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Shape Analysis of the Mid-Sagittal Craniogram in Some European Middle and Upper-Paleolithic Adult and Subadult Crania

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ABSTRACT

In order to evaluate the lateral shape contour of the Neanderthal cranium, the mid-sagittal profiles (glabella-opisthocranion) in adult and subadult Neanderthal remains were examined and compared with those of other specimens of fossil Homo. Size normalized boundaries were digitally acquired as ordered series of coordinates; the series of the distances from the glabella opisthocranion axis, was decomposed in Fourier polynomials; the extracted amplitudes and phase angles were used as variables to carry out multivariate discriminant analysis (PCA). The first and the second components accounted for 70% of the total variance. Neanderthal and European Upper Paleolithic subadults differ from adults of their respective groups: the subadult Homo sapiens are more similar to the adult, as the element characterizing the group is constituted by a steep craniogram with a noticeable equilibrium between the anterior and posterior district. In Neanderthal subadults, the adult model seems partially delineated and the mature cranial architecture is reached trough a phase of local allometric differentiation.

Key words: *paleoanthropology, subadult Neanderthals, analytic morphometry*

Introduction

The aim of the Research Unit, in the framework of the »Programma Nazionale di Ricerca MURST (Ministero dell'Università e della Ricerca Scientifica e Tecnologica), 1998–2000«, was to study the skeletal morphology of human fossil remains, applying both traditional research into skeletal morphology and morphometric analysis based on analytical procedures.

The areas of research include, in particular, the clarification of phylogenetic

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problems, seen essentially in terms of shape differentiation, that were approached using shape analytical descriptors. This type of approach, in evolutionary morphological studies and more generally in the definition of morphological characteristics, allows the repeatability of the observations, and in this specific case, the numerical evaluation of the morphology of anthropologically significant remains. The analytical procedures contained in the morphological diagnosis system S.A.M. (Shape Analytical Morphometry)[1] were used for this purpose. The system treats curves of different complexity, using two main groups of parameters to describe two classes of shape information, different both for concept and for descriptive procedure. The first class concerns information related to the »local« shape characteristics of the studied boundaries; the second is connected to information related to the general trend, which may characterize the architectural plane of the object under study. In the first case, an exact description is required, without residuals, of the studied object; thus a trigonometric interpolation based on Fourier polynomials is used. In the second case, the evaluation of symmetry is carried out by means of parabolic fitting.

One of the primary aspects of the project was to study the morphological differentiation of the crania in Neanderthals. Within this context, the definition of some characteristics of Neanderthal cranial shape, useful for a morphological definition of the group, even when compared to other groups of humans, was considered. The morphological features that characterize the lateral shape contour of the Neanderthal skull, when considered individually, can be found in other groups, but, when considered together, constitute an apomorphic feature of the group. In order to evaluate these distinctive features, in relation to the emergence of the Neanderthal morphocline, the shape variations of the midsagittal profile (glabella-opisthocranion) in remains from the Mid and Upper European Pleistocene were previously studied[2]. Three groups of craniograms (remains attributed to Asian *Homo erectus*, Neanderthal forms and remains attributed to the European Upper Paleolithic) were described using Fourier analysis. The analysis, sub-dividing the information according to phase and amplitude, was able to fully separate the studied groups, revealing the variations caused by the progressive posterior dislocation typical of the Neanderthal cranium.

A further aspect of the study, reported in the following, consists in the shape analysis of the mid-sagittal craniogram in Neanderthal and European Upper Paleolithic adults and subadults. The results obtained in the first part of the research project suggested that the analysis could be extended to subadult remains; the verification of the existence of differentiated growth models could indeed contribute significantly to the debate about the attribution of specificity to the Neanderthal phenomenon. Increasing interest is, in fact, demonstrated by many authors[3–6] in studying subadult specimens in order to better understand the development of adult morphological features and the evolutionary relationships between Neanderthals and early modern humans.

The results obtained extending the analysis to subadult Neanderthal remains, and comparing them to anatomically modern remains from the European Upper Paleolithic and to modern sample, are thus reported. In this way, the characterization of the Neanderthal cline, already approached in terms of phylogenetic relations[2], was studied in relation to the phenomenon of differentiation due to growth.

