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Human Activity Patterns and Skeletal Metric Indicators in the Upper Limb

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A B S T R A C T

This study investigates skeletal metric traits of long bones of upper limb and the relationship between these traits and human activity in males of a recent, well-documented skeletal sample of Italian population from the Frassetto collection (Department of Experimental Evolutionary Biology, University of Bologna). The study analyzes the impact of some human activities on the skeleton, taking into account the possibility of an assessment of functional stresses caused by these activities on the basis of metric characteristics. The data consist of measurements of linear and angular bone traits, obtained by traditional and new instruments. With the purpose to find out the best indicators of occupational stress among the measured traits and indices, univariate and multivariate statistical analyses were carried out. Then the results obtained previously were used to analyze a sample with unknown occupation. The efficacy of metric stress indicators is discussed.

***Key words:** skeletal markers, functional stress, long bones, anthropometric traits*

Introduction

Habitual human activities and postures may exert mechanical influences on the skeleton in relation to different levels or types of functional loading. The assessment of reliable indicators of functional stress – also called »skeletal markers of occupational stress« or »activity-induced skeletal markers«[1] – is an important goal for biological anthropologists interested in the behavior and lifestyle of individuals or populations from the past. This is probably the reason why the study of occupational stress markers on human remains has been gaining increasing importance in the field of skeletal biology in recent decades, particularly regarding

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skeletal morphological variations. Only a few researchers have examined the effects of functional stress on bone size in humans, focusing their attention on cortical bone thickness as a stress indicator[2–5] or on several other quantitative traits[6–10].

The present study deals with metric traits of the upper limb in recent human skeletons of individuals with known activities. The main objectives were to determine whether the quantitative approach is adequate to discriminate among different functional stresses by analyzing different human occupational groups and to identify the traits that best assure such discrimination, i.e. the best indicators of biomechanical stress.

Finally, the discriminant functions developed on the basis of the samples with known activity were used to attribute other individuals with unknown occupation (contemporaneous or from past periods) to the groups with the greatest similarity of the type and level of functional stress.

Material and Methods

Skeletal materials

The human skeletal sample consisted of 103 Italian individuals from the Frassetto collection (Department of Experimental Evolutionary Biology, University of Bologna, Bologna, Italy), coming mainly from the cemetery of Sassari, Sardinia; only 7 of them were from the cemetery of Bologna, Emilia-Romagna. The age at death, sex, provenience, and occupation of these individuals were known (being well documented by the cemetery archives). The osteometric data were collected on the right and left long bones of the upper limb (humeri, radii, ulnae). The reference sample comprised only male adults, from 20 to 60 years old, who died at the beginning of the 20th century. Subjects older than 60 years were excluded because of the possible influence of aging on the osteometric traits, as observed in a previous study[11].

Different trades practiced by the subjects were grouped into seven main »activity groups« (Table 1) on the basis of similarities among the physical activities involved; shepherds could not be included in the agricultural group or other activity groups on the basis of the test of homogeneity. We also analyzed the skeletal remains of several beggars – indicated as »inactivity group« – for which we assume that they performed at least some temporary, even if not habitual, occupation, probably characterized by some habitual posture.

TABLE 1
SAMPLE SUBDIVIDED INTO DIFFERENT ACTIVITY GROUPS

Working activity groups	N
Manual activities:	
1. Sheep-rearing	3
2. Agriculture	58
3. Heavy manual activity (1) (brick activity)	9
4. Other heavy manual activity (2) (carpenters, carters, miners)	11
5. Martial activity	7
Non manual activities:	
6. Sedentary activity (students, clerks)	9
Inactivity:	
7. Beggary	4
Total	103

For application purposes and to test the ability of the discriminant functions (developed on the basis of the above-mentioned samples) to classify other individuals from the same Mediterranean area, several specimens of different historical periods were used (Table 2). All these in-

TABLE 2
INDIVIDUALS WITH UNKNOWN OCCUPATION

Skeletal remains	Provenience	Dating	Age (yrs.)
Recent specimens:			
A	Frassetto. (Bologna, Emilia-Romagna)	XX century	24
B	Frassetto. (Bologna, Emilia-Romagna)	XX century	58
C	Frassetto (Sassari, Sardinia)	XX century	43
D	Frassetto (Sassari, Sardinia)	XX century	39
Medieval specimens:			
A – skel. n.1, in small chapel	S. Severo (Ravenna, Emilia-Romagna)	VII–X century AD	~40
B – skel. n.2, in small chapel	S. Severo (Ravenna, Emilia-Romagna)	VII–X century AD	>40
C – skel. 3, out small chapel	S. Severo (Ravenna, Emilia-Romagna)	VII–X century AD	adult
D – tomb A	Strada Maggiore (Bologna, Emilia-Romagna)	VIII century AD	50–60
Ancient specimens:			
A – remain No. 1	S. Margherita di Pula (Cagliari, Sardinia)	II–I century BC	young adult

dividuals were males with unknown occupation; the sex and age were known for the recent ones, while they had been estimated in previous analyses for the others. In particular, four cases were contemporary with the reference sample and were taken from the same collection (Frassetto). The ancient material comprised well-preserved skeletons from various burial sites in Emilia-Romagna or Sardinia. They had been examined in previous anthropological studies[12–14], with the exception of the C-medieval skeleton from the Basilica of S. Severo.

