STEREOPLOTTING HOMINID BRAIN ENDOCASTS : SOME PRELIMINARY RESULTS

RESTITUTION STEREOMÉTRIQUE DE MOULAGES ENDOCRANIENS D'HOMINIDÉS : QUELQUES RÉSULTATS PRÉLIMINAIRES

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Abstract

To objectively and quantitatively demonstrate regional differences in brain endocast morphology, traditional anthropometric caliper measurements must be replaced by a system providing not only «localness», but homology and reasonable freedom from allometric distortion. Stereoplotting the radial distances from endocast surface (the closest point to the once underlying brain cortex) to a homologous center every ten degrees provides some 300 + data points for each dorsal endocast surface, thus giving the requisite «localness». These measurements provide a large matrix of data suitable for a number of multivariate statistical techniques, and the translation of such data and analyses to readily visualized «maps», which can then be compared in relation to both taxonomic and functional knowledge about the cerebral surface. This paper describes some preliminary results from using such methods on a sample of 64 undistorted endocasts composed of both pongids and fossil hominids. While sample sizes within taxonomic groups need to be augmented, the preliminary and tentative pilot studies conducted so far suggest that the method has excellent potential, and that two major areas of the brain endocast surface show the greatest shape changes : 1) the posterior association areas (inferior parietal lobule); 2) the anterior prefrontal areas.

Résumé

Pour décrire de manière objective et quantitative les différences morphologiques entre régions de moulages endocrâniens, les mesures anthropométriques traditionnelles à l'aide du compas doivent être remplacées par un système renseignant non seulement sur la «spécificité» mais sur l'homologie et les distorsions allométriques raisonnablement acceptables. La restitution des mesures stéréométriques des distances radiales entre des points de la surface du moulage (de 10 en 10 degrés) et un centre commun donnent quelques 300 points d'où l'on tire la «spécificité». Ces mesures apportent une moisson de données qui autorisent un traitement statistique multivarié et l'établissement de «cartes» que l'on peut alors comparer relativement à ce que l'on sait de la surface cérébrale tant au plan taxonomique qu'au plan fonctionnel. L'auteur décrira ici quelques résultats préliminaires acquis avec de telles méthodes à partir d'un échantillon de 64 moulages endocrâniens – sans distorsion – de pongidés et d'hominités fossiles. La taille de l'échantillon à l'intérieur de chaque groupe taxonomique a certes besoin d'être augmentée, mais les études préliminaires et novatrices qui viennent d'être poussées assez loin laissent entendre que la méthode est bonne et que deux zones majeures de la surface endocrânienne présentent les modifications morphologiques les plus importantes : la zone d'associations postérieure (lobe pariétal inférieur) et la zone prefrontale antérieure.

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Introduction

Brain endocasts are difficult to measure, since traditional caliper measurements only apply to landmarks imparted by the surrounding internal table of bone of the cranium, and these have little or no functional information relevant to the once underlying brain. Length, width, height measurements, either in chord or arc measurements, and their attending ratios help describe space only, which while relevant from a taxonomic viewpoint, do not provide the critical «localness» to compare regions between taxa in any objective, statistically significant way.

The coordinate stereoplotter, devised by Oyen and Walker (1), allows for more accurate and replicable measurements to be taken and provides additional advantages with polar coordinates for objects that may require allometric correction. In addition, the coordinate measurements may be mapped in several ways, including the results of various multivariate analyses, to graphically depict regions showing maximal changes, which can next be related to neuroanatomical and neurophysiological maps, yielding functional interpretations.

During the past few years, some 64 brain endocasts of various pongids and hominids have been measured using the stereoplotting apparatus. While large sample sizes within various taxa are needed, and control measurements from actual brain casts required, the first results indicate considerable promise and are thus reported here in preliminary form.