Materials

In the present study, the following material, collected from literature, was studied:

- 10 Neanderthal craniograms: Circeo 1 and Saccopastore 1[7]; La Chapelle-aux-Saints, La Ferrassie 1, Neanderthal, Le Moustier, Spy 1 and Spy 2[8]; Amud I, Shanidar I[9];
- 18 craniograms belonging to European forms of the Upper Paleolithic: Predmosti 3, 4, 9, 10, 11, Brno 1, 2, 3 and Mladec 1[10]; Sungir 1, Pavlov 3 and Markina Gora[11]; Cro-Magnon, Combe-Capelle[12]; Bruniquel[13]; Obercassel[14]; Vado all'Arancio 1[15]; Villabruna (CT-scan, present study);
- 21 modern skulls (CT-scans, present study), aged from 23 to 76 years;
- subadult remains: La Quina (H18) (ca 7 year-old)[16], Engis 2 (ca 5 year-old)[17], Devil's Tower (ca 5 year-old)[18], Teshik-Tash (ca 9 year-old)[17], Montgaudier 3 (ca 8–12 year-old)[19], Predmosti VII (ca 12–14 year-old)[10], Grimaldi (Grotte des Enfants 6) (ca 12–13 years-old) and Arene Candide (Il Principe) (ca 15 years-old)[20], Qafzeh 10, (ca 6 years-old) and Qafzeh 11 (ca 12–13 years-old)[17], 4 modern skulls aged 6, 8, 10 and 12.

The following craniograms were also described for comparison: Qafzeh 6, Qafzeh 9 and Skhul V[21].

The subadult craniograms were chosen considering their geographic distribution in relation to Europe and near East and their state of preservation and completeness in relation to the studied profile.

Methods

The craniograms were analyzed for the mid-sagittal profile from glabella to opisthocranion. The contours, considered in a Cartesian reference system, were dimensionally normalized (the distances glabella-opisthocranion were scaled to insure that all profiles are the same size in order to reduce size influence). An ordered series of 190 equidistant pairs of co-ordinates was collected for every craniogram. The series of the distances, in respect to the glabella-opisthocranion axis, was interpolated using a Fourier trigonometric polynomial up to 94 harmonics, the maximum permitted by the number of points in which the profiles were divided. From the pairs of sine/cosine coefficients of the sinusoidal components obtained from the analysis, the relative spectra were synthesized and the values of amplitude and phase angle were calculated. The values of amplitude and phase angle of the first 7 sinusoidal components were used as variables to carry out multivariate discriminant analysis (PCA).

The acquisition and analytical treatment of data were carried out using the S.A.M. (Shape Analytical Morphometry) software[1]; for this study the section for the analysis of open curves was used. The statistical evaluation was carried out using the Systat package[22].

Results and Discussion

The analyses conducted in the first part of the study[2] revealed that while the modern forms can be distinguished by the height of the profile, described mainly in terms of the prevalence of the Fourier amplitude, in Neanderthals the first and second harmonics tend to be in phase opposition, describing the flattening of the high part of the forehead and the tendency of the *vertex* to be placed towards the back of the contour (Figure 1). This data, which are to be evaluated within the more general context of the apomorphic Neanderthal characteristics, correspond to the tendency to increase the antero-posterior cranial diameter. The cranial contour of the Upper Paleolithic remains can be seen, on the other hand, prevalently as an increase in Fourier's amplitude in relation to the heightening of the forehead typical of modern skull.

In the principal component analysis performed by using amplitudes and phase values, the first and the second components contain 70% of the total variance (Table 1). The first component was scarcely or negatively correlated to amplitude variables; it reveals a positive correlation to phase variables. The second component is scarcely correlated to phases, but a certain degree of correlation is expressed for the low order amplitudes (I, II, III and IV order amplitudes).

By using the I and II components to obtain the single point distribution, Neanderthal and *Homo sapiens* adults were distributed almost without superimposition (Figure 2); the European Upper Paleolithic forms and the recent sample largely overlap.

This data suggests significantly different morphological models: in Neanderthals the relationship between first phase harmonics describes the flattening of the high part of the forehead and the tendency of the vertex to be placed towards the back, together with the flattening of the lambda. On the other hand, *Homo sapiens* forms are distinguished by the height of the profile, described essentially in terms of prevalence of Fourier's amplitude in relation to the frontal elevation of modern forms.

