Activity Patterns in the Sahara Desert: An Interpretation based on Cross-Sectional Geometric Properties

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ABSTRACT The Garamantian civilization flourished in modern Fezzan, Libya, between 900 BC and 500 AD, during which the aridification of the Sahara was well established. Study of the archaeological remains suggests a population successful at coping with a harsh environment of high and fluctuating temperatures and reduced water and food resources. This study explores the activity patterns of the Garamantes by means of cross-sectional geometric properties. Long bone diaphyseal shape and rigidity are compared between the Garamantes and populations from Egypt and Sudan, namely from the sites of Kerma, el-Badari, and Jebel Moya, to determine whether the Garamantian daily activities were more strenuous than those of other North African populations. Moreover, sexual dimorphism and bilateral asymmetry are assessed at an intra- and inter-population level. The inter-population comparisons showed the Garamantes not to be more robust than the comparative populations, suggesting that the daily Garamantian activities necessary for survival in the Sahara Desert did not generally impose greater loads than those of other North African populations. Sexual dimorphism and bilateral asymmetry in almost all geometric properties of the long limbs were comparatively low among the Garamantes. Only the lower limbs were significantly stronger among males than females, possibly due to higher levels of mobility associated with herding. The lack of systematic bilateral asymmetry in cross-sectional geometric properties may relate to the involvement of the population in bilaterally intensive activities or the lack of regular repetition of unilateral activities. Am J Phys Anthropol 146:423–434, 2011. © 2011 Wiley-Liss, Inc.

Physical activity has been shown to influence long bone diaphyses through structural modeling or remodeling (Bass et al., 2002; Weiss, 2003; Lieberman et al., 2004; Ruff et al., 2006; Shaw and Stock, 2009a,b). Based on this, a number of archaeological studies have used this approach to interpret past activity patterns (see for example, Stock and Pfeiffer, 2001; Holt, 2003; Marchi et al., 2006; Stock, 2006; Marchi, 2008; Ruff, 2008 and references therein; Sparacello and Marchi, 2008; Stock et al., 2011).

This article applies cross-sectional geometric principles to study the activity patterns of a late Holocene Saharan population, the Garamantes. The Garamantian civilization developed in Fezzan, South-West Libya, at a time when the desertification of the Sahara had reached levels comparable to the present. The Garamantes are most likely the settled descendants of mobile Neolithic Pastoral Saharan communities (Mattingly, 2000; Di Lernia et al., 2002). In addition to the first urbanism in the Central Sahara, the Garamantes also developed other important innovations in the region, such as irrigated agriculture, trans-Saharan trade and a hierarchical, probably slave-using society. Garamantian society went through various stages of development which included a substantial population increase. In the Early phase (1000–500 BC), the settlements were located on defensible locations and the economy was based on irrigated agriculture. In the Proto-Urban phase (500–1 BC), the building of the capital of the state, Garama, began, whereas settlements were primarily located at the bottom of the valleys. In the Classic phase (1–400 AD), Garama was completed and adorned with public buildings. In addition, other urban settlements and villages grew up around it. Finally, in the Late phase (400–700 AD), there was a renewed interest in defensive structures as a result of the collapse of the centralized state. During this period, agricultural activity was restricted to oases and trade exchanges decreased (Mattingly, 2006). Little is known about the fate of the Garamantes after the fragmentation of their kingdom as a result of the further lowering of the water table around 500 AD (Barker, 2006). Some scholars propose an ancestor-descendant relationship between the Garamantes and the Tuareg (Pace et al., 1951) or the Teda (Newbold, 1928), although no evidence for such relationships exists.

Although much is known archaeologically about the Garamantes, no study of their markers of activity has been conducted, much as this would be of particular interest in terms of the evaluation of the stresses imposed by the desert environment on a daily level. Current

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understanding of the Garamantian period (Mattingly, 2003a,b,c,d) allows a number of predictions regarding the activity patterns of the population to be made. At first, one of the main subsistence activities of the population was agriculture based on subterranean channels (foggaras), and later, as the water levels dropped even further, on wells (Wilson, 2003). The construction and maintenance of these structures must have demanded substantial labor, particularly among male subjects. Agriculture itself involves numerous activities throughout the year as part of field preparation and tending, planting and harvesting. In terms of sexual division of labor, significant inter-population differences can be found in agricultural societies (Hudson, 1976; Bridges, 1989; Meyerson, 1990; Bolin, 1998). However, the general pattern is that economic activities tend to be less sex-specific than among hunter-gatherer groups (Murdock and Provost, 1973; Ruff, 1987). The advent of farming is generally associated with decreased diaphyseal asymmetry in the upper and lower limbs, although there is no consistent trend in limb robusticity (Larsen, 1981; Ruff et al., 1984; Ruff, 1987; Bridges, 1989; Ruff, 2000; Marchi et al., 2006). No specific archaeological evidence exists for sexual division of labor among the Garamantes. However, given the pivotal role of agriculture in the Garamantian economy, and the fact that both sexes must have engaged in the various tasks, we would expect relatively low levels of sexual dimorphism and bilateral asymmetry in the cross-sectional geometric properties of the upper and lower limbs (although also see below).

Keeping livestock was also important to the Garamantes (Mattingly, 2003d), although in state-level societies herding is usually performed by a specialized subset of the population (Bonte, 1981; Chang and Koster, 1986). It is not clear to what extent the Garamantes had to cover long distances on foot as part of pastoralism-related mobility; however, the uneven terrain should have imposed great stresses on the lower limbs of the population even when the individuals covered small distances (Ruff, 1999; Pearson and Cordero, 2004; Marchi et al., 2006; Pearson et al., 2006; Sparacello and Marchi, 2008). Indeed, the landscape in Fezzan is variable, comprising great sand seas (Dahān Ubārī and Dahān Murzuq), gravel and boulder strewn wastelands, and hyperarid rock plateaux (Cremaschi and Di Lernia, 1996a,b; Di Lernia et al., 1997). Among agro-pastoralist societies, the main production activities are usually associated with males, whereas females are engaged in more sedentary tasks (Ehrenberg, 1989). The archaeological data available do not allow any clear predictions to be made. Nevertheless, we would expect the Garamantes to conform to the general pattern observed in other agro-pastoral societies, with males more involved in livestock keeping and consequently more mobile than females, a pattern which should manifest as somewhat greater robusticity in the lower limbs of male subjects.

Other significant economic activities of the Garamantes included metallurgy, working of semi-precious stones and beads, as well as pottery production (Mattingly, 2003d). These may have influenced the morphology of the major limb bones, but since such specialized tasks would have engaged only a small part of the population under study, it is unlikely that clear signs of such activities will be identified in our sample. Trans-Saharan trade was also a fundamental economic activity for the population and spanned sub-Saharan Africa, Egypt, and the Mediterranean littoral of North Africa. Trade presupposed long-distance traveling (Mattingly, 2003a,d), but since these trips took place on camels, they should also not have led to increased lower limb diaphyseal robusticity.

Another activity that must have imposed significant loads on the entire skeleton of male individuals was their involvement in the construction of private houses and public buildings. Indeed, in the Classic Garamantian phase monumental architecture appeared, while in the Early and Late Garamantian phases strong fortifications were built (Mattingly, 2003c). Finally, the Garamantes, especially in the Early and Late phases, appear to have engaged in hostile encounters with their neighbors, particularly the Romans and populations from sub-Saharan Africa. This is suggested by the placement of habitation sites on positions with strong natural defenses, protected further by walls and defensive structures (Mattingly, 2003c). The above tasks should result in males exhibiting more robust upper and lower limbs than females, while warfare may also increase the levels of bilateral asymmetry among males as a result of the unilateral use of weapons (Sparacello et al., 2011).

