |
| Australoid tribes | 20 | 16 |
| Mongoloid tribes | 14 | 9 |
| Caucasoid tribes | 2 | 0 |
| Others‡ | 34 | 25 |
| Total | 153 | 86 |

†Based on traditional social hierarchy and economic strength, the Indian castes are categorized into upper, middle and lower; upper caste consists of Brahmins, Kshatriyas and Vaisyas, middle caste of land-owning agricultural groups and lower caste circumscribe artisan groups, and traditionally untouchable scheduled and backward castes.

‡All non-Indian groups irrespective of ethnic affiliations are included in the 'Others' category.

means of the 10 finger ridge-counts for each of the 239 populations. It is possible to carry out the biplot computations with each data point appropriately weighted for differing sample sizes and standard errors; we chose not to do this, in order to keep the analysis and computations simple. We admit, however, that such an analysis may have produced a picture of the ridge-count structure of the populations in a better manner and with less distortion.

## 3. Biplot

The biplot technique developed by Gabriel (1981) is a graphical technique in which the data matrix, or a suitably preprocessed version of it, is represented with the help of row markers as well as column markers; in our data set the entire data will be represented on a graph in such a way that both the populations and the 10 ridge-counts are simultaneously represented in the graph. The representation is obtained by approximating the given $n \times p$ data matrix by a product of an $n \times 2$ and a $2 \times p$ matrix. The rows of the $n \times 2$ matrix are row markers and the columns of the $2 \times p$ matrix are the column markers. The inner product between a row (say the $l$th) and a column (say the $j$th) gives an approximation to the $lj$th element of the data matrix. This representation displays the scatter of the rows (populations) as well as the configuration of the columns (ridge-counts); that is, the distances between the rows (populations) are preserved as much as possible and the variances of the columns (ridge-counts) and the correlations between them (ridge-counts) are preserved as much as possible; also the plot relates the rows with the columns; the column in whose direction and neighbourhood a row lies displays higher values of that variable. The row and column markers are distinguished by representing rows as points and columns by arrows. The length of the arrow is approximately proportional to the variance of the variable, and the cosine of the angle between two arrows represents approximately the correlation between the two variables. For this display it is convenient to take the average of the biplot points as the origin; this is what we have done in our plots. The mathematical technique of obtaining the biplot is via the singular value decomposition of the data matrix. It is also possible to modify the biplot to weight the variables. For details see Gabriel and Zamir (1979) and Gabriel (1981).

When the number of rows is very large, as is the case with our data set, representing each row as a point makes the display very crowded. If the rows are grouped—into regions or ethnic/social groups as in our case—then the groups can be represented by the centroids (mean vectors) of the points in the group; however, this kind of biplot has only limited use, since the differences between elements within the groups are not represented in the graph. In such cases a nice way of displaying the rows is to use a *concentration ellipse* for each group of points (see Dempster 1969, Gabriel 1981). A concentration ellipse is a two-dimensional analogue of a one-standard-deviation interval about the mean. The centre of the concentration ellipse of a group is the centroid (mean vector) of the elements of the group, and its shadow in any direction is the one-standard-deviation interval about the mean of the variable displayed in that direction. The concentration ellipse thus displays the mean and scatter of the elements belonging to the group and represents the large number of points by a simple figure.

The biplot is not only one of a number of multidimensional techniques for dimensionality reduction and graphical display of data. Many of these techniques can be viewed in a unified manner in the framework of correspondence analysis (see

Greenacre 1984), which is a collection of techniques for the reduction and representation of a $n \times p$ data matrix, especially a two-way contingency table. A unifying mathematical idea of all correspondence analysis techniques is the *singular value decomposition*. In these techniques the data matrix undergoes preprocessing, such a centring, etc., before singular value decomposition is applied to it; further, the results of the singular value decomposition are normalized and scaled before presenting them graphically. Various ways of preprocessing, normalizing and scaling produce the different techniques, which include principal component analysis and biplot. Greenacre (1984, pp. 348–349) presents an interesting table listing the various techniques, showing what preprocessing, normalizing and scaling operations lead to them. One of the unique features of the biplot in this collection of techniques is the possibility of reproducing the data, at least approximately, from the final results. In the other methods in this collection, starting from the $n \times p$ data matrix, one calculates a function of the matrix (e.g. covariance or correlation matrix for principal components) and produces a representation of the matrix by metric or non-metric methods; in such cases one cannot even approximately reproduce the data matrix from the representation (see Gabriel 1984).

Both the principal components plot and the biplot display row points as orthogonal projections of $p$-dimensional points on to the best-fitting two-dimensional subspace. While in the principal component plot the row points are considered in Euclidean space, in biplot they are considered in the Mahalanobis space. Thus, the principal component plot approximates the Euclidean distance between rows and the biplot approximates the Mahalanobis distance between rows. Generally principal component analysis is carried out by computing the spectral decomposition of the correlation or the covariance matrix and plotting row points; however, by carrying out a singular value decomposition of suitably preprocessed data matrix and normalizing and scaling the results suitably, row points as well as column points for principal components can be obtained in a manner analogous to the biplot described here (see Gower and Digby, 1981, pp. 90–91). But this is not usually done. For interpretation the main differences are that (i) in biplot row markers can be viewed in terms of Mahalanobis distances, whereas in principal component plot they can be viewed in terms of Euclidean distances; (ii) in biplot the column markers can be viewed in terms of variances and correlations, whereas in the principal component plot there seems no such useful interpretation. Thus we believe that, compared to principal component plots, the biplot contains more information, and more interpretable and useful information at that.