Anthropometric traits

The anthropometric traits were measured on the right and left side for each individual. We considered the following traits, for the humerus: maximum length, trochlear and torsion angles, minimum perimeter; for the radius: maximum length, collo-diaphysial and torsion angles; for the ulna: maximum length, joint axis angle, upper transverse-superior and upper dorso-volar diameters. We also calculated the angle between the ulna and humerus during extension, the elbow angle, as the sum of the trochlear angle of the humerus and joint axis angle of the ulna.

All the linear measurements (lengths and diameters) of the three upper limb bones were taken according to traditional methods[15]. For the humeral trochlear angle and the radial collo-diaphysial and torsion angles, we referred to Wilder's original definitions[16], for the ulnar joint axis angle and the elbow angle to Singh and Bhasin's definitions[17], for the humeral torsion angle to previous definitions[17–18] with modifications[19]; reference no. 19 also contains a critical discussion of various measurement definitions reported in the literature.

The curvature of the shaft was measured by constructing the highest perpendicular to a tangent (chord) along the convex side of the radius[17] or the ulna[16]. For the Curvature Index of the ulna and radius, we used the following formula[17]: (perpendicular/chord) × 100. The Robusticity Index of the humerus and the Platoleny Index of the ulna were also computed[18].

The asymmetry index[6] was calculated for all the linear and angular characters measured, as

$$\frac{|R-L|}{Min(R,L)}\times 100$$

where R is the value of the measure taken on the right side and L is the value measured on the left (for the same individual). Min(R,L) is the minimum value between the measures taken on the right side and on the left.

After a statistical comparison (Kruskal-Wallis non-parametric test) between individuals with different origins (Sardinia and Emilia-Romagna), it was possible to reduce the number of traits used to estimate the influence of habitual activity on the bones. Measurements chosen to evaluate the effects of occupational stress did not take into account the bone lengths, which are traits with a strong hereditary component (Sardinians are a typical Mediterranean population characterized by lower height and generally smaller size than northern Italian populations).

The linear measurements were taken with an osteometric board, metric tape or sliding caliper. The angles were measured with a digital osteogoniometer[19], since intra-observer and inter-observer comparisons for repeated measurements had demonstrated greater precision in angular measurements with this technique than with traditional methods (i.e. it minimizes the parallax error).

Statistics

Means and standard deviations of the twelve traits and the curvature and robusticity indices were provided for the right and left sides, and for the asymmetry indices. Normal distribution of the variables was tested by Shapiro and Wilk's W test, using a mathematical transformation for the humeral torsion angle and ulnar joint axis angle.

After a comparison (see the »Anthropometric traits« section) of the two subsamples with different origins (Sardinia and Emilia-Romagna) by the Kruskal-Wallis non-parametric test for homogeneity between populations, an analysis of variance was performed on the subsamples with different trades with the aim of clustering the single trades in more general and homogeneous activity groups, with an higher number of subjects (see the »Skeletal materials« section). An ANOVA was then applied to the seven new activity groups obtained. The ANOVAs were accompanied by a Bonferroni test for multiple pairwise comparisons of means. Finally, a Stepwise Discriminant Analysis[20] was performed on the 103 individuals of the reference sample. It was carried out in three stages. The first stage generated functions from all possible combinations of the variables in each single bone to identify the relative importance of single skeletal elements in indicating the functional stress level, and thus their relative importance in classifying isolated bones. In the second stage, all the variables of the right and left upper limb were used in the statistical procedure. Finally, the discriminant functions developed in the second stage served to test the skeletal specimens with unknown activity.

Results and Discussion

The general characteristics of the reference sample – without division into activity groups – are reported separately for the right and left sides in Table 3.

Table 4 shows the descriptive statistics for the sample divided into the seven activity groups, with the exclusion of traits (i.e. bone lengths) depending strictly on the population characteristics. ANOVA revealed significant variation among the activity groups for some traits, particularly the asymmetry indices of the radial torsion angle ($p<0.001$) and ulnar joint axis angle ($p<0.01$), as well as some angular traits and curvature indices for the humerus (right trochlear angle, $p<0.001$), for the radius (left collo-diaphysial angle, $p<0.01$; right and left curvature indices, $p<0.001$) and for the ulna (right joint axis angle, $p<0.01$; right elbow angle, $p<0.05$; curvature index on the right, $p< 0.001$, and on the left, $p<0.05$). Post hoc analysis showed significant differences mainly between the sheep-rearing activity group and all the others, with particular reference to its higher values of the humeral trochlear angle, radial torsion angle, ulnar joint axis angle, ulnar curvature index and elbow angle.