Materials and Methods

Sixty-four endocasts, made a latex rubber, were processed for 10 *Pan paniscus*, 10 *Pan troglodytes*, 10 *Gorilla gorilla*, 5 *Homo erectus* (Java), 5 *Homo erectus* (China), 5 *Solo*, 6 *Homo sapiens*, 4 *Australopithecus africanus*, 3 *Aust. robustus*, and 7 assorted endocasts of early hominids from Lake Turkana, Kenya; Omo, Ethiopia; and Olduvai Gorge, Tanzania, which have been left in an «unclassified» group for the present.

Each endocast, representing the most complete or undistorted endocasts available, was placed in the apparatus (see Figure 1) and measured in both horizontal and vertical transects evely 10°. The endocasts were first oriented such that a homologous center was defined as the exact midpoint between frontal and occipital poles in the mid sagittal plane. Each measurement is thus a radial distance from the surface to such a center point. Both left and right sides of each endocast were measured when possible, but the initial statistical analyses have only been performed on one side (mainly left, except in those fossil specimens where only the right side was available).

Figure 2 shows a resultant coordinate map of an endocast. Each intersection, every 10°, represents a measurement of radial distance. For preliminary testing, and statistical reasons to be discussed later, analyses were only performed on transects of 20° intervals, both horizontally, and vertically. These are referred to as «pilot» analyses.

Each measurement was punched onto data cards, and specimens arranged according to taxa in a subfile list. The data were treated in a number of statistical ways using procedures given in the SPSS manual (2).

First, using «scattergram», each point for all 64 endocasts was converted to $\log_{10}$ equivalents, as was the endocranial volume, and each point plotted against volume, yielding a straight line regression equation of form :

$$\log_{10} \text{rad. dist.} = k + a \log \text{brain size}, \text{ or,}$$

$$\text{rad. dist.} = k \times \text{brain size}^{a}$$

Secondly, for each point, this equation was used to calculate the empirically determined *expected* value of radial distances for each point on the sample. This in turn was subtracted from the *actual* value, yielding a *residual* which was called DIFF 1 to 10, depending on its angular location.

Thus, each transect of 20° intervals had 10 *DIFFs*, or residuals, and each transect was analyzed separately by a combination of Discriminant, Anova, Oneway, and Factor analyses. 20° intervals were chosen to keep the number of variables roughly equal to the number of taxonomic groups for discriminant purposes, and the maximal number of specimens within taxa (N=10).

Preliminary Results

1 - The scattergram results very clearly indicate two things : 1) radial distances are allometrically related to brain endocast size; yet 2) each taxon tends to have a unique pattern of residuals. The correlation coefficients vary between .93 and .98, averaging about .96. They are all significant at the .00001 level. The exponents, or slopes, vary between .28 and .45 depending on the particular point and angular transect, averaging about .3 or slightly higher, as one would expect from simple geometric considerations. Once the values are corrected for allometry, the *residuals do not* show any significant relationship with endocast volume. Indeed, using Factor analysis (principle components, Type PA 1) with Varimax rotation, always provides a 1st factor accounting for roughly 95% of the variance, which is clearly size. If the residuals are analyzed by Anova, with taxon group as the independent variable, the *residuals* or *DIFFs* as the dependent variables and $\log_{10}$ volume the covariate, there are no significant covariate F ratios; that is, the taxonomic groups account for most of the variance.

2 - Discriminant analyses, using the direct method as described in SPSS, and only on those known taxonomic groups (N=9), yield % classification scores which vary for each transect (Table 1). By and large, only 3 discriminant functions are significant at less than the .05 level, and account for 75 to 90% of the variance. Two patterns emerge depending on the transects run : 1) Within the vertical transects, it is the lower points, i.e., toward the horizontal plane, which load highest on the discriminant scores, and 2) within the horizontal transects, it is the posterior elements which provide the highest F's for discriminant scores. Naturally, the same pattern emerges from either Anova, or Oneway (without a covariate) analyses of variance. These areas, incidentally, are usually roughly in the inferior parietal and posterior temporal regions.