## 4. Finger ridge-count plots and interpretation

### *4.1. The plots*

The biplot of our finger ridge-count data is presented in figure 1 (see also Key to figures below). Here we have only given the plot of geographical groups and not the individual populations; for the number of individual populations is very large and the display with all these points will make it very crowded. When we present the arrows (for the ridge-counts), as well as points for the populations, the points are not that well spread out; thus one could say that the differences between populations in ridge-counts are not that overwhelming. Anyhow, in order to be able to see population differences in a better light we have presented another biplot, where the arrows are omitted and the display is blown up; this is presented in figure 2. In a later plot we get over this problem by representing each region by its concentration ellipse. To obtain this plot we computed the biplot coordinates of the 239 populations using the 239 × 10 data matrix and computed the centroids (the mean vectors) of populations belonging to each gender of each of the 14 regions. These centroids are plotted as points: the 10 ridge-counts are plotted as arrows starting at the centre.

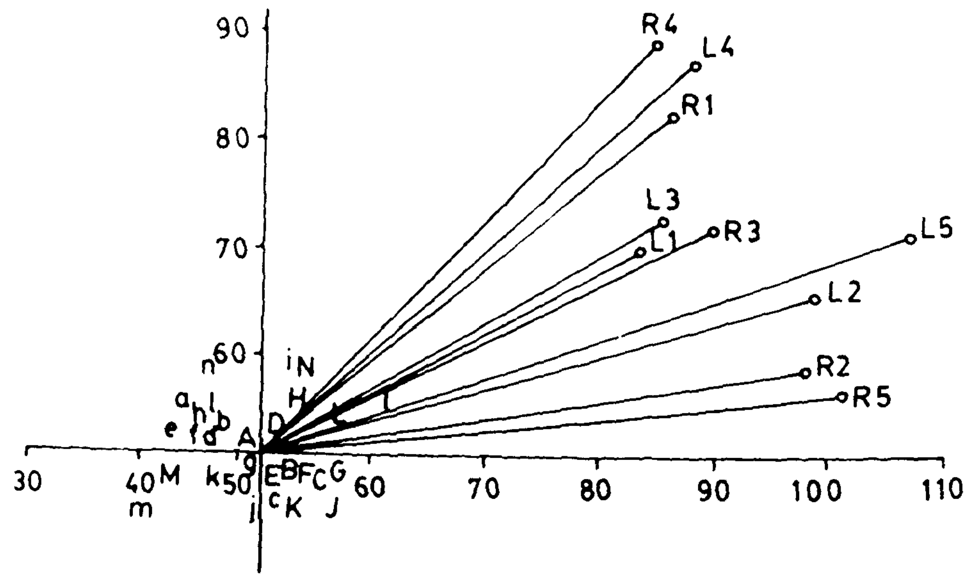

Figure 1. Biplot of finger ridge-counts by region and gender.

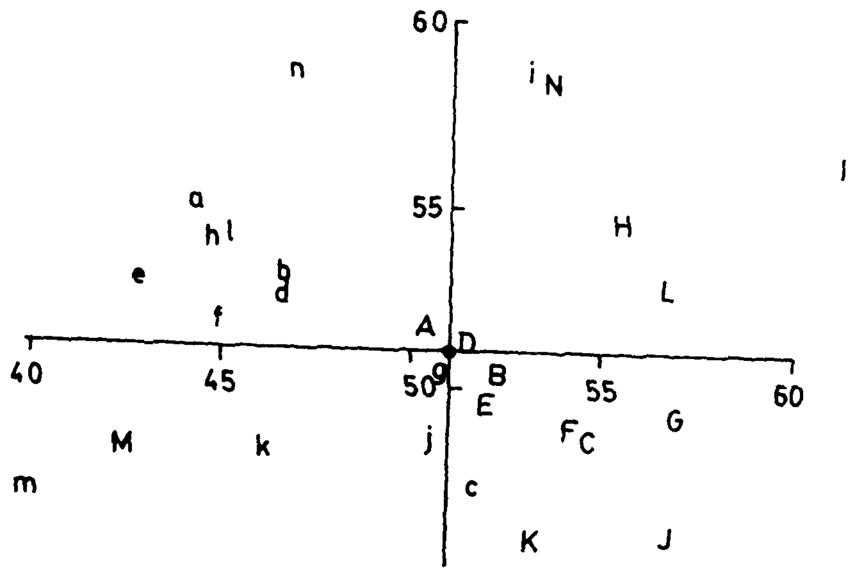

Figure 2. Centroids of biplot coordinates by region and gender.

*4.2. Variance and correlation structure of finger ridge-counts*

Now let us study the biplot. From the plot we obtain a representation of the variance and correlation structure of the ridge-counts, the similarity structure of the populations as well as the relationship between ridge-counts and populations. These variances and correlations are those obtained from the columns of the data matrix and hence they are obtained in terms of the means of populations. They are therefore not exactly the same as the variances and correlations as might be obtained from observations on individual members of populations.