We then compared the groups using a discriminant analysis, separately for each long bone and for the upper limb as a whole. The classification functions and the classification matrices for various activity groups are reported in the tables (Table 5), with the variables that best discriminate among the activity groups presented in order of selection by a stepwise procedure. For the humerus, these variables were mainly on the right side: torsion angle, right robusticity index, minimum perimeter. However, the first selected variable was the asymmetry index

TABLE 3
CHARACTERISTICS OF THE REFERENCE SAMPLE

Variables	N	X	SD
HUMERUS			
ML: right (mm)	100	312.9	20.5
left (mm)	99	310.5	19.7
ML Asymmetry index	97	1.2	2.0
TRA: right (°)	100	80.9	4.7
left (°)	99	80.7	4.2
TRA Asymmetry index	97	2.7	3.3
TA: right (°)	98	9.5	6.4
left (°)	96	9.4	6.3
TA Asymmetry index	95	51.3	79.2
MP: right (mm)	101	65.0	4.4
left (mm)	101	63.8	4.4
MP Asymmetry index	99	3.0	2.2
RI: right	100	20.8	1.7
left	99	20.6	1.6
RADIUS			
ML: right (mm)	98	233.5	14.6
left (mm)	99	231.7	14.5
ML Asymmetry index	95	1.0	0.8
CDA: right (°)	99	168.6	3.2
left (°)	100	168.8	2.8
CDA Asymmetry index	97	1.1	1.6
TA: right (°)	98	40.4	15.8
left (°)	99	41.3	15.1
TA Asymmetry index	95	21.7	36.2
CI: right	100	4.4	2.7
left	101	4.2	2.8
ULNA			
ML: right (mm)	98	252.2	15.0
left (mm)	101	250.2	14.8
ML Asymmetry index	96	1.2	0.9
JAA: right (°)	100	82.4	4.1
left (°)	100	82.6	4.0
JAA Asymmetry index	97	2.4	2.7
EA: right (°)	98	163.2	6.3
left (°)	96	163.2	5.4
EA Asymmetry index	92	1.9	2.0
TD: right (mm)	99	19.3	2.4
left (mm)	102	18.7	3.0
TD Asymmetry index	98	6.5	7.3
DD: right (mm)	99	22.1	2.3
left (mm)	102	22.0	2.4
DD Asymmetry index	98	5.2	6.3
CI: right	101	3.3	2.4
left	103	3.3	2.1
PI: right	99	88.3	12.7
left	102	85.7	16.1

ML – maximum lenght; TRA – Trochlear angle; TA – Torsion angle; MP – Minimum perimeter; RI – Robusticity index; CDA – Collo-diaphysial angle; JAA – Joint axis angle; EA – Elbow angle; TD – Transverse-superior diameter; DD – Dorso-volar diameter; CI – Curvature index; PI – Platolenia index