In general the variability of *Homo sapiens* forms appears greater if compared to the distribution of Neanderthals. Qafzeh adults, Skhul and some Central European remains are placed near the

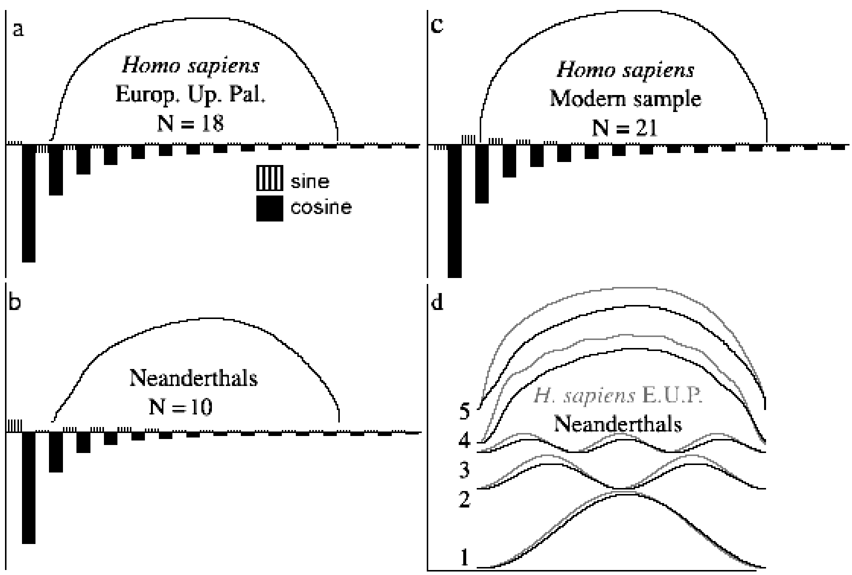

Fig. 1. Mean craniograms and mean Fourier spectra (sine and cosine coefficients, first 15 harmonics) for the studied groups; on (d) synthesis and comparison by superimposition of the first 3 mean harmonics (1–3), sum of the first 7 mean harmonics (4) and mean craniograms obtained from the total summation of 94 harmonics (5). The principal morphological features and the main difference between profiles are already evident in the sum of the first 7 harmonics.

TABLE 1
PRINCIPAL COMPONENT ANALYSIS: FIRST AND SECOND COMPONENT ACCOUNTED FOR 70% OF THE TOTAL VARIANCE

Fourier variables		Component loadings				
		1	2	3	4	5
I	amplitudes	0.026	0.222	0.803	–0.218	0.342
II	amplitudes	–0.533	0.587	0.312	–0.387	–0.062
III	amplitudes	–0.605	0.608	0.283	–0.132	–0.164
IV	amplitudes	–0.703	0.593	0.194	0.111	0.002
V	amplitudes	–0.754	0.578	–0.082	0.180	0.042
VI	amplitudes	–0.757	0.489	–0.264	0.251	0.038
VII	amplitudes	–0.759	0.395	–0.344	0.219	0.079
I	phase angles	0.571	0.106	0.445	0.487	0.352
II	phase angles	0.437	0.596	–0.509	–0.249	0.227
III	phase angles	0.708	0.506	–0.394	–0.126	0.187
IV	phase angles	0.806	0.502	–0.180	–0.051	0.096
V	phase angles	0.869	0.435	0.032	0.025	–0.114
VI	phase angles	0.781	0.499	0.131	0.131	–0.279
VII	phase angles	0.717	0.484	0.269	0.178	–0.295
		Latent roots (eigenvalues)				
		6.441	3.395	1.789	0.737	0.554
		Percent of total variance explained				
		45.792	24.251	12.782	5.265	3.957

periphery of the group; they present a prominent glabellar region and, sometimes, a certain degree of occipital depression. These characteristics are sampled from amplitude values, which have lower values than in *Homo sapiens* morphology of the fully modern type, in which such features are absent.

Considering the subadult remains, the frontal region appears »anteriorized« with respect to adults.

The subadult *Homo sapiens* craniograms are collocated, each according to its own characteristic, within the morphology typical of the group, even if it seems difficult to establish a clear relationship with age.

The adult and subadult Neanderthal forms appear similar for the backwards position of the vertex and the flattening at lambda, even though these typical bone features appears attenuated (Figure 3). They show, instead, significant differences in the morphology of the glabellar region that is lightly expressed, evidentiating a rather rounded frontal. This feature explains the position of the subadult Neanderthals (mainly Teshik-Tash, Devil's Tower and La Quina), that in PCA score appear near to the remains having *sapiens* morphology.

In conclusion, with respect to the adult morphological models, the Neanderthal and European Upper Paleolithic subadult remains seem to differ.