Therefore, Garamantian activities were variable and imposed several different loads across the skeleton and between the sexes. The main hypotheses that can be formulated based on the activities discussed above are the following: The two principal economic activities of the population, agriculture and herding, result in different patterns of robusticity and dimorphism. A large portion of the population is expected to have engaged in agricultural production, whereas herding possibly involved a subset of males. As a result, we would expect relatively low levels of sexual dimorphism and rather low levels of mobility in the majority of the individuals under study. Despite the low sexual dimorphism expected by the subsistence practices, the engagement of males in warfare and construction work should result in increased robusticity and greater bilateral asymmetry among male subjects. Moreover, the harsh Central Saharan environment is expected to have forced the Garamantes to work with greater intensity, resulting in greater upper and lower limb robusticity in comparison to other North African populations occupying a less inhospitable environment. Finally, in terms of subsistence practices, the Garamantes should be more similar in lower limb robusticity to other sedentary populations, and less robust than populations who relied primarily on pastoralism.

MATERIALS AND METHODS

Osteological samples

The Garamantian sample analyzed in the present study is currently kept at the Museum of Jarma, Department of Antiquities of Libya. The date of the material spanned the entire Garamantian period, from the Early to the Late phase, and was excavated at several sites around Garama since the 1950s. Specifically, some of the material was excavated by a Sudanese archaeologist, Mohammed Ayoub (1968a,b), but was very poorly recorded, while the bulk of the skeletons under study came from a number of excavations conducted by Charles Daniels (Daniels, 1989; Nikita et al., 2010) and by the Desert Migrations Project (Mattingly et al., 2008, 2009, 2010).

In addition, el-Badari, Kerma, and Jebel Moya individuals, currently curated at the Duckworth Laboratory, University of Cambridge, UK, were studied for comparative purposes. These populations occupied environments with more ample water resources than the Garamantian territory, so they should give us an indication of how much more strenuous life for the Garamantes was in the hyper-arid Central Sahara. Moreover, as will be described below, the activity patterns of these groups were different, with the el-Badari greatly relying on nomadic pastoralism, the Jebel Moya initially also being nomadic herders and later becoming sedentary, and the Kerma relying on agriculture, trade and herding. Thus, based upon overall behavioral patterns, we would generally expect to find a greater similarity between the Garamantes and the people from Kerma than between them and those from el-Badari and the Jebel Moya.

The Badarian skeletons examined came from the site el-Badari, Northern Upper Egypt. They were excavated by Sir Flinders Petrie in 1924–1925, from predynastic sites near Badari. The Badarian culture is associated with the earliest evidence of agriculture in Upper Egypt and dates to approximately 5000–4000 BC (Brunton and Caton-Thompson, 1928; Arkell and Ucko, 1965; Hassan 1988; Kobusiewicz, 1992; Wetterstrom, 1993; Keita, 2005). Among the cultivated species were barley, wheat, flax, vegetables, lentils, tubers, and various fruits, such as watermelon and dates (Arkell and Ucko, 1965; Hendrickx and Vermeersch, 2000; Phillipson, 2005). Herding was also an important subsistence activity. Domesticated livestock included cattle, goats, sheep, and pigs (Arkell and Ucko, 1965). Fishing, especially of Nile perch, was also of major importance, and may have been the principal economic activity at certain times of the year (Hendrickx and Vermeersch, 2000). Despite the presence of wild bovine remains at el-Badari, it appears that hunting was only a marginal activity (Hendrickx and Vermeersch, 2000; but also see Arkell and Ucko, 1965). The lack of remains of permanent constructions and the rather thin layer of animal dung possibly indicate that the settlement was not permanent. Indeed, the Badarians were probably primarily semi-nomadic egalitarian pastoralists rather than sedentary farmers (Hassan 1988; Hendrickx and Vermeersch, 2000; Midant-Reynes, 2000).

The Kerma skeletons incorporated in the current analyses were excavated in the "Eastern Cemetery" at Kerma by Reisner in 1913–1914 and 1915–1916, and belong to the Middle (2000–1700 BC) and Classic (1700–1550 BC) Kerma periods (Keita, 1988). Kerma was the capital of the Kingdom of Kush, in Upper Nubia (Hafsaas-Tsakos, 2009). The location of the city on the east bank of the Nile provided it with ample water and formed a continuous oasis. As a result, there were large areas available for cultivation and pasture. Indeed, agriculture was well developed and herding was also an important economic activity (Trigger, 1976; Adams, 1977; Chaix and Grant, 1993). Kerma's economy was additionally based on trade and craft production. Faience, copper objects, and fine ceramics were produced by skilled artisans (Cremin, 2007), while the city controlled the trade between Egypt, central Africa, and the East (Kendall, 1997; Edwards, 2004; Hafsaas-Tsakos, 2009). The variation in the size of the tombs and the grave goods suggests that the society was hierarchical (Chaix and Grant, 1993).

The Jebel Moya material is dated to the 1st millennium BC, and was excavated at the site of Jebel Moya, 250 km South-Southeast of Khartoum, Sudan, between 1911 and 1914 (Mukherjee et al., 1955). Although there have been no comprehensive geological studies of the area, Jebel Moya is located in a basin-like valley. Permanent water sources made this location favorable to occupation (Williams et al., 1982), although the site is thought to have been probably the annual meeting place of widely distributed mobile small groups that herded cattle and goats. It is only after 500 BC that the settlement became permanent and flourished. During the 8th century, imported goods started appearing, several of which were luxury objects (for example, beads and amulets made from faience and semi-precious stones) and possibly suggest the emergence of a social hierarchy (Gerharz, 1994).

TABLE 1. Sample distribution per population and sex

	Garamantes	Jebel Moya	Kerma	Badari
Males	13	47	31	5
Females	29	22	37	5
Total	42	69	68	10

Sample sizes by population and sex are presented in Table 1. Not all of the individuals examined preserved the entire skeleton; therefore, analysis-specific sample sizes are given throughout the article. Due to the small sample sizes under study, no age control was performed other than the use of only adult material, with fused long bone epiphyses. Adult skeletons displaying poor preservation or diseases that could affect diaphyseal shape were excluded, as were individuals who did not preserve the femoral head. Sex was estimated by considering classic macroscopic aspects of the skull and the pelvis (Buikstra and Ubelaker, 1994).

Methods of analysis

For the examination of the impact of mechanical loading on bones, biomechanical principles were utilized. It has been shown that a beam model is suitable for long bone diaphyses (Frost, 1973; Huiskes, 1982; Wainwright et al., 1982). Based on this model, mathematical formulae designed to assess the mechanical strength of hollow beams are applied to the cross-sectional geometry of long bone diaphyses to predict the resistance of the elements to bending or torsional forces (Ruff et al., 1993; Shackelford, 2007).

The cross-sectional morphology of clavicles, humeri, ulnae, radii, femora, and tibiae was assessed using a periosteal mould based technique, which excludes the medullary cavity. Although this causes some miscalculations of true section properties, these are not severe enough to significantly affect our comparisons. Recent studies have indeed found very high correlations between biomechanical properties and external bone dimensions (Rockhold, 1988; Pearson, 2000; Wescott, 2001; Stock and Shaw, 2007). In addition, Sparacello and Pearson (2010) showed that cortical thickness has minimal impact on the average biomechanical properties of most groups, and thus the information obtained from subperiosteal contours can be used to characterize intergroup differences in bending rigidity. It should be noted that, given the endosteal expansion that occurs with aging, the exclusion of the medullary cavity has a small benefit in cases such as ours where there is no age control of the samples.