TABLE 4
MEAN (± SD) CHARACTERISTICS OF THE DIFFERENT ACTIVITY GROUPS

Variables	Sheep-rearing	Agricul-ture	Heavy man. activity 1	Heavy man. activity 2	Martial activity	Sedentary activity	Beggary
HUMERUS							
ML Asymmetry I.	1.5(1.6)	1.2(2.5)	1.1(0.8)	1.1(0.9)	1.0(0.4)	0.9(0.8)	1.4(0.7)
TRA: right (°)	84.8(2.3)	80.6(4.0)	84.9(9.0)	80.9(4.8)	81.3(4.0)	78.4(4.1)	82.2(5.6)
left (°)	83.5(4.4)	81.0(3.7)	82.3(5.6)	80.0(4.4)	82.0(1.4)	77.5(3.9)	82.8(5.9)
TRA Asymmetry I.	1.6(1.3)	2.7(3.5)	4.7(5.9)	2.9(1.9)	3.4(1.3)	2.1(1.8)	1.1(0.9)
TA: right (°)	1.7(0.7)	10.1(6.1)	10.2(6.8)	8.7(5.9)	10.3(9.0)	6.0(7.1)	10.0(3.0)
left (°)	2.1(0.2)	10,4(6.5)	9.5(5.8)	8.9(4.8)	7.8(6.4)	6.7(6.9)	8.8(6.4)
TA Asymmetry I.	29.2(41.2)	52.7(93.1)	33.5(52.1)	49.3(25.9)	39.2(62.3)	50.5(65.4)	105.9(67.0)
MP: right (mm)	64.0(5.7)	65.4(4.0)	65.8(5.5)	65.0(4.5)	64.9(3.1)	62.3(6.2)	64.0(5.5)
left (mm)	62.3(4.0)	64.2(4.0)	64.4(6.6)	63.8(4.6)	63.9(3.0)	61.7(5.2)	63.3(5.0)
MP Asymmetry I.	4.0(1.4)	3.3(2.2)	4.6(2.5)	1.9(1.6)	2.0(2.0)	2.7(1.4)	1.2(1.4)
RI: right	20.6(1.1)	21.2(1.8)	20.8(1.9)	20.3(1.0)	20.2(0.8)	20.1(2.0)	20.4(1.4)
left	20.0(1.8)	21.0(1.8)	20.6(2.0)	20.2(1.0)	20.0(0.8)	19.8(1.5)	20.4(1.4)
RADIUS							
ML Asymmetry I.	1.5(1.2)	1.1(0.9)	0.7(0.5)	0.8(0.6)	0.7(0.5)	1.2(0.9)	1.0(0.5)
CDA: right (°)	167.4(3.0)	168.5(3.1)	168.1(3.3)	170.0(3.1)	167.6(1.7)	167.6(3.9)	166.2(5.3)
left (°)	167.2(0.5)	169.2(2.6)	168.6(2.4)	169.8(3.9)	168.4(1.6)	167.2(6.0)	166.7(6.0)
CDA Asymmetry I.	1.3(0.4)	1.2(2.0)	0.9(0.9)	0.9(0.6)	0.4(0.3)	1.3(1.3)	0.9(0.4)
TA: right (°)	55.0(14.6)	40.7(16.6)	36.8(12.6)	43.2(10.6)	32.8(16.0)	42.4(17.2)	31.3(17.8)
left (°)	45.1(13.8)	42.4(16.2)	41.1(12.1)	40.7(12.3)	40.0(17.5)	36.0(14.9)	38.6(16.7)
TA Asymmetry I.	23.3(6.3)	16.9(17.0)	27.2(23.0)	9.3(12.0)	*58.5(120)?*	22.6(34.2)	56.2(55.5)
CI: right	5.0(0.5)	3.9(1.7)	3.0(0.7)	8.1(5.7)	3.6(1.9)	4.2(1.6)	5.2(1.8)
left	5.9(1.6)	3.6(1.7)	2.8(1.0)	7.2(6.0)	3.4(2.1)	4.5(1.3)	6.2(4.2)
ULNA							
ML Asymmetry I.	2.3(1.5)	1.3(0.8)	0.9(0.5)	1.0(1.0)	1.1(0.6)	1.6(1.1)	0.5(0.6)
JAA: right (°)	86.0(3.0)	81.5(3.7)	83.6(49)	84.1(2.7)	83.5(2.8)	83.9(3.6)	80.8(9.0)
left (°)	85.9(1.9)	82.0(3.7)	82.6(5.1)	83.5(2.5)	83.5(4.1)	84.3(3.6)	81.9(9.2)
JAA Asymmetry I.	1.2(0.9)	2.5(2.8)	3.6(2.4)	1.5(1.4)	2.8(5.0)	1.5(1.1)	4.0(4.8)
EA: right (°)	172.5(2.5)	162.0(5.8)	166.5(9.5)	164.9(5.7)	165.9(4.2)	162.0(5.1)	163.0(7.6)
left (°)	169.4(6.3)	162.9(5.3)	162.7(6.9)	163.6(5.0)	165.6(3.8)	160.7(5.6)	164.7(6.1)
EA Asymmetry I.	0.2(0.1)	2.1(2.0)	2.7(3.3)	1.6(1.0)	1.7(1.1)	1.3(1.1)	1.5(2.5)
TD: right (mm)	20.7(1.5)	19.2(2.5)	19.2(1.8)	19.7(3.2)	19.0(3.1)	19.7(1.6)	19.5(2.5)
left (mm)	22.0(2.6)	18.3(2.9)	19.0(2.0)	19.9(3.4)	18.0(3.8)	19.0(2.2)	19.0(4.3)
TD Asymmetry I.	13.6(6.6)	6.9(7.9)	4.1(5.7)	5.1(4.8)	8.0(8.8)	7.7(9.4)	8.5(6.0)
DD: right (mm)	24.3(1.2)	21.6(2.1)	23.1(2.0)	22.8(2.3)	22.7(2.1)	22.0(3.6)	22.0(1.6)
left (mm)	23.7(2.5)	21.4(2.3)	22.9(2.0)	23.0(2.4)	22.4(2.8)	22.6(3.2)	22.8(1.7)
DD Asymmetry I.	5.9(3.1)	5.3(6.7)	2.7(3.1)	5.9(5.8)	11.4(10.2)?	2.5(2.3)	3.5(2.3)
CI: right	10.4(0.7)	3.2(2.2)	2.3(0.8)	3.9(2.2)	2.1(0.5)	3.4(2.6)	3.0(0.8)
left	8.8(0.4)	3.1(2.1)	2.2(0.4)	4.4(1.7)	2.3(0.9)	3.3(2.0)	4.0(1.5)
PI: right	85.2(9.9)	89.7(14.0)	83.3(6.5)	86.9(14.9)	83.8(10.3)	90.8(10.0)	88.6(8.7)
left	94.0(20.6)	86.1(17.7)	83.1(7.5)	87.1(16.4)	81.4(19.2)	85.2(11.7)	83.1(14.7)

ML – maximum lenght; TRA – Trochlear angle; TA – Torsion angle; MP – Minimum perimeter; RI – Robusticity index; CDA – Collo-diaphysial angle; JAA – Joint axis angle; EA – Elbow angle; TD – Transverse-superior diameter; DD – Dorso-volar diameter; CI – Curvature index; PI – Platolenia index

TABLE 5
CLASSIFICATION FUNCTIONS AND MATRICES FOR ACTIVITY GROUPS BY TRAITS (SINGLE LONG BONES)