Let us first study the ridge-counts. A study of the lengths of the arrows denoting the ridge-counts shows which counts have a large variance and which have a small variance. Digit 5 has the largest variance, followed by digit 4, 2, 3 and 1. Left-hand ridge-counts have somewhat larger variation than right, a fact noticed by Leguebe and Vrydagh (1981). The angles between these arrows represent the correlations; the smaller the angle, the more highly correlated they are. A striking feature of this biplot is that all the arrows lie in the first quadrant, clustered together. This means that there are no negative correlations. The structure of the correlations exhibited by the biplot is as follows. Homologous pairs of digits exhibit a fairly high level of correlation. There are, however, other pairs, which exhibit a higher level of correlation than some homologous pairs. For instance, the highest of R4 is with L4, but of R2 is with R5. The correlations between homologous counts L5 and R5 and between L1 and R1 are not so high. From the biplot, in terms of the correlation between pairs of homologous counts, the digits can be arranged in decreasing order as 4, 3, 1, 2, 5. However, taking into account the positions of the left digit as well as the right digit in the biplot, the five digits can be arranged in the order 4, 1, 3, 2, 5, or rather as a tripartite division of 4, 1 & 3, 2 & 5. This does to a large extent support the tripartite theory, but with a different combination from the ones other studies have revealed; other studies have found the tripartite division to be 1, 2 & 3, 4 & 5 (see Siervogel *et al.* 1978, Reed *et al.* 1978, Meier 1981, Santos *et al.* 1990, Krishnan 1991, Krishnan and Reddy 1992). Apart from this there does not seem to be any clear-cut structure in the correlations. On the other hand, when we considered radial and ulnar counts separately, of the subsaharan African populations, the correlation matrix and hence the biplot exhibited a much clearer structure, reflecting the tripartite division of digits 1, 2 & 3, 4 & 5 (see Krishnan 1991, Krishnan and Reddy 1992); the reasons for this may be three-fold: the heterogeneity of the populations; the differing sample sizes and standard errors of the means; summarizing the 20 counts into 10. However, on the whole the biplot does represent the population ridge-count structure fairly well.

*4.3. Geographical variation*

The first striking feature of the biplot with respect to the populations is that males are much closer to the lines representing the ridge-counts, indicating that males have larger ridge-counts than females. For females, relatively, ridge-counts of digits 4 and 1 are higher. Tibet and Bhutan have on the whole larger ridge-counts, as is the case with Mongoloids in general, as seen later. The Middle East has relatively large ridge-counts with respect to digit 4. European populations have higher counts on digits 2 and 5. African populations have on the whole the lowest ridge-counts. American populations have on the whole somewhat low ridge-counts. European and African populations are fairly close, and they also exhibit a certain amount of similarity to American populations. Middle Eastern and Tibeto-Bhutan populations are on the other side of the plot; they have quite a different ridge-count structure from the rest of the world.

The closer affinity between Middle Eastern and Tibeto-Bhutan populations can be explained by the fact that five of the seven Middle Eastern populations are Turkman groups with Mongoloid element as is the case with Tibeto-Bhutan populations. The Indian and Australian populations are in the middle of the plot and form a fairly close cluster. The reason for the Australian populations to group with the Indian populations is perhaps the inclusion of aboriginal populations in the Australian group. These findings, although based on a limited number of samples, are in general conformity with the earlier observations on racial and geographical variations based on a large number of genetic loci, archaeological and linguistic evidence (Nei and Roychoudhury 1974, 1982; Cavalli-Sforza, Piazza, Menozzi and Monntain 1988; Nei and Livshits 1989). Their observations converge, broadly supporting Africans being closer to Europeans than to Asians or Australians, while Europeans and Asians are closer to each other when compared to Africans. The present findings based on finger ridge-counts seem to fall in line. Given that dermatoglyphs are polygenic, stable age-wise and environmentally, and are probably selectively neutral, the usefulness of dermatoglyphic traits in portraying prehistoric relationships may be conjectured as apparent here; as several earlier authors have observed, dermatoglyphs may not be useful in portraying local and recent microevolutionary histories (see Rothhammer *et al.* 1979, Meier 1980, Jantz *et al.* 1982). Although Babler's (1978) fœtal evidence and Rosa's (1983) climate correlations of dermal ridge-counts may be claimed as indirect evidence for the operation of natural selection, the direct evidence in the form of differential fertility and mortality of individuals with different ridge-counts is not forthcoming (van Valen 1963, Loesch and Wolanski 1985).

Although broad geographical contiguity is reflected in the relative positions of populations on the basis of finger ridge-counts, it is not so in minor details. For

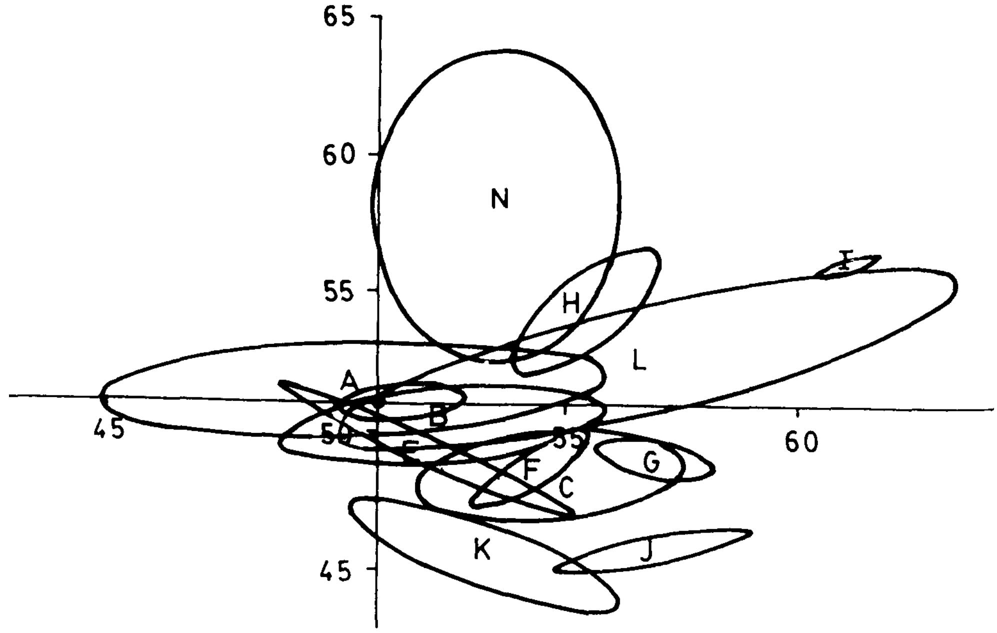


Figure 3. Biplot concentration ellipses of regions (males).