The moulds were taken at the mid-shaft of all elements except for the humeri, for which the 35% distance from the distal end was used to avoid the deltoid muscle attachment. For the making of the moulds, Coltene President polysiloxane impression material was used. Each mould was then digitized and cross-sectional geometric properties were estimated using the software package Image J using Moment Macro (www.hopkinsmedicine.org/fae/macro.htm). During digitization, all bones were oriented antero-posteriorly, except for the clavicles that were oriented supero-inferiorly.

Among the estimated cross-sectional geometric properties, TA, the total sub-periosteal area, is a measure of bone "robusticity" and periosteal expansion, and is related to bending/torsional strength (Ruff et al., 1993; Ruff, 2008). Second moments of area express resistance to bending loads applied antero-posteriorly (I_x) and mediolaterally (I_y), and are calculated in relation to centroidal axes oriented through the bone cross-section. In the case of the clavicles, I_x expresses resistance to loads applied supero-inferiorly and I_y to those applied antero-posteriorly. In addition, the maximum ($I_{\max}$) and the minimum ($I_{\min}$) second moments of area are measures of the maximum and minimum bending rigidity, respectively. In this study, the second moments of area were calculated not to be used per se, but to estimate the ratios of I_x/I_y and $I_{\max}/I_{\min}$. These are useful indicators of cross-sectional shape as they represent the distribution of cortical bone within the section in relation to perpendicular axes (Ruff, 2008 and references therein).

The interpretation of diaphyseal shape indices is not always straightforward, especially for the upper limbs (Ruff and Larsen, 2001). Furthermore, each index has its own disadvantages. $I_{\max}/I_{\min}$ has the significant disadvantage that it does not inform on orientation of maximum (or minimum) bending rigidity, while I_x/I_y has the disadvantage of being influenced by the orientation of the diaphysis during the positioning of the limb for scanning/digitizing (Stock and Pfeiffer, 2001; Shaw and Stock, 2009b). In our case, the preservation of the elements under study was very good, thus orientation during digitizing was not an issue. However, the two ratios give somewhat different information. I_x/I_y indicates anteroposterior/mediolateral bending rigidity and increased values have been found to associate with greater mobility (Ruff, 2008), while $I_{\max}/I_{\min}$ indicates maximum/minimum bending rigidity. Therefore, both are reported here. It should be noted that although our method excluded the medullary cavity, thus slightly overestimating I_x, I_y, $I_{\max}$ and $I_{\min}$ in comparison to true cross-sectional properties, the ratios $I_{\max}/I_{\min}$ and I_x/I_y have been shown to be very highly correlated with true $I_{\max}/I_{\min}$ and I_x/I_y measures (Stock and Shaw, 2007).

Finally, the sum of the perpendicular second moments of area ($I_x + I_y$ or $I_{\max} + I_{\min}$) produces the polar moment of area (J), which reflects torsional and (twice) average bending rigidity (Ruff, 2000). However, in the current study TA is favored over J and it is the variable presented and discussed in the following sections, since, due to the exclusion of the medullary cavity, TA is the only variable very accurately measured, and also highly correlated with "true" J values calculated from CT scans or direct sectioning (Stock and Shaw, 2007). The use of TA makes the results of this study more easily comparable to published literature, while demonstrating mechanical variation similar to J values.

Based on the above, the current paper studies TA and I_x/I_y, $I_{\max}/I_{\min}$. TA is used as a property that reflects the magnitude of average overall loading of the limb, and I_x/I_y, $I_{\max}/I_{\min}$ as properties which reflect differences in orientation of loading.

Since skeletal robusticity is by definition the strength/rigidity of a structure in relation to body size, TA was standardized according to body mass. Body mass was used as a measure of body size in this study, since it affects axial, bending and torsional loadings (Ruff et al., 1993). Although the upper limbs are not weight-bearing, it has been found that the humerus follows the same scaling relationships to body size as the femur (Ruff, 2000). Thus, the same approach was applied for the upper and lower limbs, using body mass to standardize TA values (Ruff, 2008). Body mass was calculated as the average of three equations (Auerbach and Ruff, 2004):

$$\mathrm{BM} = 2.239 \times \mathrm{FHD} - 39.9 \text{ (McHenry, 1992)} \tag{1}$$

$$\mathrm{BM} = 2.268 \times \mathrm{FHD} - 36.5 \text{ (Grine et al., 1995)} \tag{2}$$

$$\mathrm{BM} = 2.741 \times \mathrm{FHD} - 54.9 \text{ (males); } \mathrm{BM} = 2.426 \times \mathrm{FHD} - 35.1 \text{ (females) (Ruff et al., 1991)} \tag{3}$$

where BM is the body mass (in kg) and FHD is the supero-inferior femoral head diameter (in mm). Estimates from Eq. (3) were adjusted downwards by 10%, as recommended by the authors.

Bilateral asymmetry was calculated using the maximum–minimum method, to account for both right and left-handed asymmetry (Trinkaus et al., 1994; Churchill and Formicola, 1997; Ruff, 2000; Stock and Pfeiffer, 2004). Thus, asymmetry was calculated as:

$$a = 100 \times (X_{\max} - X_{\min})/X_{\min} \tag{4}$$

where X stands for any biomechanical property.

Percent sexual dimorphism was determined by comparing differences in mean values for males and females as:

$$d = 100 \times (X_{\mathrm{male}} - X_{\mathrm{female}})/X_{\mathrm{female}} \tag{5}$$

Statistical differences were examined by parametric or nonparametric tests depending on the nature of the data. Specifically, inter-population comparisons were examined for males and females separately using univariate analysis of variance (ANOVA) with Hotchberg GT2 or Games-Howell post-hoc tests, depending on the results of the Levene's test for equality of variance. Intra-population sexual dimorphism was studied by independent t-tests, while bilateral asymmetry was assessed by Wilcoxon signed-rank test. In addition, pairwise inter-population comparisons of bilateral asymmetry were performed using Mann-Whitney tests with Holm-Bonferroni correction. Significance was set at $P \leq 0.05$ for all comparisons. All analyses were performed using SPSS for Windows, version 18.0.