	Sheep-rearing	Agricul-ture	Heavy man. activity 1	Heavy man. activity 2	Martial activity	Sedentary activity	Beggary
HUMERUS							
MP Asymmetry I.	–1.54895	–1.83855	–1.38434	–2.15807	–2.05027	–1.81844	–2.31794
TA (right)	2.58693	3.65749	4.01808	3.16838	4.57765	2.49471	3.74276
RI (right)	–4.32445	–2.72524	–4.97453	–3.81643	–4.19874	–3.12490	–1.21796
MP (right)	4.16893	4.19096	4.83318	4.55341	4.54581	4.12109	3.72.429
TA (left)	1.36286	2.51755	2.17324	2.60176	1.03784	2.52966	2.22585
TA Asymmetry I.	–0.00764	0.00081	–0.00416	–0.00064	–0.00668	0.00023	0.00924
TRA Asymmetry I.	–0.86197	–0.75988	–0.55818	–0.71018	–0.61558	–0.76727	–0.92477
RI (left)	10.30301	9.01754	10.84105	9.76561	10.00496	9.01459	7.44204
ML Asymmetry I.	–2.00191	–1.92565	–2.26572	–2.08205	–2.02589	–2.04824	–1.63654
MP (left)	–1.58476	–1.57621	–2.17180	–1.84276	–1.83837	–1.62613	–1.10171
Constant	–145.24860	–158.20503	–154.54729	–155.39583	–152.30882	–139.24835	–156.15457
Classification matrix: correct (%)	100.0	29.8	37.5	50.0	42.9	42.9	25.0
RADIUS							
CI (right)	–3.39840	–3.16107	–3.26155	–2.58667	–3.31769	–3.24347	–2.95330
CDA (left)	21.21333	21.23155	21.06111	21.27672	21.18355	20.82144	20.62003
TA Asymmetry I.	0.23960	0.21758	0.22172	0.21752	0.25231	0.22411	0.24403
CI (left)	9.92523	9.04608	8.88219	9.22764	9.29002	9.20881	9.10845
TA (right)	1.14882	0.97520	0.91032	1.00465	0.93369	1.05856	0.82932
TA (left)	–0.41746	–0.29404	–0.23928	–0.31496	–0.26187	–0.38681	–0.16024
ML Asymmetry I.	12.16276	11.70812	11.16292	11.12922	11.03010	11.61013	11.10227
CDA Asymmetry I.	5.50960	5.46992	5.26429	5.46811	5.04785	5.52177	5.12812
CDA (right)	5.10819	5.18412	5.22053	5.26737	5.06877	5.33686	5.04269
Constant	–2261.1545	–2269.7754	–2245.3596	–2295.3894	–2242.6245	–2226.8425	–2145.6389
Classification matrix: correct (%)	66.7	49.1	70.0	60.0	16.7	50.0	66.7
ULNA							
CI (right)	–2.86025	–4.70891	–4.91709	–5.36539	–5.01851	–4.52458	–5.40103
DD Asymmetry I.	–0.79891	–0.75019	–0.90838	–0.76352	–0.51679	–0.82576	–0.86573
CI (left)	3.22207	3.34644	3.10674	4.12065	3.17195	2.87153	4.39227
EA (right)	–0.61627	–0.72828	–0.44569	–0.54719	–0.66328	–0.67921	–0.60033
EA (left)	6.24652	5.89754	5.70047	5.78121	5.89169	5.76883	5.93388
ML Asymmetry I.	15.65808	14.37704	13.89198	14.13967	14.19226	15.12983	13.04956
JAA Asymmetry I.	5.27834	4.69538	4.99365	4.77713	4.58089	4.66040	5.23119
EA Asymmetry I.	–5.41654	–4.23154	–4.40479	–4.36457	–4.34087	–4.53637	–4.62113
PI (right)	45.62799	45.40794	45.20627	45.29570	45.28294	45.76746	45.01707
TD (left)	3.25134	2.82994	3.11818	3.56907	3.44691	3.22725	3.11305
PI (left)	–0.21947	–0.16294	–0.13377	–0.22304	–0.22163	–0.15929	–0.21084
DD (right)	189.27214	188.19751	187.75639	187.61035	187.84885	189.79553	186.43953
TD (right)	–218.02167	–216.57990	–216.13959	–216.36812	–216.54367	–218.60555	–214.70340
Constant	–2541.6963	–2431.6641	–2433.0281	–2432.7839	–2430.2156	–2453.8701	–2423.7481
Classification matrix: correct (%)	100.0	32.1	62.5	44.4	80.0	71.4	75.0

ML – maximum lenght; TRA – Trochlear angle; TA – Torsion angle; MP – Minimum perimeter; RI – Robusticity index; CDA – Collo-diaphysial angle; JAA – Joint axis angle; EA – Elbow angle; TD – Transverse-superior diameter; DD – Dorso-volar diameter; CI – Curvature index; PI – Platolenia index

TABLE 6
CLASSIFICATION FUNCTIONS AND MATRICES FOR ACTIVITY GROUPS BY TRAITS (ALL LONG BONES)

