CONTRIBUTIONS

Analytical morphometry and human phylogenesis

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Morphological analysis is traditionally based on evaluations of discrete measurements calculated with reference to canonical points and their derivate fractions; these, however, show inadequacy for shape analysis, which is particularly relevant for the identification and characterization of the phenotype during evolution. The problem became so relevant that R. Holloway strongly but efficaciously said «measurements such as lenght, width, height, whether in chords or arcs, only describe space... and further run into the abyss of allometric correction» (HOLLOWAY, 1981).

We carried out a study of skull shape from the phyletic hominid series using analytical morphometrical procedures (BOOKSTEIN, 1978; DULLEMEIJER, 1971; LESTREL, 1974; OXNARD, 1973 & 1984), with the dual aim of verifying the classifications based on traditional morphological procedures and, above all, of obtaining a numerical, and therefore objective, description of these samples.

The techniques of analytical morphometry are effective in describing shapes and can also be subject to rigid standardization criteria. However, in this case and in this phase of the research, the logico-cognitive phases, which are based on experience, must be taken into account, to guide the morphologist into the specimen observation and description. In this way, numerical data may be univocally referred to morphological data.

The analytical procedures able to extract numerical parameters constituted the S.A.M. (Shape Analytical Morphometry) software system implemented at the Laboratory of Anthropology of the University of Bari .

The sagittal fronto-facial profiles *(vertex-prosthion),* after standardization of the position according to the Frankfurt plane, and after size normalization which consists of digitizing all the examined profiles in the same number of points, are acquired by computerized densitometric video-scanning which subdivides the profile in a standard number of points using a density cut-off value.

The abscissa and ordinate values of each point of the digitized profile represent the starting data for all the analytical procedures.

These procedures consist of:

a) Kth order polynomial equations;
b) Fourier harmonic analysis;
c) Janus procedure.

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a) The Kth order polynomials, because of their smoothing effect, provide a new curve, more simple than the original one, which expresses the essential characteristics of the profile by eliminating any details which could be due to individual characteristics of the skull; the best approximation polynomials are between the 6th and 8th order and the function curves produced are mostly useful for classification and comparison (Pesce Delfino *et al.,* 1987b).
The comparison between the two profiles is carried out by computing the two reciprocal error points. This are actually expressed by the root of mean square error. This evaluation is performed in conditions of minimization, i.e. in the position corresponding to the lowest distance value of the two profiles. This distance is obtained by progressively shifting one profile towards the other along the abscissa axis. This condition eliminates any residual dimensional differences between the compared skulls and therefore the obtained evaluator is to be only referred to shape differences of the different parts of the profile (fig. 1).
With reference to the *Homo sapiens* skull, the values of morphological distance are as follows: *Plesianthropus transvaalensis* 14, *Zinjanthropus boisei* 10.7, *Homo habilis* 6.7, Circeo I 5.9, Steinheim 4.6, Predmosti III 2.9, Cro-Magnon I 2.1 (Pesce Delfino *et al.,* 1986d); the median gives a value of 10.35 for the fossils of over one million and a half years and a value of 4 for the skulls under three hundred thousand years.

b) Fourier harmonic analysis allows an exact description of the profile which is considered as a curve obtained by the sum of sinusoids of different amplitude, period and phase (Jacobsagen, 1982; Johnson *et al.,* 1986; Lestrel, 1974); a straight line through the back most point of the fronto-nasal section perpendicular to the abscissa axis is considered as a zero line for the description which the examined profile presents in relation to it. In the comparison between *Plesianthropus transvaalensis* (STS5) and *Homo sapiens s.* it resulted that while in the modern skull the second harmonic is less than the fundamental one, in the profile of *Plesianthropus transvaalensis* the situation is inverted and the second harmonic is greater in absolute (Pesce Delfino *et al.,* 1987a). The extracted parameters are represented by the amplitude of the maximum harmonic, by the amplitude of the fundamental one, by the sum of the amplitudes, etc., of the whole set or of various subsets, whose sine-cosine coefficient histograms are provided. By tracing the histograms using a constant scale value, since the profiles are normalized, a direct comparison is possible (Fig. 2).

c) The «Janus» procedure is useful for separately evaluating and quantifying the allometry and isometry of a skull profile.
To this aim, the two standardized and normalized fronto-facial profiles are compared after a mirror inversion of one of them; then they are separated by a straight line. A parabolic fitting is carried out, and the arc-chord complex constituted by the segment of the parabola corresponding to the computed arc and by the segment of the straight line joining its two extremes (chord) is calculated.
A further calculation of the allometric percentage (the area between the arc and the chord) and the isometric percentage (which is a function of the position of