3 - Most misclassifications occur between very closely related taxa : e.g., between *Pan paniscus* and *Pan troglodytes*, and between Indonesian and Chinese *Homo erectus* samples. Interestingly, *Homo sapiens* and both *Australopithecus* groups tend to classify correctly at 100% correct

4 - Some attempts have been made, using discriminant analyses, to classify «unknown» specimens such as KNM-ER 1805, 1813, 1470, 3733, and OH-9, and the Rhodesian endocast. In some cases, the classifications are «reasonable», i.e., 1470 as a *Homo erectus* or robust *Australopith.* 1805 is almost always classified as *Gorilla*, which on the face of it sounds absurd, but actually makes sense condidering its very unique form. Unfortunately, the SPSS routine does not have the requisite flexibility to correctly classify these unknowns, since one cannot assign 0 probability to certain groups, e.g., *Gorilla*, a group to which none of the «unknowns» belong.

5 - Some preliminary t-tests between each pair of taxonomic groups on the DIFFs have been carried out, and the probabilities mapped on two-dimensional graph paper, thus giving a ready visual picture of areas or zones of endocast surface which show significant differences at $<.05$ level. Depending on the groups contracted, variable probability maps result with different distributions of statistically-significant t-scores. However, since these are based on such small sample sizes for each taxon, it seems premature to present them here, except as an example of one possible technique for depicting the taxonomic differences in a localizable way relative to particular zones of underlying cerebral cortex (see Figures 3, 4 and 5).

Discussion

It must be stressed that these results are regarded only as *tentative*, but promising, preliminary studies, the major purpose of which is to indicate whether the methods show promise for presenting clearcut hypotheses to be further tested with larger sample sizes, and to provide ideas for better depiction and illustrative techniques. It is already apparent from certain mapping technique, e.g., the F-ratios from Anova, t-tests and resulting probabilities, or the distribution of Brodmann's numbers of cytoarchitectonic cerebral distributions, that many more specimens are needed, and most imperatively, that actual *brain* (not endocasts) casts be similarly plotted, and in finer detail, i.e., every 10°. Until this is done, it seems premature to this writer to make assertions about *where* on the dorsal endocast surface most changes have taken place, although so far, everything indicates that the major changes have occurred in anterior prefrontal regions, Broca's and Wernicke's areas.

I believe the choice of the homologous central point is reasonable. Certainly, both frontal and occipital poles appear to be close homologous points, in the strictly functionnal sense, between pongids and hominids. On the other hand, shape factors could be influenced by other adaptive processes than cerebral reorganization alone, e.g., craniobasal flexion, postural adjustments, adaptations to masticatory functions, etc. In addition, a number of other considerations should be mentioned. 1) Is the method of analyzing *residuals* from allometric corrections the best approach, since the *residuals* are to some extent relative, as they are dependent on sample sizes within taxonomic groups ? 2) While polar coordinate stereoplotting *intuitively* suggests a way of dealing with volumetric expansion and stability of the location of neuroanatomical landmarks, is this really true ? Can it be tested without laboriously measuring scores of actual, undistorted brain casts ? 3) Will we ever have enough fossil hominid forms (endocasts) to truly measure their differences between other fossil taxa and living forms ? 4) What exactly does it mean, statistically, to simultaneously compare living and fossil groups ?

Whatever the answers to these questions, the stereoplotting methods give the necessary «localness» in studying brains and endocasts, and while extremely laborious in un automated fashion, shows the best available promise for *objectively* demonstrating and testing hypotheses, quantitatively, about the evolutionary shape and size changes in this most important organ of human adaptation.

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References

1 - Oyen O.J. and Walker A. *Stereometric Craniometry*. Amer. J. Phys. Anthro., 46 : 177-182. 1977.