Variables	Sheep-rearing	Agricul-ture	Heavy man. activity 1	Heavy man. activity 2	Martial activity	Sedentary activity	Beggary
Humerus + Radius + Ulna							
CI (right) *U*	–10.2226	–12.68619	–12.76444	–13.55739	–12.82211	–12.08875	–12.26347
CI (right) *R*	–1.42788	–1.65137	–1.44812	–0.66301	–1.40363	–1.49909	–1.17429
TA Asymm. I. *R*	–0.24418	–0.38756	–0.33622	–0.39105	–0.41715	–0.37670	–0.20643
CDA (right) *R*	6.33223	10.50354	10.38985	9.84273	10.17711	10.31390	9.60987
DD Asymm. I. *U*	–7.08477	–6.53601	–6.80848	–6.67449	–6.34288	–6.70992	–6.96149
MPAsymm. I. *H*	1.31871	2.44594	2.79404	1.64448	1.99730	2.66762	1.28137
TA (left) *H*	–14.86382	–4.87403	–6.02765	–6.94448	–7.14480	–6.51763	–13.74866
RI (left) *H*	24.07069	25.33690	25.49431	23.86745	24.35942	24.59418	23.91455
TA (right) *H*	–0.91917	–2.49626	–1.20360	–1.75329	–0.99416	–1.98232	4.35143
DD (left) *U*	56.38988	57.51894	59.52229	57.90607	58.26208	60.55437	62.01433
PI (left) *U*	14.88412	15.14601	15.62173	15.20047	15.23073	15.86693	16.13004
MP (right) *H*	2.31989	2.40070	2.40208	2.31289	2.49274	1.85026	1.77289
CDA (left) *R*	29.41776	26.03125	26.11160	26.72939	26.13719	25.68768	25.77126
JAA Asymm. I. *U*	9.68523	6.59246	6.79064	7.18244	6.72421	6.65503	8.24898
PI (right) *U*	0.40312	1.33985	1.20953	1.02042	1.14312	1.33856	1.11809
ML Asymm. I. *R*	17.22520	8.34686	7.83270	8.83585	8.30867	8.21710	9.55091
EA Asymm. I. *U*	4.50220	9.15382	9.23941	8.44395	8.62541	8.79637	7.80814
EA (right) *U*	2.22901	1.27726	1.47898	1.67204	1.31484	1.26190	1.68038
EA (left) *U*	7.04395	6.71927	6.47121	6.59132	6.76740	6.47199	6.39563
TD (left) *U*	–79.32611	–85.05429	–86.77116	–83.59695	–84.76358	–87.79517	–87.97141
CI (left) *U*	3.16699	0.55764	0.19536	0.98958	–0.42619	–0.61456	0.94963
CI (left) *R*	13.37429	16.04776	15.60586	15.88863	16.46175	16.61217	15.67900
TA Asymm. I. *H*	–0.02590	0.01414	0.01000	0.01730	0.00577	0.02098	0.00770
CDA Asymm. I. *R*	8.44987	8.05055	7.83954	8.13076	7.54382	8.32770	7.58163
TA (right) *R*	2.06169	0.89806	0.81452	1.10928	0.86705	0.85280	1.09630
TA (left) *R*	–1.98884	–0.75500	–0.68834	–0.97176	–0.77290	–0.76886	–1.01045
ML Asymm. I. *H*	10.19314	7.35033	7.35949	8.23018	7.43655	7.42237	8.59996
DD (right) *U*	10.76955	13.85545	13.74227	12.96584	13.29106	14.24334	13.00924
ML Asymm. I. *U*	–3.59785	–0.19487	–0.30780	–0.67910	–0.28137	–0.40217	–2.82544
RI (right) *H*	–23.21468	–25.60927	–26.42313	–24.27136	–25.35439	–25.28969	–23.16873
TRA Asymm. I. *H*	–8.92179	–9.00161	–8.98510	–9.11713	–8.80637	–8.84004	–8.86414
Constant	–4536.9648	–4512.2617	–4524.0234	–4545.4453	–4475.0938	–4419.1680	–4406.6680
Classification matrix: correct (%)	100.0	74.5	87.5	77.8	80.0	100.0	100.0

ML – Maximum lenght; TRA – Trochlear angle; TA – Torsion angle; MP – Minimum perimeter; RI – Robusticity index; CDA – Collo-diaphysial angle; JAA – Joint axis angle; EA – Elbow angle; TD – Transverse-superior diameter; DD – Dorso-volar diameter; CI – Curvature index; PI – Platolenia index; Asymm. I. – Asymmetry index; H – Humerus; R – Radius; U – Ulna

of minimum shaft perimeter. Only the first four functions discriminated significantly ($p<0.05$) among the activity groups, as shown by Wilk's lambda and the approximate F statistics, whose values (a transformation of Wilk's lambda) can be compared with the F distribution. The first selected variable for both the radius and ulna was the curvature index of the right shaft. The next selected variables were: for the radius, the collo-diaphysial angle, torsion angle asymmetry index and curvature index (left); for the ulna, the dorso-volar diameter asymmetry index, curvature index (left) and elbow angle. The first six (radius) and ten (ulna) functions discriminated significantly among activities. The reported classification matrix was computed by classifying each case into the activity group with the highest posterior probability. On the basis of the single long bones, the greatest probability of misclassification was for the martial activity group using the radius (83.3%). The correct classification of sheep-rearers based on either humeral or ulnar traits approached 100%. The accuracy of classification was also good for the heavy manual activity 1 group using the radius (70%) or ulna (62.5%), and for the martial (80%) and sedentary (71.4%) activity groups and beggars (75%) using the ulna. Nevertheless, the classification values are an optimistic estimate of correct classification, since the values were lower when the Jackknifed classification matrix was used to confirm previous results (cross-validation method).

TABLE 7
PERCENT OF CORRECT CLASSIFICATION WITH LONG BONES CONSIDERED ONE BY ONE OR TOGETHER ON ALL THE SUBJECTS

Long bone	% correct
Humerus	35.8
Radius	51.6
Ulna	45.5
Humerus + radius + ulna	79.8

The results of the discriminant analysis using all the upper limb variables are presented in Tables 6 and 8. The selection of variables by the stepwise procedure confirmed the importance of traits measured on the right side, particularly the curvature indices of the radial and ulnar shafts and the radial collo-diaphysial angle. The asymmetry indices are very important, especially those of the radial torsion angle, ulnar dorso-volar diameter and humeral minimum perimeter. The humerus appears to have less importance for discrimination: the first humeral trait selected (asymmetry index of minimum perimeter) gained only the sixth position and the last two traits selected were humeral ones. However, the percentage of correct classifications (Table 7) on the total number of cases increased when all the variables (humeral, radial, ulnar) were combined: additional discriminant power was generally obtained and there was an exceptionally good result for all the activity groups. Misclassification was low (about 25%) even in the group with