RESULTS

Inter-population comparisons

Tables 2–5 present the inter-population comparisons in the two diaphyseal shape indices and TA for the upper and lower limbs, in each side of the body and each sex separately. In addition, Figures 1–8 present boxplots for I_x/I_y and TA. I_x/I_y was preferred over $I_{\max}/I_{\min}$ in the

TABLE 2. Inter-population comparisons of cross-sectional geometric properties among males (upper limbs)

Bone	Property	Mean ± se				Significance		
		Garamantes	Jebel Moya	Kerma	Badari	G vs. JM	G vs. K	G vs. B
Right side								
Clavicle	TA	151.3 ± 7.2	176.4 ± 13.9	154.5 ± 4.9	128.7 ± 2.4	n.s.	n.s.	n.s.
G = 9, JM = 7	I_x/I_y	0.65 ± 0.08	0.50 ± 0.05	0.66 ± 0.05	0.73 ± 0.04	n.s.	n.s.	n.s.
K = 14, B = 3	I_{max}/I_{min}	1.93 ± 0.16	2.31 ± 0.23	1.83 ± 0.09	1.46 ± 0.09	n.s.	n.s.	n.s.
Humerus	TA	420.0 ± 16.9	490.9 ± 18.8	442.4 ± 8.9	366.5 ± 15.7	0.026	n.s.	n.s.
G = 8, JM =15	I_x/I_y	1.08 ± 0.05	0.97 ± 0.03	1.09 ± 0.03	1.28 ± 0.07	n.s.	n.s.	n.s.
K = 26, B = 5	I_{max}/I_{min}	1.30 ± 0.07	1.18 ± 0.03	1.21 ± 0.03	1.43 ± 0.06	n.s.	n.s.	n.s.
Radius	TA	182.9 ± 4.7	222.4 ± 11.1	187.1 ± 5.4	156.4 ± 5.5	0.017	n.s.	n.s.
G = 7, JM=10	I_x/I_y	0.67 ± 0.04	0.77 ± 0.27	0.68 ± 0.22	0.68 ± 0.28	n.s.	n.s.	n.s.
K = 20, B = 4	I_{max}/I_{min}	1.55 ± 0.08	1.39 ± 0.04	1.56 ± 0.05	1.70 ± 0.20	n.s.	n.s.	n.s.
Ulna	TA	205.3 ± 5.6	245.3 ± 11.4	203.7 ± 5.6	169.1 ± 0.9	0.043	n.s.	0.002
G = 7, JM = 8	I_x/I_y	0.92 ± 0.08	1.24 ± 0.05	0.78 ± 0.03	0.74 ± 0.11	0.004	n.s.	n.s.
K = 9, B = 2	I_{max}/I_{min}	1.61 ± 0.22	1.47 ± 0.07	1.43 ± 0.06	1.76 ± 0.38	n.s.	n.s.	n.s.
Left side								
Clavicle	TA	144.7 ± 7.8	188.8 ± 9.1	151.4 ± 4.6	134.8 ± 2.1	0.001	n.s.	n.s.
G = 8, JM = 8	I_x/I_y	0.65 ± 0.04	0.64 ± 0.06	0.65 ± 0.04	0.65 ± 0.04	n.s.	n.s.	n.s.
K = 19, B = 2	I_{max}/I_{min}	1.75 ± 0.18	1.98 ± 0.11	1.70 ± 0.08	1.57 ± 0.12	n.s.	n.s.	n.s.
Humerus	TA	395.2 ± 15.6	457.7 ± 17.6	409.8 ± 9.4	360.4 ± 18.1	n.s.	n.s.	n.s.
G = 6, JM =14	I_x/I_y	1.09 ± 0.04	1.06 ± 0.03	1.06 ± 0.03	1.24 ± 0.34	n.s.	n.s.	n.s.
K = 23, B = 5	I_{max}/I_{min}	1.27 ± 0.09	1.17 ± 0.21	1.23 ± 0.03	1.31 ± 0.05	n.s.	n.s.	n.s.
Radius	TA	177.5 ± 5.6	215.3 ± 10.5	184.8 ± 5.4	163.9 ± 6.3	0.023	n.s.	n.s.
G = 7, JM = 9	I_x/I_y	0.76 ± 0.04	0.71 ± 0.04	0.77 ± 0.03	0.71 ± 0.03	n.s.	n.s.	n.s.
K = 21, B = 4	I_{max}/I_{min}	1.47 ± 0.12	1.51 ± 0.08	1.50 ± 0.05	1.52 ± 0.04	n.s.	n.s.	n.s.
Ulna	TA	200.8 ± 8.1	241.7 ± 16.1	195.7 ± 3.8	185.0 ± 9.6	n.s.	n.s.	n.s.
G = 8, JM = 5	I_x/I_y	1.02 ± 0.08	1.27 ± 0.09	0.66 ± 0.05	0.84 ± 0.01	n.s.	0.002	n.s.
K = 11, B = 3	I_{max}/I_{min}	1.49 ± 0.18	1.41 ± 0.08	1.66 ± 0.12	1.46 ± 0.12	n.s.	n.s.	n.s.

TAs are standardized by estimated body mass.
Abbreviations: G, Garamantes; JM, Jebel Moya; K, Kerma; B, Badari.

TABLE 3. Inter-population comparisons of cross-sectional geometric properties among males (lower limbs)

Bone	Property	Mean ± se				Significance		
		Garamantes	Jebel Moya	Kerma	Badari	G vs. JM	G vs. K	G vs. B
Right side								
Femur	TA	869.0 ± 31.7	962.3 ± 10.7	870.7 ± 19.4	754.5 ± 38.8	0.016	n.s.	n.s.
G = 7, JM =31	I_x/I_y	1.42 ± 0.15	1.32 ± 0.05	1.29 ± 0.05	1.36 ± 0.18	n.s.	n.s.	n.s.
K = 18, B = 4	I_{max}/I_{min}	1.65 ± 0.16	1.52 ± 0.04	1.37 ± 0.04	1.43 ± 0.18	n.s.	n.s.	n.s.
Tibia	TA	751.2 ± 36.1	850.1 ± 17.9	760.1 ± 21.8	680.6 ± 21.9	n.s.	n.s.	n.s.
G = 7, JM=14	I_x/I_y	2.12 ± 0.12	1.89 ± 0.09	1.88 ± 0.08	2.14 ± 0.12	n.s.	n.s.	n.s.
K = 17, B = 4	I_{max}/I_{min}	2.28 ± 0.13	1.93 ± 0.09	1.99 ± 0.08	2.17 ± 0.11	n.s.	n.s.	n.s.
Left side								
Femur	TA	914.7 ± 25.4	961.7 ± 12.7	866.5 ± 10.9	751.9 ± 103.1	n.s.	n.s.	0.013
G = 6, JM=26	I_x/I_y	1.37 ± 0.12	1.35 ± 0.05	1.15 ± 0.05	1.46 ± 0.21	n.s.	n.s.	n.s.
K = 19, B = 2	I_{max}/I_{min}	1.52 ± 0.11	1.43 ± 0.05	1.30 ± 0.04	1.53 ± 0.16	n.s.	n.s.	n.s.
Tibia	TA	730.0 ± 19.8	821.0 ± 18.1	731.1 ± 28.4	637.7 ± 31.6	n.s.	n.s.	n.s.
G = 6, JM= 12	I_x/I_y	2.25 ± 0.20	2.06 ± 0.14	1.99 ± 0.09	2.22 ± 0.22	n.s.	n.s.	n.s.
K = 16, B = 4	I_{max}/I_{min}	2.38 ± 0.23	2.21 ± 0.12	2.05 ± 0.08	2.28 ± 0.21	n.s.	n.s.	n.s.

TAs are standardized by estimated body mass.
Abbreviations: G, Garamantes; JM, Jebel Moya; K, Kerma; B, Badari.

boxplots because it exhibited comparatively more significant inter-population differences, as seen in Tables 2–5.

When comparing the upper limb, significant differences were observed in the ulnae of male Garamantes, which were stronger than those of both the males from el-Badari and Kerma (Table 2). In contrast, the Jebel Moya sample was significantly more robust than the Garamantes in several upper limb elements. Boxplots (Fig. 1) show that I_x/I_y was much higher among the Jebel Moya for the right ulna and much lower among the Kerma for the left ulna in comparison to the Garamantes. In addition, Figure 2 shows considerably higher TA among the Jebel Moya sample for all upper limb bones. In the lower limbs (Table 3), the male Garamantes showed very few significant differences to all comparative populations. This is corroborated by the boxplots in Figure 3 for I_x/I_y. TA values showed greater variation among populations, with the Jebel Moya being the most robust and the el-Badari the most gracile (Fig. 4).