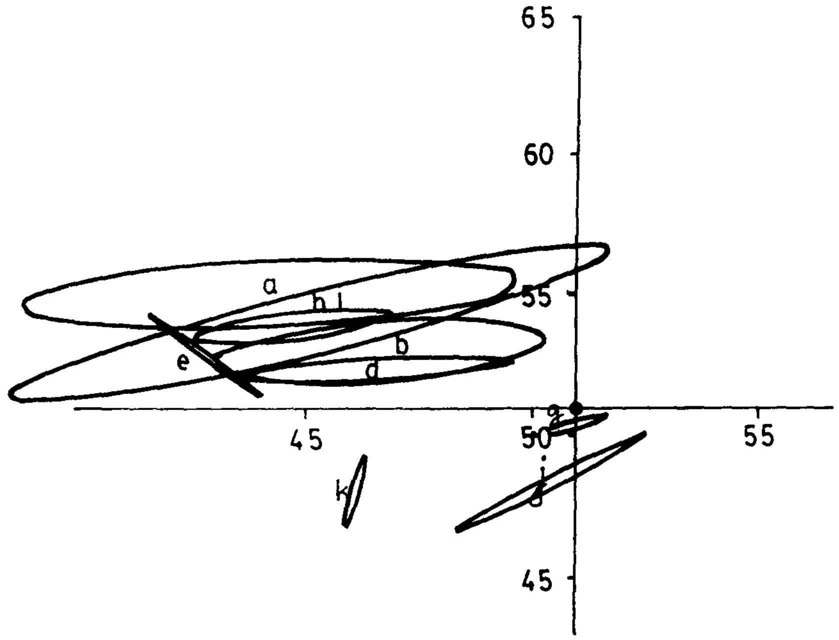


Figure 4. Biplot concentration ellipses of regions (females).

example, populations from Madhya Pradesh are placed in between Northern and Southern Andhra populations, while the latter two are placed somewhat more divergently between them. Similarly, Uttar Pradesh populations are more proximately placed to Northern Andhra groups when compared to the other Hindi-speaking populations. However, populations from Maharashtra and Rajasthan & Punjab are placed closest to each other, conforming to the geographical pattern. The populations from Assam are, however, far removed from the rest of the Indian populations, and placed relatively close to other Mongoloid populations from Tibet & Bhutan, Indonesia and the Middle East. This pattern among females is somewhat consistent with that of males when the single sample from Maharashtra is ignored. However, males seem to be relatively more dispersed compared to female populations.

Figures 3 and 4 present the concentration ellipses for males and females, respectively. Comparing figures 3 and 4 it is clear that males have larger variation than females; this was also the conclusion of Leguebe and Vrydagh (1981). The groups within which variations are large are the Middle East and Australia, followed by Southern Andhra and America. Tibet & Bhutan display a small variation. There are large overlaps among the groups, the ellipses crisscrossing with each other. Among females, only Australia displays a large variance (there are only two samples though).

### *4.4. Social/ethnic group variation*

Figures 5 and 6 present concentration ellipses for various social/ethnic groups for males and females respectively. The centres of the ellipses represent the centroids of the groups and the spread of the ellipses in a given direction represents the standard deviation of the variable displayed in that direction. Our interpretations below are based on these ellipses as well as a biplot of these groups similar to figure 1 for regions

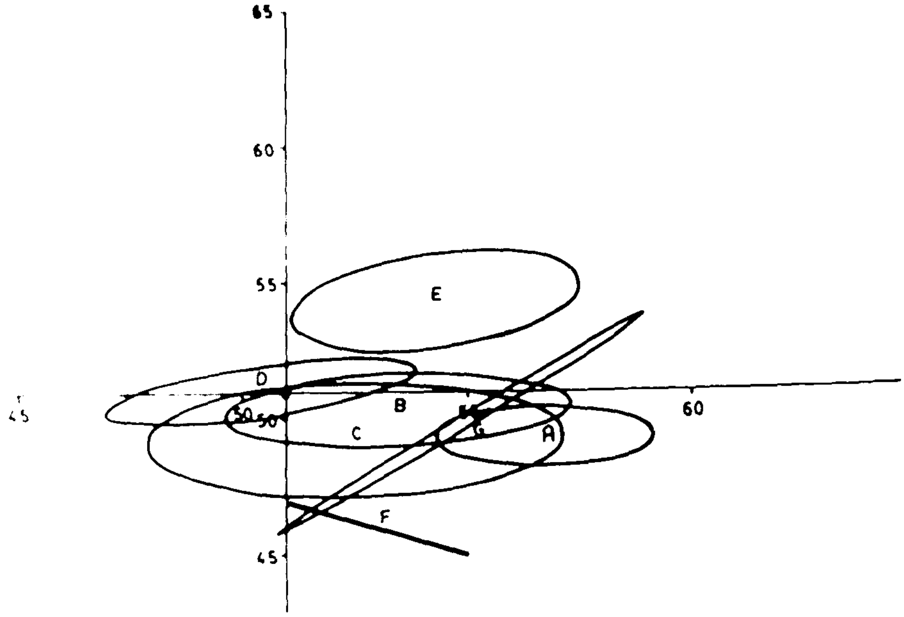


Figure 5. Biplot concentration ellipses of social/ethnic groups (males).