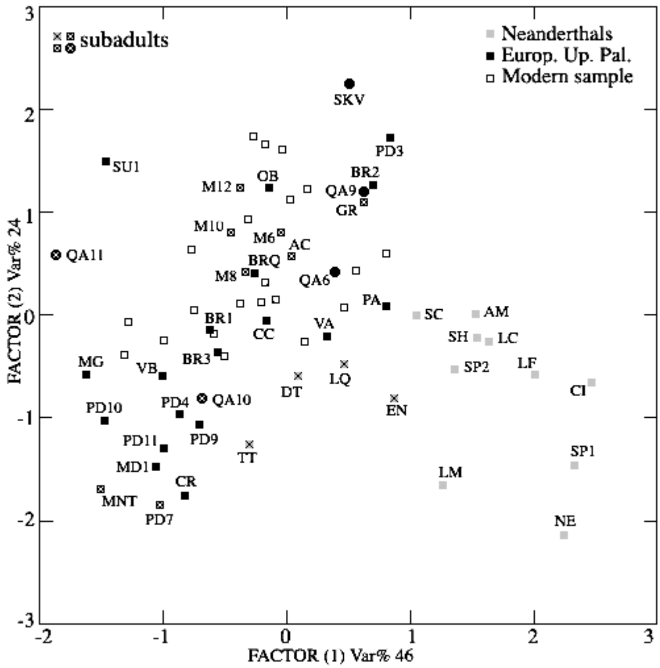

Fig. 2. Multivariate discriminant analysis (PCA), distribution of the individual scores: Circeo 1 (CI), Saccopastore (SC), La Chapelle (LC), La Ferrassie 1 (LF), Neanderthal (NE), Le Moustier (LM), Spy 1, 2 (SP1, 2), Amud I (AM), Shanidar I (SH), La Quina H18 (LQ), Engis 2 (EN), DT (Devil's Tower), Teshik-Tash (TT). Predmosti 3, 4, 9, 7, 10, 11 (PD3, 4, 7, 9, 10, 11), Brno 1, 2, 3 (BR1, 2, 3), Mladec 1 (MD1), Pavlov (PA), Markina Gora (MG), Cro-Magnon (CR), Combe-Capelle (CC), Obercassel (OB), Sungir 1 (SU1), VA (Vado all'Arancio), Villabruna (VB), Bruniquel (BRQ), Montgaudier (MNT), AC (Arene Candide), GR (Grimaldi); Qafzeh 6, 9, 10, 11 (QA6, 9, 10, 11); Skhul V (SKV); modern adults (empty squares); modern subadults (M6, M8, M10, M12).

The examined subadults *Homo sapiens* are more similar to the adult model, as the element characterizing the group is constituted by a steep craniogram contour with a noticeable equilibrium between the anterior and posterior districts. It is possible to hypothesize a precocious phase of allometric differentiation, related to the general phenomenon of encephalization and cerebral volume increase, typical of the hominid line, followed by a prevalently isometric phase in which the local allometric elements, due to natural growth differentiation, appear secondary and do not significantly modify the base model.

As for the examined Neanderthal subadults, the adult model seems partly delineated. Here too, it is possible to hypothesize a precocious phase of general allometric differentiation followed by a phase of local allometric type, related to the expression of the apomorphic characteristics of the mature Neanderthal cranial architecture (torus, backward position of the *vertex*, flattening at lambda). Such differentiation is more evident in the European Neanderthals than in the Near Eastern forms which reveal such features in a more attenuated manner.

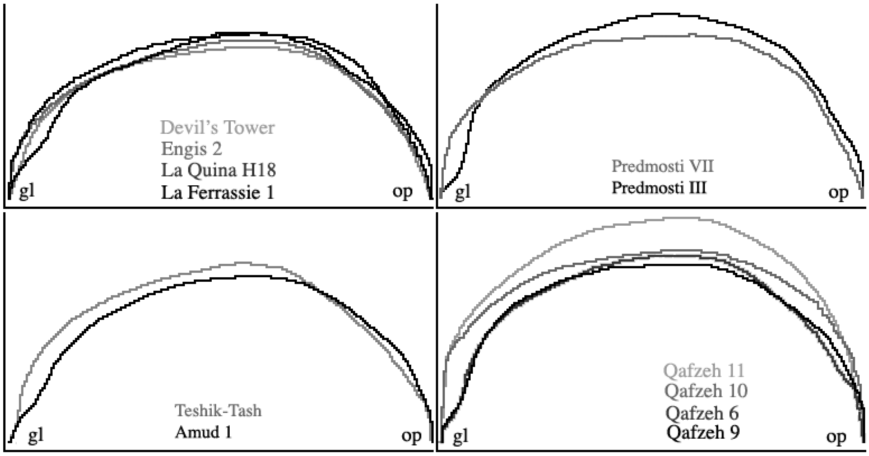

Fig. 3. Adult and subadult craniograms after dimensional normalization: comparison by superimposition.