Among the females, the Garamantian upper limbs exhibited stronger radii than the el-Badari, as well as stronger ulnae and more gracile humeri than the Kerma females. In comparison to the Jebel Moya, the Garamantes showed stronger humeri, while the Jebel Moya had stronger clavicles and ulnae (Table 4). The above trends can also generally be seen for I_x/I_y (Fig. 5) and TA (Fig. 6). In the lower limbs, significant differences were only found in TA between the Garamantian tibiae and those of Jebel Moya (Table 5; Fig. 8). Figure 7 suggests that I_x/I_y was very similar among all populations.

TABLE 4. Inter-population comparisons of cross-sectional geometric properties among females (upper limbs)

Bone	Property	Mean ± se				Significance		
		Garamantes	Jebel Moya	Kerma	Badari	G vs. JM	G vs. K	G vs. B
Right side								
Clavicle	TA	138.0 ± 6.3	169.3 ± 6.2	128.6 ± 3.9	138.8 ± 17.9	0.019	n.s.	n.s.
G = 15, JM= 6	I_x/I_y	0.71 ± 0.04	0.58 ± 0.04	0.64 ± 0.04	0.64 ± 0.06	n.s.	n.s.	n.s.
K = 20, B = 3	I_{max}/I_{min}	1.64 ± 0.08	1.92 ± 0.19	1.78 ± 0.08	1.70 ± 0.17	n.s.	n.s.	n.s.
Humerus	TA	385.4 ± 8.9	411.8 ± 20.1	362.2 ± 7.0	391.0 ± 28.4	n.s.	n.s.	n.s.
G = 14, JM= 9	I_x/I_y	1.02 ± 0.06	1.03 ± 0.04	1.17 ± 0.04	1.18 ± 0.085	n.s.	0.025	n.s.
K = 32, B = 4	I_{max}/I_{min}	1.39 ± 0.05	1.18 ± 0.04	1.32 ± 0.03	1.32 ± 0.05	0.026	n.s.	n.s.
Radius	TA	167.4 ± 6.1	185.9 ± 9.9	161.6 ± 3.3	169.0 ± 7.7	n.s.	n.s.	n.s.
G = 14, JM= 6	I_x/I_y	0.74 ± 0.03	0.68 ± 0.05	0.66 ± 0.02	0.56 ± 0.04	n.s.	n.s.	n.s.
K = 19, B = 3	I_{max}/I_{min}	1.50 ± 0.07	1.60 ± 0.13	1.63 ± 0.06	1.87 ± 0.10	n.s.	n.s.	n.s.
Ulna	TA	190.1 ± 6.4	196.5 ± 61.0	177.9 ± 3.8	206.7 ± 5.4	n.s.	n.s.	n.s.
G = 16, JM= 2	I_x/I_y	0.96 ± 0.06	1.15 ± 0.01	0.75 ± 0.04	0.83 ± 0.09	n.s.	0.033	n.s.
K = 15, B = 3	I_{max}/I_{min}	1.53 ± 0.08	1.27 ± 0.02	1.62 ± 0.07	1.70 ± 0.29	n.s.	n.s.	n.s.
Left side								
Clavicle	TA	143.9 ± 7.2	155.7 ± 12.6	124.4 ± 4.3	144.3 ± 13.8	n.s.	n.s.	n.s.
G = 12, JM= 5	I_x/I_y	0.74 ± 0.06	0.63 ± 0.03	0.59 ± 0.03	0.67 ± 0.10	n.s.	n.s.	n.s.
K = 17, B = 3	I_{max}/I_{min}	1.71 ± 0.11	1.80 ± 0.13	1.85 ± 0.09	1.58 ± 0.20	n.s.	n.s.	n.s.
Humerus	TA	387.2 ± 11.6	404.2 ± 22.7	355.2 ± 7.7	390.8 ± 30.7	n.s.	n.s.	n.s.
G = 14, JM= 8	I_x/I_y	1.01 ± 0.04	1.14 ± 0.06	1.17 ± 0.03	1.10 ± 0.08	n.s.	0.032	n.s.
K = 25, B = 4	I_{max}/I_{min}	1.31 ± 0.04	1.23 ± 0.04	1.33 ± 0.03	1.25 ± 0.04	n.s.	n.s.	n.s.
Radius	TA	163.3 ± 4.1	202.3 ± 14.6	154.0 ± 3.4	175.1 ± 2.7	n.s.	n.s.	n.s.
G = 15, JM= 9	I_x/I_y	0.72 ± 0.03	0.73 ± 0.04	0.74 ± 0.02	0.57 ± 0.01	n.s.	n.s.	0.005
K = 19, B = 3	I_{max}/I_{min}	1.49 ± 0.06	1.48 ± 0.09	1.54 ± 0.04	1.80 ± 0.02	n.s.	n.s.	n.s.
Ulna	TA	185.8 ± 6.5	210.7 ± 14.5	175.6 ± 4.7	195.2 ± 4.2	n.s.	n.s.	n.s.
G = 12, JM= 4	I_x/I_y	1.05 ± 0.10	1.48 ± 0.08	0.65 ± 0.04	0.73 ± 0.09	0.027	0.002	n.s.
K = 13, B = 3	I_{max}/I_{min}	1.66 ± 0.11	1.83 ± 0.15	1.74 ± 0.12	1.61 ± 0.14	n.s.	n.s.	n.s.

TAs are standardized by estimated body mass.
Abbreviations: G, Garamantes; JM, Jebel Moya; K, Kerma; B, Badari.

TABLE 5. Inter-population comparisons of cross-sectional geometric properties among females (lower limbs)

Bone	Property	Mean ± se				Significance		
		Garamantes	Jebel Moya	Kerma	Badari	G vs. JM	G vs. K	G vs. B
Right side								
Femur	TA	771.8 ± 40.1	828.1 ± 18.1	773.0 ± 12.0	832.7 ± 43.0	n.s.	n.s.	n.s.
G = 6, JM=14	I_x/I_y	1.17 ± 0.14	1.28 ± 0.05	1.14 ± 0.04	1.25 ± 0.02	n.s.	n.s.	n.s.
K = 24, B = 2	I_{max}/I_{min}	1.41 ± 0.13	1.39 ± 0.05	1.29 ± 0.02	1.28 ± 0.04	n.s.	n.s.	n.s.
Tibia	TA	657.0 ± 20.2	760.1 ± 21.0	627.6 ± 13.1	662.1 ± 31.5	0.005	n.s.	n.s.
G = 15, JM= 8	I_x/I_y	1.92 ± 0.11	1.97 ± 0.13	2.24 ± 0.13	2.40 ± 0.28	n.s.	n.s.	n.s.
K = 20, B = 2	I_{max}/I_{min}	2.05 ± 0.12	1.98 ± 0.13	2.27 ± 0.13	2.49 ± 0.22	n.s.	n.s.	n.s.
Left side								
Femur	TA	814.6 ± 20.0	846.4 ± 11.3	784.2 ± 14.3	881.3 ± 68.6	n.s.	n.s.	n.s.
G = 14, JM=15	I_x/I_y	1.12 ± 0.08	1.19 ± 0.06	1.06 ± 0.05	1.09 ± 0.04	n.s.	n.s.	n.s.
K = 19, B = 4	I_{max}/I_{min}	1.41 ± 0.06	1.33 ± 0.05	1.30 ± 0.04	1.40 ± 0.17	n.s.	n.s.	n.s.
Tibia	TA	653.4 ± 19.0	762.3 ± 24.2	633.7 ± 17.9	629.4 ± 11.7	0.012	n.s.	n.s.
G = 16, JM = 7	I_x/I_y	1.94 ± 0.07	1.81 ± 0.10	2.21 ± 0.15	2.42 ± 0.24	n.s.	n.s.	n.s.
K = 17, B = 2	I_{max}/I_{min}	2.06 ± 0.08	1.85 ± 0.10	2.26 ± 0.15	2.52 ± 0.16	n.s.	n.s.	n.s.