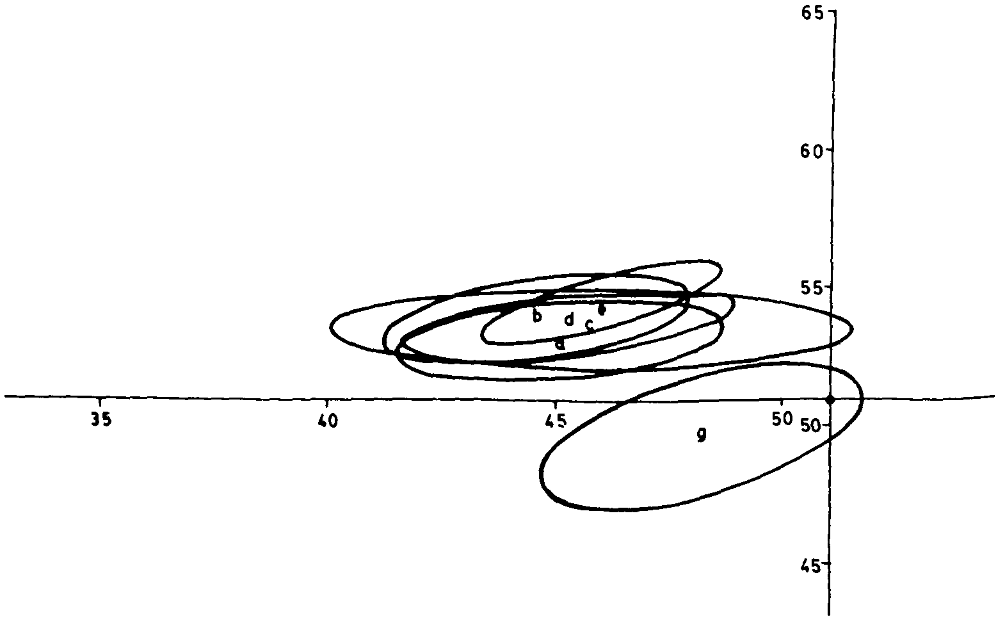


Figure 6. Biplot concentration ellipses of social/ethnic groups (females).

(which we have not presented). The configurations of the groups reflect only a limited amount of similarity. The male counts are mostly in the fourth quadrant and the females in the second quadrant. Thus males have relatively higher counts in digits 2 and 5 and females in 1 and 4, as pointed out earlier. Mongoloid males have larger counts on the whole, since the point lies in the first quadrant; however, Mongoloid females have only slightly larger counts than other female groups. The Caucasoid males have quite a different structure representing rather low counts in digits 4, 1 and 3, and relatively larger L2 and R3 counts. These patterns are consistent with what was observed with respect to the regions. The lower-caste Indian group has a large variation, and so also do the Mongoloid tribes. The Indian castes are close to each other in males as well as females. The Caucasoid tribes display small variation, probably due to the fact that they are represented by only two samples. The Mongoloid and Caucasoid tribe males seem distinct in the sense that their concentration ellipses do not intersect with any other ellipse. The Australoid tribe male group is in the middle of the plot. This is consistent with the evidence that these Australoid tribals were the original (autochthonous) inhabitants of the Indian subcontinent, before the Aryan invasion. The relative amount of overlap in the ellipses of the three caste categories and the Australoid tribes is also in order, given the ethno-historical interactions, especially after the so-called Aryan invasion. This may suggest that the finger ridge-counts subtly reflect even the historic relationships among the Indian populations. In females the 'Other' group's concentration ellipse does not intersect with any other. This is quite expected given that this group constitutes mostly non-Indian populations along with a few Indian groups which do not fall into traditional caste hierarchy; for example Muslims, Parsis, etc. The other ellipses crisscross, and there is much overlap in the scatter of the other groups. Even in this, there is a subtle indication of the relatively newer Mongoloid tribals being somewhat divergent from the rest.

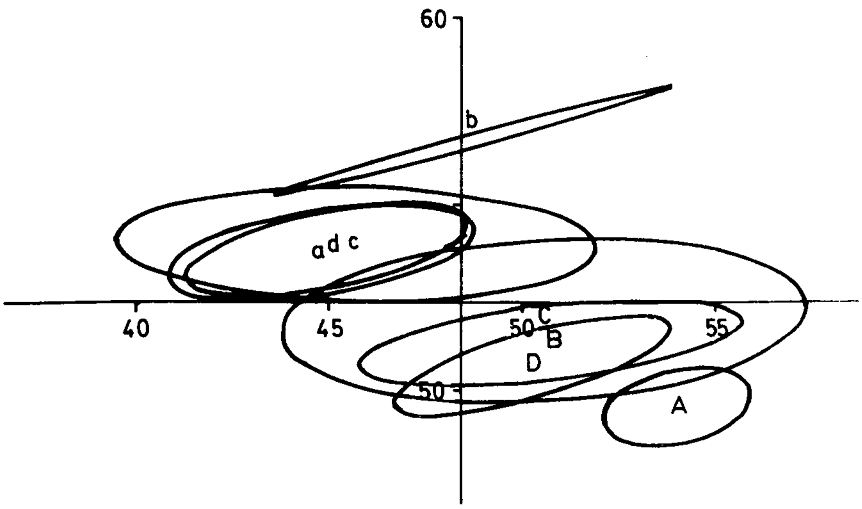


Figure 7. Biplot concentration ellipses of Andhra populations by social/ethnic groups and gender.