2 - Nie N.H. and al. *SPSS Statistical Package for the Social Sciences*. McGraw-Hill Book Company, N.Y. 2

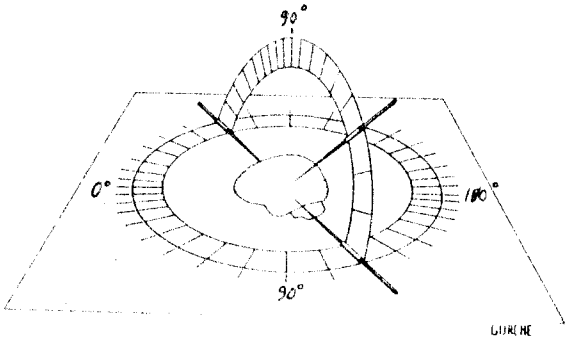

Figure 1 - Stereoplotting apparatus, adapted from Oyen and Walker (1). Measurements are taken by a mm-rule from the outer edge of the vertical arch.

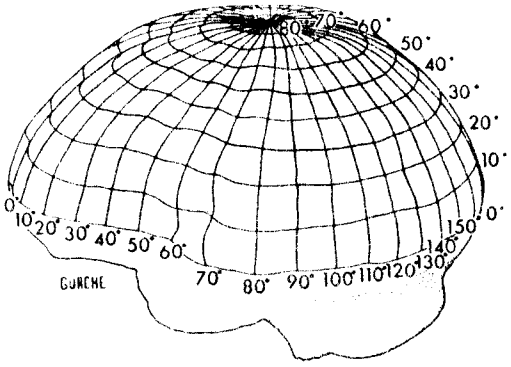

Figure 2 - Endocast showing angular transects marked on the dorsal surface. Measurements are taken every 10 degrees where the transects intersect.

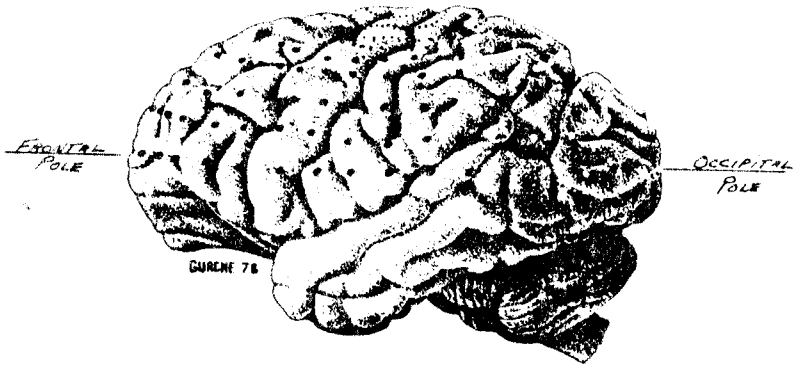

Figure 3 - Drawing of an actual chimpanzee brain cast, showing how the angular transects align on the dorsal surface.

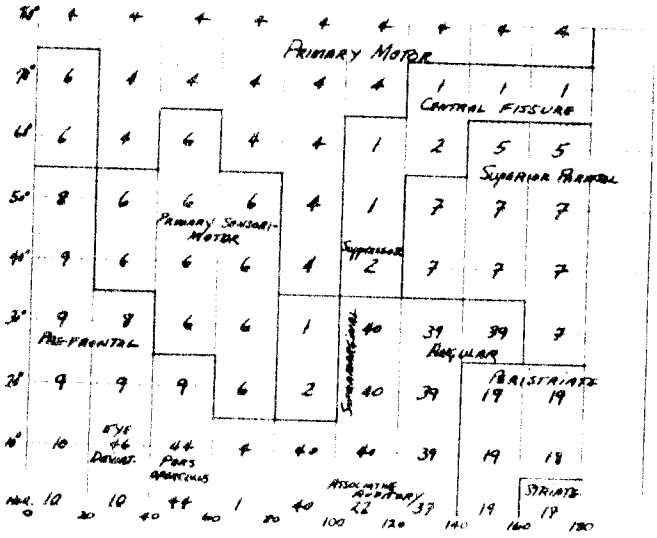

Figure 4 - A tentative translation of Broadmann's map into angular transects, based on 20 degrees intervals.