Conclusions

The differences between the adult Neanderthal and *Homo sapiens* models, respond to a hypothesis of differentiation of the Neanderthal morphological cline due to successive accumulation, which beginning in the mid-Pleistocene appears strongly channeled at the end of that period, stabilizing in the Würmian pleniglacial[23]. With respect to this phenomenon, the lateral contour of the neural cranium considered as a whole, is to be considered one of the typical morphs of the group. The affirmation of the Neanderthal line, from a dynamic perspective, can be analyzed and interpreted as an evolutionary entity undergoing canalization, which modifies its morphological characteristics in relation to an epigenetic context, stabilizing in a stationary phase[24]. This evidence is underlined by the growth models that appear different in young Neanderthal forms in respect to *Homo sapiens* remains. This observation, moreover, is consistent with differences observed when comparing Neanderthal growth trajectory, based on dental and postcranial maturation data, to fossil and modern *Homo sapiens*[4]. A prevalently allometric model, referred to the growth of the fronto-facial district, is also reported for *Homo sapiens* in comparison with *Australopithecus africanus* in Pesce Delfino et al. (1993)[25].

The observed differences could be discussed in terms of shifting in time maturation (the similarity between subadults and adults *Homo sapiens*, or subadults and adults Neanderthals, can be considered as more or less paedomorphic), but heterochronic changes should be analyzed as relationships between ancestor-descendant species, which is not the case[26]. In this case we are observing the maturation of two different morphologies according to two different models. To verify how they evolved, from a possible ancestral model, is a difficult task because of the scarcity of subadult remains.

Some insight, in this respect, is given by the analysis of Mojokerto child vault shape; according to Antón (1997)[27], cranial vault contours differ between adult *Homo erectus* and *Homo sapiens* and between juvenile and adult *Homo erectus*, but do not differ between juvenile and adult *Homo sapiens*. That is, juvenile

Homo erectus cranial contours are similar to those of both juvenile and adult modern humans, suggesting that *Homo sapiens* is paedomorphic relative to *Homo erectus* for vault shape. The growth pattern reported for Mojokerto appears similar to the pattern we found in the present study for Neanderthal subadults: they, infact, differ from adult Neanderthals but are similar to modern humans. This evidence suggests that in the Neanderthal line, despite the noticeable volume differences (for Mojokerto is reported a projected adult cranial capacity of 740 to 860 cc), an ancient growth pattern is preserved for vault shape. It is also possible, as often occurs in the study of fossil hominid ontogeny, that the studied specimens, scattered in time and space, are not fully representative of their populations, and in this case generalizations could result useless[4,17].

Nevertheless, from a paleoauxological perspective (according to Tillier, 2000)[28], the assumption that the subadult Neanderthal skull is a small isometric equivalent of the adult one is not supported. It is possible, in fact, to identify at least one growth phase in which the Neanderthal features seem only partially expressed.

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ANALIZA OBLIKA MID-SAGITALNOG KRANIOGRAMA U NEKIH EUROPSKIH ODRASLIH I DJEČJIH LUBANJA RAZDOBLJA SREDNJEG I GORNJEG PALEOLITIKA

S A Ž E T A K

Kako bi se odredio oblik lateralne konture kraniuma u Neandertalaca provedene su analize mid-sagitalnih profila (glabella – opistokranium) dječjih i odraslih neandertalskih nalaza, te su rezultati uspoređeni s onima drugih populacija fosilnog roda homo. Veličina normaliziranih granica digitalno je određena kao serija koordinata, udaljenosti od osovine glabella–opistokranium raščlanjena je u Fourijerovim polinomijalima; izvučene amplitude i kutovi faze korišteni su kao varijable kako bi se načinila multivarijatna diskriminantna analiza (PCA). Prve i druge komponente odgovorne su za 70% cjelokupne varijance. Dječji neandertalski i europski gornjopaleolitski nalazi razlikuju se od odraslih individua. Dječji Homo sapiens sličniji je odraslom, jer element koji karakterizira grupu je sastavljen od kosog kraniograma sa zamjetljivom ravnotežom između prednjeg i stražnjeg dijela. Kod dječjih neandertalskih nalaza model koji je primijenjen na odraslima djelomično je opisan i odrasla kranijalna arhitektura dosegnuta je kroz fazu lokalne alometričke diferencijacije.