*4.5. Ethnic variation in Andhra Pradesh*

As already mentioned, a large number of sampled populations (49 male and 42 female) are from Andhra Pradesh and represent diverse socioeconomic groups, such as upper, middle and lower castes and the Australoid tribes. To examine the finger ridge-count variation within a linguistically homogeneous area, we have drawn separate plots for this region (figure 7). The relative positioning and the overlap of concentration ellipses somewhat mimic the overall Indian pattern. The lower castes show very large variation, which circumscribes the entire middle caste ellipse and most of that of the Australoids. The overlap of upper castes, as expected, is minimal, and is even more distinct compared to the all-India pattern. This could be an artefact of pooling geographically heterogeneous groups under a single ethnic/social category, thus increasing the within-category variation in the case of the latter. However, in the case of females, as in the all-India pattern, there is much greater overlap compared to males; unlike in males the concentration ellipses of middle castes rather than the upper castes lie somewhat in the periphery.

*4.6. Comparison between biplots and component plots*

In order to compare biplots with principal component plots we computed the first two principal components of the ridge-counts and made plots similar to the biplots described above—plots of region centroids and ethnic/social group centroids by gender and concentration ellipses for regions and social/ethnic groups for males and females. However, we present only the plot of the region centroids in figure 8. However, the following interpretations are made taking into account all the plots that we made. A comparison of biplots and principal component plots is valid only with respect to the relative positioning of the groups, and not the actual coordinates of the points; for the two biplot coordinates do not have any particular interpretations and

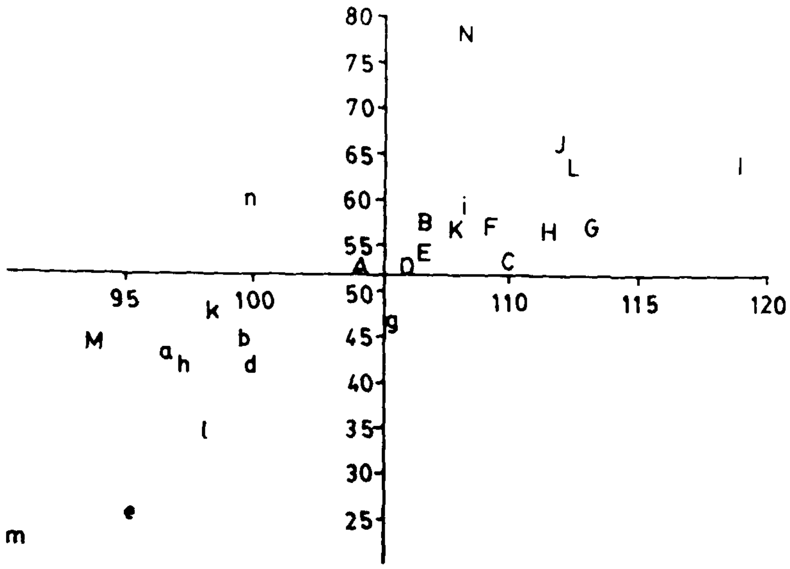


Figure 8. Centroids of principal components by region and gender.

they are not directly comparable to the principal components. There are many similarities between these plots and the biplots. Male and female populations are separated out quite clearly. Tibeto-Bhutan females lie among the male groups. African males lie among the female groups. Madhya Pradesh and Southern Andhra are in the centre of the plots. The Middle East and Australia are away from the other regions. A striking difference between these plots is that the American male group is away in the biplot whereas this group is well within the other groups in the principal component plot. A comparison of the concentration ellipses, of course, leads to the same conclusions as to the positioning of the ellipses. However, for reasons mentioned above, the configurations of the ellipses need not be similar in the two plots. We notice, however, that there is a strong similarity in the position of the ellipses, and their sizes, in the two plots. The biplot ellipses are somewhat more spread out than the principal component ellipses and hence more useful. There are some differences—for the Bengal male group principal component ellipse is wider than the biplot ellipse; for Andhra groups the biplot ellipses are more spread out than principal component ellipses.

In conclusion the biplot, an alternative to principal component analysis, is able to capture the essential differences between the various populations in respect of their finger ridge-counts and to relate populations with individual counts. When used to study geographical and gender variations the biplots bring out the features of geographical and ethnic variability, especially within India, that Leguebe and Vrydagh's studies bring out for the world populations, with only a few minor differences. As pointed out in §3, since the biplot represents Mahalanobis distances and the principal component plot the Euclidean distances, there are bound to be some differences in the plots. We believe that the biplot is a better representation since the Mahalanobis distance is a better metric, taking into account the differing variances of the ridge-counts and their correlations. Unlike the principal component plot, the biplot also relates the ridge-counts with the populations and hence gives more information.

***Acknowledgements***

The authors thank two anonymous referees, whose comments helped in removing some errors and in improving the presentation.

**Key to figures**

*Area codes:*

(upper case: male; lower case: female).

A, a: Southern Andhra; B, b: Northern Andhra; C, c: Maharashtra; D, d: Madhya Pradesh; E, e: Uttar Pradesh; F, f: Rajasthan & Punjab; G, g: Bengal; H, h: Assam; I, i: Tibet & Bhutan; J, j: Europe; K, k: America; L, l: Australia; M, m: Africa; N, n: Middle East.