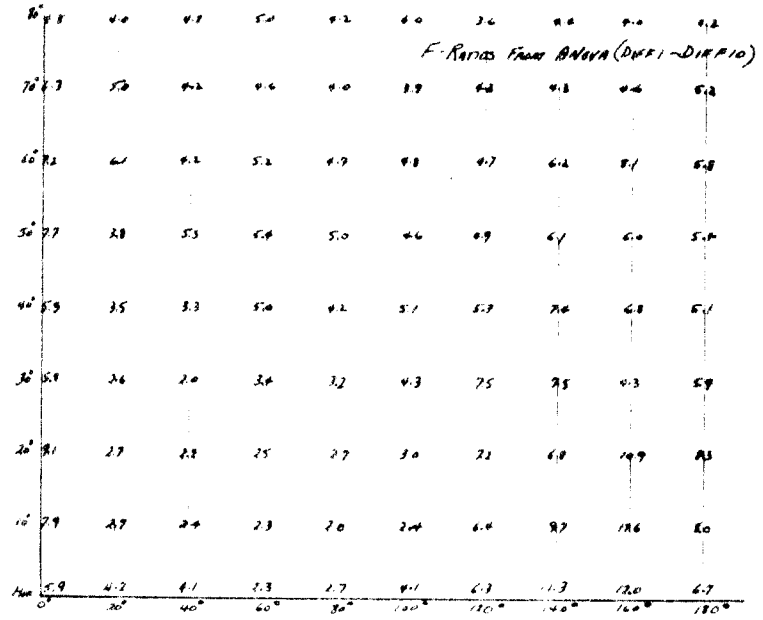

Figure 5 - Translation of F-ratios from Anova to coordinate points. (Values are for a composite sample of 64 endocasts, all taxa).

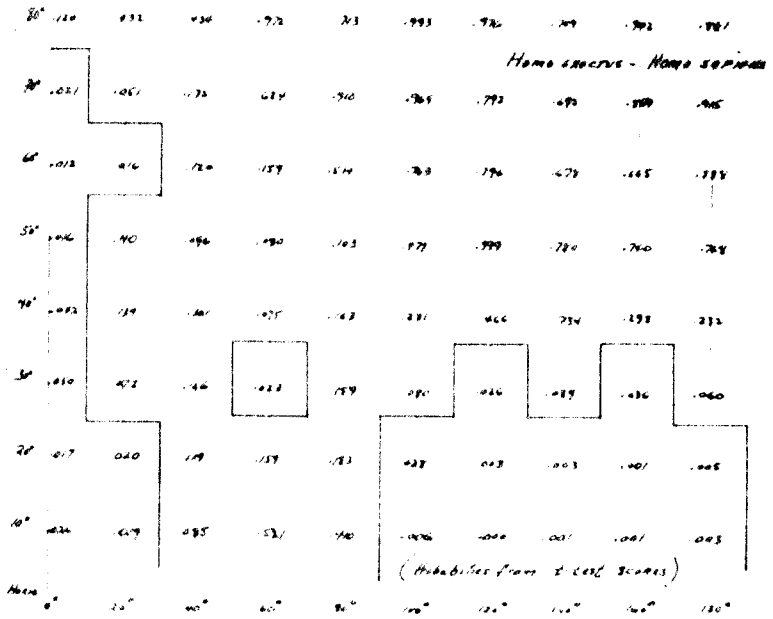

Figure 6 - A tentative mapping of probability values associated with t test scores between *Homo erectus* (Java, N = 5), and modern *Homo sapiens* (N = 6). Blocked values are those P's less than .05.

Transects (Horizontal)	Classifications, %	Transects (Vertical)	Classification,%
10°	77	20° ant.	67
20	86	40	74
30	77	60	65
40	65	80 post.	69
50	79	80	62
60	72	60	76
70	63	40	77
80	56	20	88

Table 1 - % Correct Classifications of Groups

Classification results from SPSS Discriminant Analysis, direct method. Each transect, whether horizontal or vertical, contains 10 measurements (DIFF1-10), and runs from anterior to posterior, every 20 degrees. (See Figure 2).