TAs are standardized by estimated body mass.
Abbreviations: G, Garamantes; JM, Jebel Moya; K, Kerma; B, Badari.

It should be clarified that, in the above comparisons, very often only one side turned out to be significantly different between populations. However, the contralateral side was also stronger in the same populations, although its difference did not reach statistical significance. The only exception was the right radial I_x/I_y, the value of which was actually higher in the Garamantes.

Bilateral asymmetry

From Table 6, it can be seen that levels of asymmetry among the Garamantes were very low, although males showed systematically greater asymmetry in TA than females. Similarly, low asymmetry was found among the Jebel Moya and the el-Badari. In contrast, several properties appeared significantly asymmetric in the Kerma males and females. In all cases where significant differences were found in TA and I_{max}/I_{min}, as well as in one out of four cases for I_x/I_y, the right side was dominant, as can be seen from the absolute values of the different properties given per side in Tables 2 and 4. The examination of inter-population differences in bilateral asymmetry gave significant results only in two cases: (a) TA for male humeri between the Garamantes and Jebel Moya (P = 0.039), and (b) I_x/I_y for female radii between the Garamantes and Kerma (P = 0.039).

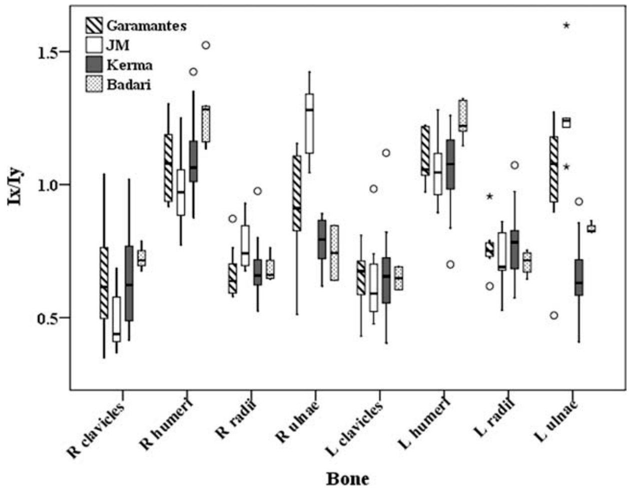

Fig. 1. Inter-population comparisons for I_x/I_y (males, upper limbs).

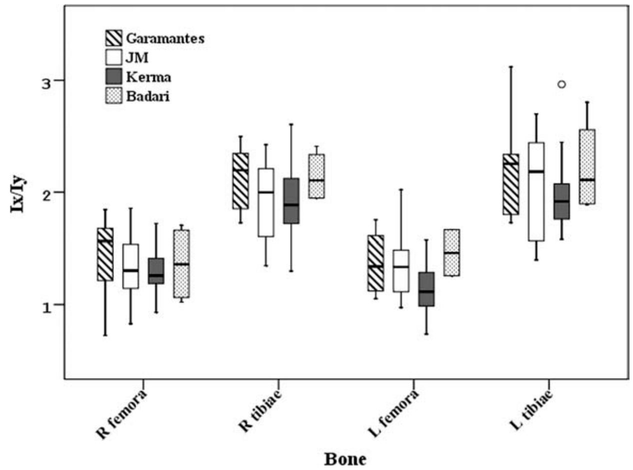

Fig. 3. Inter-population comparisons for I_x/I_y (males, lower limbs).

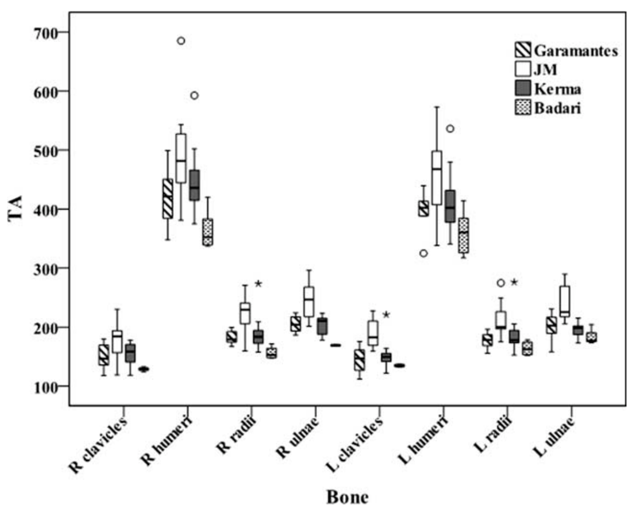

Fig. 2. Inter-population comparisons for TA (males, upper limbs).

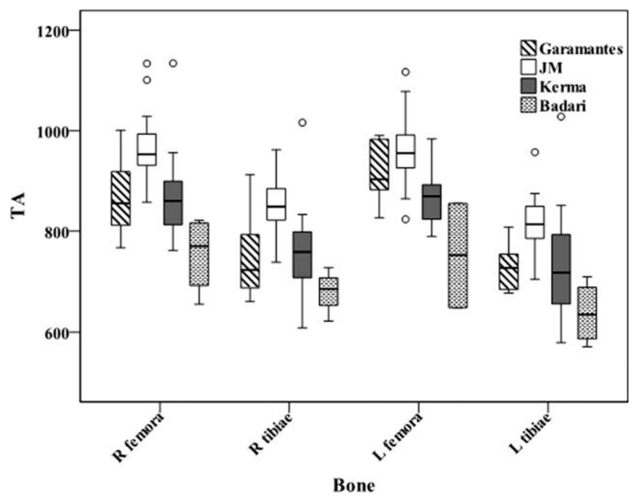

Fig. 4. Inter-population comparisons for TA (males, lower limbs).

Sexual dimorphism

Table 7 presents the statistically significant differences \between males and females for diaphyseal shape and TA among all populations. To avoid biases due to bilateral asymmetry, sexual dimorphism was explored separately for each side of the body. In the Garamantes, only the male lower limbs are significantly more robust than the female ones. As was the case in bilateral asymmetry, the samples from el-Badari and Jebel Moya also showed very low levels of dimorphism, while among the Kerma several properties and elements appeared significantly different between males and females. One property that should be noted especially is femoral I_x/I_y, since sexual dimorphism in I_x/I_y has been rather extensively investigated in the lower limbs as an indicator of differential mobility between males and females (see summary in Ruff, 2008). From Table 7, it can be seen that the average value for the Garamantes is 21.3, which is identical to the el-Badari average. In contrast, the Jebel Moya and Kerma samples exhibited much smaller values, 8.0 and 9.95, respectively.