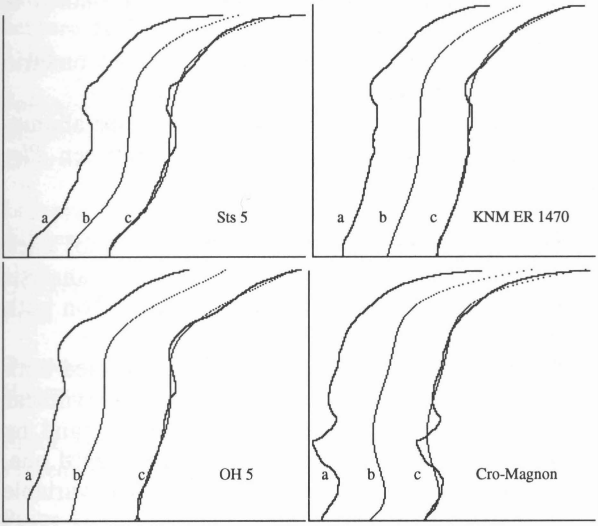

Fig. 1 - Fronto-facial normalized profiles (a); smoothed curves obtained by the original profiles by polynomial approximation (b); comparison between the original profiles and the function curves (c).

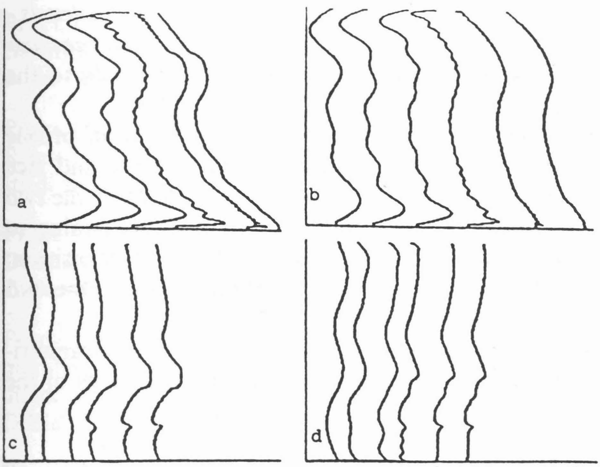

Fig. 2 - Checking of the description of the fronto-facial profiles according to Fourier harmonic analysis by progressively adding the sinusoidal components obtained from the description itself: a) *Plesianthropus transvaalensis;* b) Taung 1; c) *Homo sapiens* adult; d) *Homo sapiens* infante.

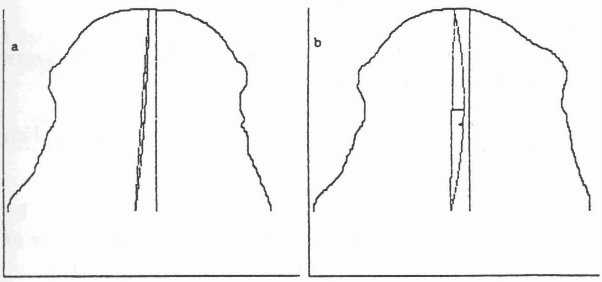

Fig. 3 - «Janus» procedure to evaluate situations of allometry/isometry. Comparisons of the fronto-facial profiles of *Plesianthropus transvaalensis* respectively with *Homo habilis* (a) and *Zinjanthropus boisei (b).*

the separating segment compared to the interceptive value of the chord) is carried out.
The allometric fraction indicates the entity of shape differences; the isometric fraction indicates how much can be attributed to size differences.
Comparing *Plesianthropus transvaalensis* and *Zinjanthropus boisei* the allometric difference is greater than the difference in the comparison between *Plesianthropous transvaalensis* and *Homo habilis* (Fig. 3).

The parameters extracted from different procedures, independent of each other, were submitted to univariate and multivariate statistical analysis (analysis of main components and discriminant analysis) and gave useful information both of phyletic and ontogenetic significance.

The transformative relations of hominid skull profiles were also studied both by means of synthesis of new curves deriving from the Lagrange curvilinear interpolation, averaging two given curves, transformations of variables, and by means of evaluation of determinative ability of two given profiles on a third one, using these curves respectively as the first and the second independent variable and as the dependent variable in a two variable polynomial .

These models revealed differential behaviour between the frontal and maxillary profiles in the comparison between *Plesianthropus transvaalensis* and *Homo sapiens s.* and pointed out a greater linearity of the *Plesianthropus transvaalensis - Homo habilis - Homo sapiens s.* lineage compared to the *Plesianthropus transvaalensis - Zinjanthropus boisei - Homo sapiens s.* one, referred particularly to the frontal profile whose differential model is provided.

Moreover, with a merging procedure progressively replacing traits of profile of *Plesianthropus transvaalensis* by traits of profile of *Homo sapiens s.* and vice versa, new profiles were constructed. On these curves, after the patterns of the two original profiles had been defined, we carried out the Fourier analysis aiming to find situations where the pattern of harmonics shows a situation of transition; four different morphologies with this characteristic were defined (Pesce Delfino *et al.,* 1986c) .

The use of analytical devices allows us, therefore, to define and to parametrize transformations aiming to clarify the dynamics of evolutionary processes of the human skull and its morphogenesis.

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