TABLE 8
EIGENVALUES AND CANONICAL CORRELATIONS (DISCRIMINANT ANALYSIS ON ALL THE UPPER LIMB VARIABLES)

Discriminant function	Eigenvalue	Cumulative proportion of total dispersion	Canonical correlation
1	2.35611	0.43588	0.83788
2	0.98998	0.61902	0.70532
3	0.86284	0.77865	0.68058
4	0.48013	0.86747	0.56955
5	0.40118	0.94169	0.53508
6	0.31519	1.00000	0.48954

the lowest number of correct classifications (agricultural) (Table 6).

The eigenvalues are shown in Table 8. The first canonical variable accounted for 43.6% of the total dispersion, indicating a considerable degree of overlap among individuals of different activity groups. Using the first two canonical variables as the axes, we plotted the centroids of the different activity groups (Figure 1). It can be seen that the sheep-rearing group is the one most different from the others, i.e. it is at a much greater distance from all the other groups than any other two groups are from each other. The beggary group is also rather far from the remaining activity groups, which seem to cluster together at the left of the plot.

The discriminant functions obtained for the whole upper limb were used to classify subjects with unknown activity, and their ability to classify the unknown cases is shown in Table 9. This classification only provides some indications, on a probabilistic basis, of possible similarities of functional stress. For example, in the most ancient specimen (II–I century BC), the characteristics of the upper limb long bones are indicative, with a probability of 37.4%, of functional stress like that of individuals in the martial group.

Conclusions

The skeletons of Italian individuals with known occupation from the Frassetto collection provides an important opportunity to examine the effects of functional stress. Nevertheless the small number of subjects for some activity groups (martial activity, beggary, sheep-rearing) and the relationship between the percentage of correct classification and the sample size are an evident limitation of the current study. Several further limitations concern the following possibilities: (i) different activities could give rise to similar functional stresses; (ii) individuals of the same activity group could perform different tasks with different types and levels of stress; (iii) similar biomechanical stresses could have different effects on individuals owing to human variability.

Nevertheless, this study represents a different approach to the reconstruction of habitual human activities and lifestyles using the metric characteristics of a reference sample of known sex and

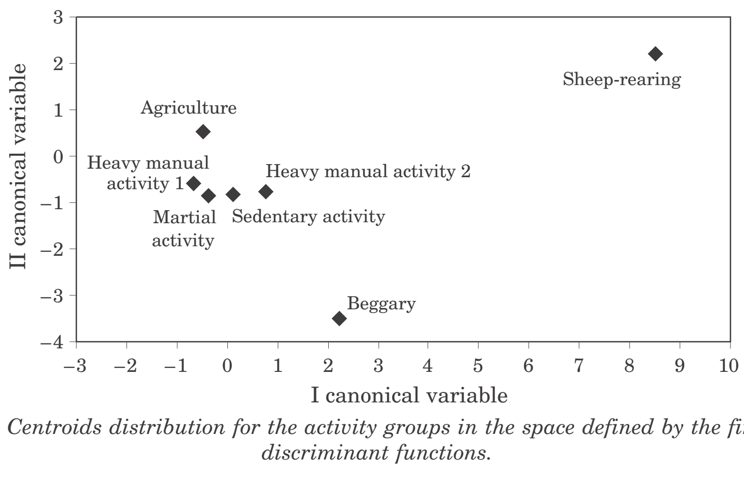

Fig. 1. Centroids distribution for the activity groups in the space defined by the first two discriminant functions.

TABLE 9
PERCENTAGE OF CORRECTLY CLASSIFIED SUBJECTS FROM DIFFERENT SAMPLES AND HISTORICAL PERIODS

	1	2	3	4	5	6	7
Unknown cases	Sheep-rearing	Agriculture	Heavy man. activity 1	Heavy man. activity 2	Martial activity	Sedentary activity	Beggary
Recent specimens							
A	–	–	–	–	42.3%	–	–
B	–	–	–	–	42.1%	–	–
C	46.0%	–	–	–	–	–	–
D	–	40.4%	–	–	–	–	–
Medieval specimens							
A	–	49.0%	–	–	–	–	–
B	–	–	–	–	49.2%	–	–
C	–	–	–	–	30.2%	–	–
D	–	–	37.6	–	–	–	–
Ancient specimens							
A	–	–	–	–	37.4	–	–

trades. There were three specific findings from this research.

First, it was demonstrated that the metric traits of the upper limb are useful for the identification of functional stress, especially the curvature indices of the radial and ulnar shafts, some asymmetry indices between sides, i.e. of the radial torsion angle, ulnar dorso-volar diameter and humeral minimum perimeter, and the radial collo-diaphysial angle. These traits and indices have functional implications, related to the mechanical action on the bone (curvature indices and stressed angle values) and the prevalent use of one arm during an activity (asymmetry indices).

Second, comparison of the results for the proximal and distal bones of the upper limb indicate that the metric traits of the forearm (radius and ulna) contribute more to the discrimination among activities than those of the arm (humerus). Moreover, the traits on the right side are more informative than those on the left. However, the greatest accuracy of attribution of individuals to each activity group is obtained when the whole upper limb is considered.