DISCUSSION

This study aimed at assessing the intensity of daily Garamantian activities at an inter- and intra-population level. The inter-population comparisons showed that the significant differences between the Garamantes and the sample from el-Badari were very few. More specifically, only the male right ulna and left femur, as well as the female left radius appeared significantly more robust in the Garamantes. Moreover, the mean values per population also show that TA was higher among male Garamantes in the upper and lower limbs and very similar among the two populations for females, with the only exception being the more robust femora of el-Badari. Diaphyseal shape indices do not follow a clear pattern. These results are rather surprising, since the population from el-Badari predates the Garamantes by at least 3,000 years, and their subsistence practice (semi-nomadic pastoralism) should have imposed greater loads on the skeleton, especially the lower limbs. Given the sedentary lifestyle of the Garamantes and the fact that it is highly unlikely that the entire male population was

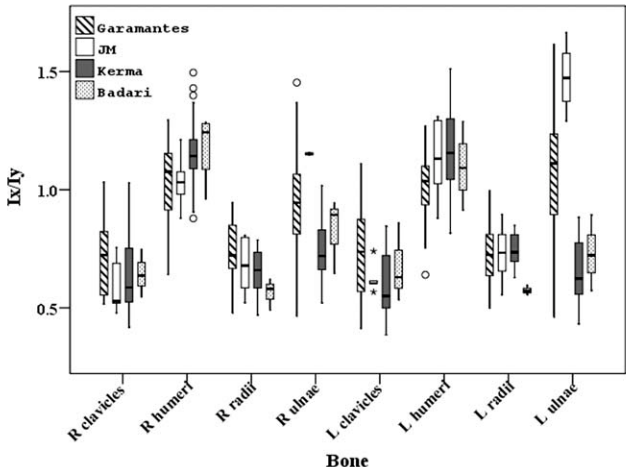

Fig. 5. Inter-population comparisons for I_x/I_y (females, upper limbs).

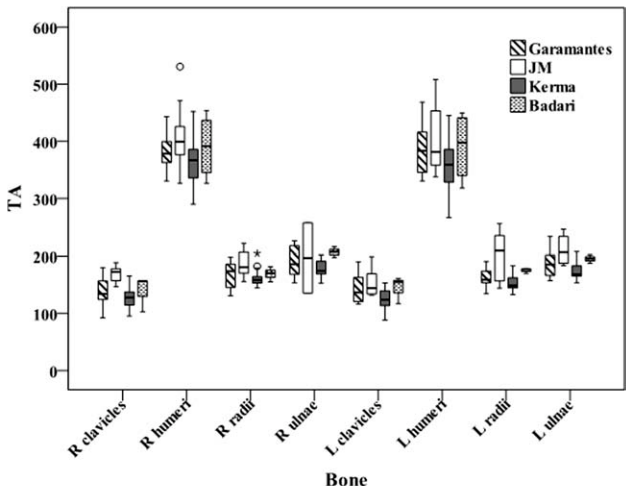

Fig. 6. Inter-population comparisons for TA (females, upper limbs).

involved in herding, it is more likely that the uneven terrain in the Fezzan was one of the primary reasons that led to increased lower limb robusticity in the male population. However, the relatively small body size of the population from el-Badari complicates the interpretation of lower limb robusticity, and the small sample size suggests that these results should be considered inconclusive.

Very few statistically significant differences were found for either sex between the Garamantes and Kerma. The mean values of TA, I_x/I_y, and $I_{\max}/I_{\min}$ among males were very similar and followed no clear pattern. Among females, the Garamantes exhibited systematically slightly higher values for TA in the upper and lower limbs, but again no clear pattern and very small differences were found in the diaphyseal shape indices. This suggests similar activity patterns for both populations and corresponds with archaeological data for similar societal structure and subsistence economy among these groups.

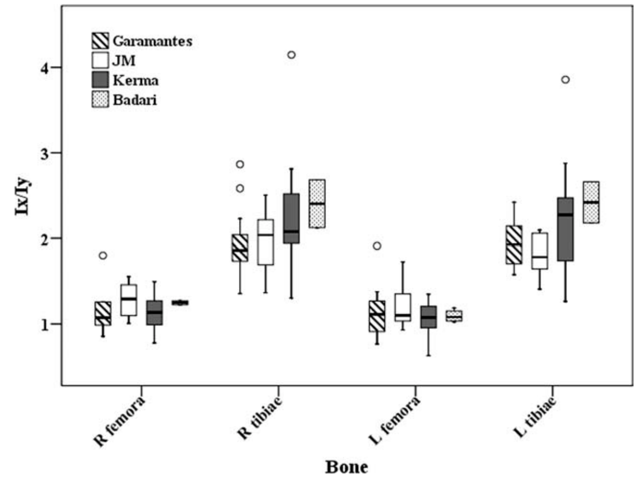

Fig. 7. Inter-population comparisons for I_x/I_y (females, lower limbs).

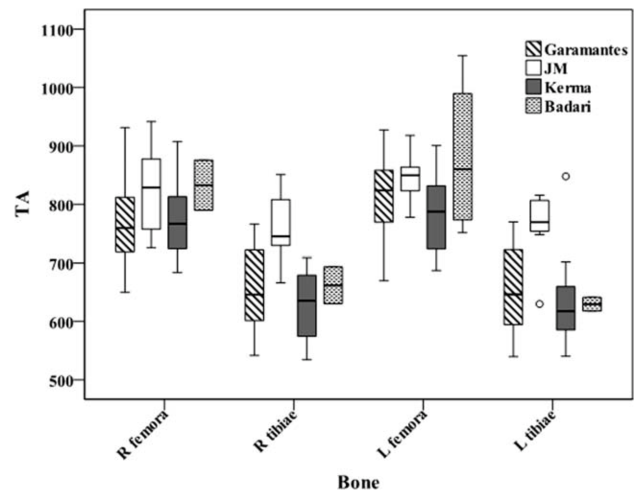

Fig. 8. Inter-population comparisons for TA (females, lower limbs).

Finally, in comparison to the Jebel Moya, Garamantian males and females appeared more gracile, particularly in the upper limbs. The mean Jebel Moya TA values were higher than those of the Garamantes in the upper and lower limbs for both sexes. No pattern was observed in diaphyseal shape indices in the upper limbs of both sexes and the lower limbs of females, whereas in the Garamantian males lower limb values were slightly higher. This may be due to the fact that the Jebel Moya had a largely pastoral economy, even though they occupied a better watered environment and a less uneven terrain than the Garamantes.

Therefore, Garamantian activities, revolving primarily around irrigated agriculture and herding, do not appear to have imposed greater physical loads on the population in comparison to those of other North African groups. Livestock herding and other tasks requiring mobility did not stress the lower limbs of the population comparatively more, except in comparison to el-Badari males, which may be biased due to small sample sizes. This suggests either that the Garamantes did not have to move for long distances on foot and/or that the uneven

TABLE 6. Median percent bilateral asymmetry among populations and sexes

		Garamantes		Badari		Jebel Moya		Kerma	
		Male	Female	Male	Female	Male	Female	Male	Female
Humerus	TA	2.0	0.03	1.7	0.04	13.0[a]	9.5	8.0[b]	2.8
	I_x/I_y	1.3	0.7	3.1	7.9	5.5	2.6	0.5	1.4
	I_{max}/I_{min}	4.1	1.3	8.2	5.8	0.01	0.4	3.0	1.0
Radius	TA	2.0	0.1	0.2	3.6	6.7	1.3	2.2[c]	4.6[c]
	I_x/I_y	13.2[c]	4.2	0.7	1.8	6.6	2.1	14.9[a]	15.6[a]
	I_{max}/I_{min}	2.5	1.5	2.8	3.6	3.8	3.7	4.7	9.9[c]
Ulna	TA	3.4	0.8		0.4	2.1		5.8	1.7
	I_x/I_y	5.7	16.6		3.9	2.7		5.3	18.8[c]
	I_{max}/I_{min}	3.9	7.5		18.0	7.9		9.3	8.8
Clavicle	TA	6.1[c]	2.9	3.1	4.0	11.4	0.3	3.2	5.2
	I_x/I_y	3.7	6.6	12.9	8.9	8.2	8.5	5.4	5.1
	I_{max}/I_{min}	9.2	6.3	11.3	10.5	9.8	4.9	10.7[c]	11.1

[a] Significant at 0.01 level.
[b] Significant at 0.001 level.
[c] Significant at 0.05 level.