*Social/ethnic group codes:*

(upper case: male; lower case: female).

A, a: Upper castes; B, b: middle castes; C, c: lower castes; D, d: Australoid tribes; E, e: Mongoloid tribes; F, f: Caucasoid tribes; G, g: Others.

## References


BABLER, W. J., 1978, Prenatal selection and dermatoglyphic patterns. *American Journal of Physical Anthropology*, **48**, 21–28.

BARBUJANI, G., and SOKAL, R.R., 1991, Zones of sharp genetic change in Europe and also linguistic boundaries. *Proceedings of the National Academy of Sciences, USA*, **87**, 1816–1819.

BARNETT, V. (ed.), 1981, *Interpreting Multivariate Data* (New York: John Wiley).

CAVALLI-SFORZA, L.L., PIAZZA, A., MENOZZI, A., and MONNTAIN, J., 1988, Reconstruction of human evolution: Bringing together genetic, archaeological and linguistic data. *Proceedings of the National Academy of Sciences, USA*, **85**, 6002–6006.

CHOPRA, V.P., 1971, Biostatische Analyse der Hautleisten von Geistig Gestorten Kindern. In *Hautleisten und Krankenheiten*, edited by W. Hirsch (Berlin: W. Hirsch), pp. 341–362.

DEMPSTER, A.P., 1969, *Continuous Multivariate Analysis* (Reading, Mass.: Addison-Wesley).

GABRIEL, K.R., 1981, Biplot display of multivariate matrices for inspection of data and diagnoses. In *Interpreting Multivariate Data*, edited by V. Barnett (New York: John Wiley), pp. 147–173.

GABRIEL, K.R., and ZAMIR, S., 1979, Lower rank approximation of matrices by least squares with any choice of weights. *Technometrics*, 21, 489–498.

GOWER, J.C., and DIGBY, P.G.N., 1981, Expressing complex relationships in two dimensions. In *Interpreting Multivariate Data*, edited by V. Barnett (New York: John Wiley), pp. 83–118.

GREENACRE, M.J., 1984, *Theory and Applications of Correspondence Analysis* (New York: Academic Press).

HANIHARA, T., 1993, Craniofacial features of Southeast Asian and Jomonese: a reconsideration of their microevolution since the late pleistocene. *Anthropological Science*, **101**, 25–46.

JANTZ, R.L., and HAWKINSON, C.H., 1979, Finger ridge-count variability in sub-saharan Africa. *Annals of Human Biology*, **6**, 41–53.

JANTZ, R.L., and HAWKINSON, C.H., 1980, Components of racial variation in finger ridge-counts. *American Journal of Physical Anthropology*, **52**, 139–144.

JANTZ, R.L., HAWKINSON, C.H., BREHME, H., and HITZEROTH, H.W., 1982, Finger ridge-count variation among various subsaharan African groups. *American Journal of Physical Anthropology*, **57**, 311–321.

JANTZ, R.L., and OWSLEY, D.W., 1977, Factor analysis of finger ridge-counts in blacks and whites. *Annals of Human Biology*, **4**, 357–366.

JANTZ, R.L., BREHME, H., and ERIKSSON, A.W., 1992, Dermatoglyphic variation among Finno-Ugric speaking populations: methodological alternatives. *American Journal of Physical Anthropology*, **89**, 1–10.

KNUSSMANN, R., 1967, Interkorrelationen im hautleistensystem des menschen und ihre factoren-analytische auswertung. *Human Genetics*, **4**, 221–243.

KRISHNAN, T., 1991, Graphical representation of finger ridge-count data. In *Dermatoglyphics Today: Proceedings of the International Conference on Progress and Trends in Dermatoglyphic Research*, edited by B. Mohan Reddy, S.B. Roy and B.N. Sarkar (Calcutta: ISI, IBRAD, ASI), pp. 29–39.

KRISHNAN, T., and REDDY, B.M., 1992, Principal components of finger ridge-counts: their universality. *Annals of Human Biology*, **19**, 153–164.

LEGUEBE, A., and VRYDAGH, S., 1979, World diversity of finger ridge-counts in male populations. *Collegium Anthropologicum*, **3**, 225–233.

LEGUEBE, A., and VRYDAGH, S., 1981, Geographic variability of digital ridge-counts: principal components analysis of male and female worls samples. *Annals of Human Biology*, **8**, 519–528.

LEGUEBE, A., and VRYDAGH, S., 1982, World variability of digital ridge-counts. *IInd Anthropological Congress of Ales Hrdlĭcka—Universal Carolina Pragensis*, pp. 311–318.

LOESCH, D.Z., and WOLANSKI, N., 1985, Dermal ridge patterns and fertility in a Polish rural sample. *Annals of Human Biology*, **12**, 463–477.

MALHOTRA, K.C., and REDDY, B.M., 1988, Genetic significance of the relationship between mean ridge count and variability on individual fingers. *Journal of the Indian Anthropological Society*, **23**, 161–177.

MEIER, R.J., 1980, Anthropological dermatoglyphics: a review. *Yearbook of Physical Anthropology*, **23**, 147–178.

MEIER, R.J., 1981, Sequential developmental components of digital dermatoglyphics. *Human Biology*, **53**, 557–573.

NEI, M., and LIVSHITS, G., 1989, Genetic relationships of Europeans, Asians and Africans and the origin of modern Homo Sapiens. *Human Heredity*, **39**, 276–281.