Third, the attribution of new cases to probable activity groups based on similarity of functional stress should be considered reliable only for subjects of the same epoch and sample. Thus the discriminant functions should be applied to individuals from the same populations used to produce them or from similar populations, as has been observed in studies on sexual dimorphism[21].

For ancient skeletal remains, the predicted attribution to a given activity group may indicate a similar type and level of functional stress, although the limits in attempting to reconstruct the habitual activities and lifestyle of individuals from the past must be carefully considered and the caution in making inferences must be underlined. A further limitation of the study of ancient skeletal remains could be poor preservation of the segments of the upper limb. Incomplete measurements on such specimens may affect the results, influencing the percentage of correct classifications (and misclassifications).

These preliminary findings indicate the potentiality of a metric approach as an additional tool in the set of methods used to determine functional activity. Indeed, the use of metric indicators in association with morphological indicators could produce a more complete pattern of the functional stresses.

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REFERENCES

1. PALFI, G., O. DUTOUR, Int. J. Anthropol., 11 (1996) 41. — 2. RUFF, C. B., E. TRINKAUS, A. WALKER, C. S. LARSEN, Am. J. Phys. Anthropol., 91 (1993) 21. — 3. MAYS, S. A., Am. J. Phys. Anthropol., 112 (2000) 349. — 4. MAYS, S., Am. J. Phys. Anthropol., 116 (2001) 34. — 5. LARSEN, C. S.: Bioarchaeology: Interpreting behavior from the human skeleton. (Cambridge University Press, Cambridge, 1997). — 6. BORGOGNINI TARLI, S., M. MASALI, Osteometria e morfoscopia dello scheletro: Indicatori metrici di stress funzionale, alimentare e ambientale. In: BORGOGNINI TARLI, S., E. PACCIANI (Eds.): I resti umani nello scavo archeologico: Metodiche di recupero e studio. (Bulzoni ed., Roma, 1993). — 7. TRINKAUS, E., J. Hum. Evol., 25 (1993) 393. — 8. RUFF, C. B., J. Hum. Evol., 16 (1987) 391. — 9. BELCASTRO, M. G., F. FACCHINI, Coll. Antropol., 25 (2001) 387. — 10. KENNEDY, K. A. R., Skeletal markers of occupational stress. In: ISCAN, M. Y., K. A. R. KENNEDY (Eds.): Reconstruction of life from the skeleton. (Alan Liss, New York, 1989). — 11. GUALDI RUSSO, E., Anthrop. Anz., 56 (1998) 289. — 12. MARTUZZI VERONESI, F.: Esame antropologico dei resti scheletrici rinvenuti nel Sacello della Basilica di S. Severo (Ravenna). (La Grafica Emiliana, Bologna, 1968). — 13. GRUPPIONI, G.: Reperti scheletrici altomedioevali rinvenuti a Bologna. (Seminario di Scienze Antropologiche. Stamperia editoriale Parenti, Firenze, 1980). — 14. GRAFFI BENASSI, E., G. GRUPPIONI, Rivista di Antropol., 62 (1982–83) 1. — 15. MARTIN, R., R. KNUSSMANN: Anthropologie. Band I.: Wesen und methoden der Anthropologie. (Gustav Fisher Verlag, Stuttgart, 1988). — 16. WILDER, H. H.: A laboratory manual of anthropometry. (Blakiston's Son & Co., Philadelphia, 1920). —17. SINGH, I. P., M. K. BHASIN: Anthropometry. (Bharti Bhawan, Delhi, India, 1968). — 18. MARTIN, R., K. SALLER: Leherbuch der Antropologie. (Gustav Fisher Verlag, Stuttgart, 1957). — 19. GUALDI-RUSSO, E., P. RUSSO, Anthrop. Anz., 53 (1995) 153. — 20. JENNRICH, R., P. SAMPSON, Stepwise discriminant analysis. In: DIXON, W. J. et al. (Eds.): BMDP Statistical Software Manual. (University of California Press, Berkeley, 1988). — 21. SAFONT, S., A. MALGOSA, M. E. SUBIRÀ, Am. J. Phys. Anthropol., 113 (2000) 317.

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UZORCI LJUDSKE AKTIVNOSTI I SKELETNI METRIČKI INDIKATORI NA GORNJIM UDOVIMA

S A Ž E T A K

Ova studija istražuje skeletne metričke osobine na dugim kostima gornjih udova i njihov odnos s aktivnosti u recentnih muškaraca dobro dokumentiranog uzorka skeletnih ostataka talijanske populacije iz Frassetto kolekcije (Department of Experimental Evolutionary Biology, University of Bologna). Studija analizira utjecaj nekih aktivnosti na skelet, uzimajući u obzir mogućnost procjene funkcionalnog stresa uzrokovanog ovim aktivnostima na temelju metričkih karakteristika. Podaci se sastoje od mjerenja linearnih i kutnih osobina kostiju, dobivenih tradicionalnim kao i novim instrumentima. Kako bi se našli najbolji indikatori okupacijskog stresa među mjerenim osobinama i indeksima, provedena je univarijatna i multivarijatna statistička analiza. Potom su prethodno dobiveni rezultati korišteni u analizi uzorka nepoznatog zanimanja, a raspravljena je i učinkovitost indikatora metričkog stresa.