TABLE 7. Mean percent sexual dimorphism among populations and sides

		Garamantes		Badari		Jebel Moya		Kerma	
		Right	Left	Right	Left	Right	Left	Right	Left
Humerus	TA	9.0	2.1	−6.3	−7.8	20.0[a]	13.3	22.2[b]	16.9[b]
	I_x/I_y	6.0	8.8	8.2	13.2	−4.9	−6.8	−6.8[c]	−8.6[c]
	I_{max}/I_{min}	−6.1	−2.8	7.8	5.4	0.2	−4.9	−8.3[a]	−7.5[c]
Radius	TA	10.6	9.3	−7.4	−6.4	6.6	6.5	15.8[b]	19.7[b]
	I_x/I_y	−10.3	6.7	21.4[c]	24.6[a]	8.6	−3.1	3.3	3.6
	I_{max}/I_{min}	2.9	−1.5	−9.1	−15.6[a]	−9.4	2.3	−4.4	−2.4
Ulna	TA	8.0	8.1	−15.8[c]	−5.2	24.4	14.7	14.6[b]	11.5[a]
	I_x/I_y	−3.9	−3.0	−7.6	14.7	7.2	−13.7	5.2	1.6
	I_{max}/I_{min}	5.5	−9.9	3.0	−9.6	17.5	−23.0[c]	−11.4	−5.0
Clavicle	TA	9.7	0.6	−7.3	−6.6	7.7	21.2	20.1[b]	21.7[b]
	I_x/I_y	−7.3	−12.8	12.7	−3.9	−15.1	1.7	2.9	10.2
	I_{max}/I_{min}	17.6	2.2	−14.2	−0.5	21.9	9.8	2.8	−8.1
Femur	TA	12.6	12.3[a]	−9.4	−14.7	16.2[b]	13.6[b]	12.6[b]	10.7[b]
	I_x/I_y	20.7	21.9	9.1	33.6	2.5	13.5	13.2[c]	6.7
	I_{max}/I_{min}	16.8	7.8	12.0	9.1	9.3	7.4	6.7	−0.6
Tibia	TA	14.8[c]	11.7[c]	2.8	1.3	11.8[a]	7.7	20.6[b]	15.4[a]
	I_x/I_y	9.6	16.1	−10.9	−7.9	−3.9	13.7	−17.2[c]	−10.2
	I_{max}/I_{min}	11.4	15.5	−13.2	−9.8	−2.7	19.1	−13.6	−9.2

TAs are standardized by estimated body mass.[a] Significant at 0.01 level.
[b] Significant at 0.001 level.
[c] Significant at 0.05 level.

terrain in Fezzan was not as stressful as would have been expected. Alternatively, it is possible that the population occupied mainly the valleys, not traversing the uneven surface of the gravel and boulder strewn wastelands and hyper-arid rock plateaux on a regular enough basis to affect the robusticity of their legs. In addition, the activities that involved the upper limbs were also not strenuous enough to affect bone morphology more than in other populations that occupied less extreme environments. From the above, it seems that a sedentary life in the Sahara Desert was not particularly more stressful in terms of mechanical loading of the adult skeleton than in other North African regions.

Population comparisons showed very low levels of bilateral asymmetry among the Garamantes. While males showed greater asymmetry in TA than females, this was not statistically significant. The low asymmetry is in accordance to results obtained from the study of other agricultural populations (Bridges, 1989; Ruff, 2000; Marchi et al., 2006) and may imply the involvement of the population in bilateral activities or the lack of regular repetition of unilateral activities. With respect to the comparative populations, the el-Badari and Jebel Moya also exhibited relatively minor asymmetry, although slightly more than the Garamantes. In contrast, the Kerma population showed significant differences among both sexes. This may imply less task specialization among the Garamantes in comparison to their neighbors.

Inter-sex differences in the Garamantes were significant only in TA for the lower limbs. The lack of a significant difference in most elements and properties agrees with the results obtained from other agricultural populations (Murdock and Provost, 1973; Ruff, 1987). On the other hand, the greater male values in TA in the lower limbs may relate to their involvement in livestock keeping. This is further supported by the high values of femoral I_x/I_y among males for the Garamantes and the el-Badari in comparison to the Jebel Moya and Kerma, which is an indication of increased mobility for the male subjects of these populations and possibly suggests rather important reliance of the Garamantian economy on pastoralism. What is surprising is that the Jebel Moya, although relying heavily on pastoralism, exhibited small dimorphism in femoral I_x/I_y, as mentioned above. However, this population showed very high and significant dimorphism in femoral TA, which is consistent with their subsistence economy. Overall, the degree of sexual dimorphism among the el-Badari and the Jebel Moya populations rarely reached statistical significance, while Kerma males and females were significantly different in several properties and elements. Thus, no consistent pattern can be traced among North African groups with respect to sexual division of labor as reflected in biomechanical loading of the skeleton, as would be expected given the different lifestyles of the populations under examination.

Therefore, our study has some interesting and rather unexpected results. On the one hand, the low sexual dimorphism identified in the Garamantian population in the upper limbs and the diaphyseal shape indices of the lower limbs conforms to the pattern found in agricultural populations in general, and is consistent with the archaeological data that point to agriculture being one of the principal subsistence practices of the population. On the other hand, the fact that the males were stronger than females in lower limb TA most likely relates to their involvement in short and long-distance mobility on the uneven Saharan terrain due to herding. In addition, very little dimorphism was found in the upper limbs of the population, although males showed systematically greater asymmetry in TA than females. This supports the view that males were more involved than females in unilateral repetitive tasks, possibly relating to warfare and construction works, although this involvement was not actually that intense. Finally, the Garamantes did not appear significantly more robust than the comparative populations, suggesting that the harsh Central Saharan environment did not require particularly more strenuous daily activities for survival than better watered environments elsewhere in North Africa.

CONCLUSION

The study of the activity patterns of the Garamantes, a population that flourished at Central Sahara approximately 3,000 years ago, offers some interesting insights on the levels of stress imposed by a sedentary life in a hyper-arid environment. The population showed low bilateral asymmetry, possibly due to limited task specialization. Moreover, the Garamantes exhibited low sexual dimorphism in the upper limbs, which is consistent to the pattern found in agricultural populations and implies that the engagement of males in warfare and construction works was not particularly intense. In the lower limbs, males were stronger in TA possibly as a result of their involvement in herding and mobility on the uneven terrain of Fezzan. Finally, the Garamantes did not appear systematically more robust than other North African populations occupying less harsh environments, indicating that life in the Sahara did not require particularly strenuous daily activities.

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