NEI, M., and ROYCHOUDHURY, A.K., 1974, Genetic variation within and between three major races of man, Caucasoids, Negroids and Mongoloids. *American Journal of Human Genetics*, **26**, 421–446.

NEI, M., and ROYCHOUDHURY, A.K., 1982, Genetic relationship and evolution of human races. *Evolutionary Biology*, **14**, 1–59.

REED, T., NORTON, Jr, S.A., and CHRISTIAN, J.C., 1978, Fingerprint pattern factors. *Human Heredity*, **28**, 351–360.

ROSA, P. J., 1983, A dermatoglyphic survey of Kenyan schoolchildren, *Annals of Human Biology*, **10**, 579–584.

ROTHHAMMER, F., CHAKRABORTY, R., and LLOP, E., 1979, Dermatoglyphic variation among South American tribal populations and its association with marker gene, linguistic and geographical distances. In *Dermatoglyphics: Fifty Years Later*, edited by W. Wertelecki and C. C. Plato (New York: Alan R. Liss), pp. 269–276.

SANTOS, R. V., MEIER, R. J., and VIEIRA-FILHO, J. P. B., 1990, Digital dermatoglyphics of three Amerindian populations of the Brazilian Amazonia: a further test of field theory. *Annals of Human Biology*, **17**, 213–216.

SIERVOGEL, R. M., ROCHE, A. F., and ROCHE, E. M., 1978, Developmental fields for digital dermatoglyphic traits as revealed by multivariate analysis. *Human Biology*, **50**, 541–556.

DU TOIT, S. H. C., STEYN, A. G. W., and STUMPF, R. H., 1986, *Graphical Exploratory Data Analysis* (Berlin: Springer-Verlag).

VAN VALEN, L., 1963, Selection in natural populations: human finger prints. *Nature*, **200**, 1237.

WANG, P. C. C. (ed.), 1978, *Graphical Representation of Multivariate Data* (New York: Academic Press).

Address for correspondence: T. Krishnan, Indian Statistical Institute, 203 Barrackpoore Trunk Road, Calcutta 700 035, India.

**Zusammenfassung.** Die graphische Methode des Biplots nach Gabriel und anderen wird erklärt und auf Mittelwerte der Leistenzahlen von zehn Fingern für 239 Populationen, vorwiegend indischen, angewendet. Die Biplots werden zusammen mit den aus ihnen resultierenden Konzentrationsellipsen herangezogen, um die Variabilität in Abhängigkeit von geographischen Faktoren, dem Geschlecht und ethnischen/sozialen Gruppen zu analysieren sowie um indische Bevölkerungen mit anderen zu vergleichen und um Zusammenhänge zwischen individuellen Counts und Bevölkerungen zu untersuchen. Die Korrelationsstruktur der Leistenzahlen zeigt eine Untergliederung der Finger in drei Gruppen, wie sie auch in zahlreichen anderen Studien gezeigt wurde, jedoch mit einer etwas abweichenden Kombination der Finger. Die Daten wurden mit den Ergebnissen von Leguebe und Vrydagh verglichen, die Principal Components, Hauptkomponentenanalysen, Diskriminanzfunktionen, Andrew-Funktionen etc. verwendeten, um regionale und geschlechtsspezifische Variationen zu analysieren. Im Vergleich zu Populationen aus den übrigen Teilen der Welt läßt sich bei indischen Populationen ein hohes Maß an Homogenität feststellen. Obwohl die Biplots eine große geographische Nähe erkennen lassen, wird diese auf lokaler Ebene (Bundesstaaten innerhalb Indiens) nicht beibehalten. Mongolide und Europide haben unterschiedliche Ridge Count-Strukturen. Die von Leguebe und Vrydagh beobachtete größere Homogenität bei Frauen und auf der linken Körperseite wird auch in den Biplots beobachtet. Ein Vergleich mit Plots der Hauptkomponenten zeigt, daß Biplots eine graphische Präsentation darstellen, die den Komponentenplots ähnlich ist und die mehr Informationen vermittelt als Komponentenplots.

**Résumé.** La technique graphique du 'biplot' due à Gabriel et d'autres, est expliquée et appliquée à dix moyennes de compte-de-crête digitaux de 239 populations, essentiellement indiennes. Les biplots ainsi que les ellipses de concentration qui en sont tirées, sont utilisés afin d'étudier la variabilité intergroupe, géographique, sexuelle, et ethnique ou sociale, pour comparer les populations indiennes à d'autres populations et pour étudier les relations entre comptes individuels et populations. La structure de corrélation des comptes-de-crêtes, présente une division tripartite des doigts décrite dans de nombreuses autres études, mais avec une combinaison de doigts quelque peu différente. Des comparaisons sont également effectuées avec les résultats de Leguebe et Vrydagh, qui ont utilisé les composantes principales, les fonctions discriminantes, les fonctions d'Andrews, etc.... pour étudier les variations géographiques et sexuelles. Il y a une forte homogénéité des populations indiennes par rapport à celles du reste du monde. Bien que les grandes proximités géographiques soient reflétées par les biplots, les contiguités locales (entre états de l'Inde) ne le sont pas. Mongoloïdes et caucasoïdes ont des structures de compte-de-crêtes différentes. Le niveau le plus élevé d'homogénéité, chez les femmes et du côté gauche, trouvé par Leguebe et Vrydagh, est également observé dans les biplots. Une comparaison avec les graphiques de composantes principales, indique que les biplots apportent une représentation graphique similaire et expriment une plus grande information.