Chapter 7

Physical activity and body size in Temple Period Malta: biomechanical analysis of commingled and fragmentary long bones

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7.1. Introduction

The reconstruction of physical activity from the human skeleton provides archaeologists with important insights into past lifestyles and lived experiences. Whilst a range of approaches have been developed to reconstruct activity in archaeological skeletons (Jurmain *et al.* 2012; Larsen 2015; Meyer *et al.* 2011), the application of skeletal biomechanics offers an objective means of quantifying and exploring habitual behaviour in past populations that has benefits over other approaches which rely on activity-related pathology or analysis of muscle attachment sites (Waldron & Rogers 1991; Wallace *et al.* 2017; Wilczak *et al.* 2017). Skeletal biomechanics applies mechanical principles to bone tissue in order to understand its form and function, and has been most widely employed to understand structural adaptation of long bones diaphyses. This particular method models the long bones as structural beams in order to quantify their cross-sectional geometric (henceforth CSG) properties related to bone strength and bending rigidity (Huiskes 1982; Ruff & Hayes 1983a,1983b), thus making it possible for bioarchaeologists to estimate the degree of mechanical strain associated with habitual activity during life.

Although skeletal morphology is influenced by a wide range of genetic, environmental, hormonal and age related factors (Kini & Nandeesh 2012), experimental studies have demonstrated that bone tissue adapts and remodels in response to *in vivo* mechanical loading (Biewener *et al.* 1983; Lanyon 1984; Lanyon & Baggott 1976; Lanyon *et al.* 1982; Simkin *et al.* 1989), and in a manner consistent with particular patterns of known and inferred habitual behaviour (Macintosh & Stock 2019; Shaw & Stock 2009a, 2009b; Stock & Pfeiffer 2001; Ruff 2019). This process, referred to as 'bone functional adaptation' (Ruff *et al.* 2006a), enables bioarchaeologists to reconstruct broad patterns of behaviour from the human skeleton and has been successfully applied to a variety of archaeological contexts to examine changes in subsistence strategy (Marchi *et al.* 2011), social change (Sparacello *et al.* 2011), patterns of mobility behaviour (Sládek *et al.* 2006b, 2006a), economy and trade (Pomeroy 2013) or genetic and cultural discontinuity (Stock & Macintosh 2016). The analysis of the Xagħra assemblage, presented in this chapter, forms a discrete part of a much larger study that explored spatial and temporal trends in body size and post-cranial robusticity across the longue durée of central Mediterranean prehistory (Parkinson 2019).

A useful by-product of CSG analysis is the acquisition of osteometric data related to body mass and long bone lengths which can be converted into estimates of stature, thus enabling an exploration of body size. The relationship between body size, skeletal growth, physiological stress and life history has been used by bioarchaeologists and economic historians to understand social and economic circumstances in modern (Stock & Migliano 2009; Tyrrell *et al.* 2016) and archaeological populations (Formicola & Holt 2007; Macintosh *et al.* 2016; Niskanen *et al.* 2018). Population history has also been shown to have an important role in understanding body size in archaeological populations, in acknowledgement of the genetic control over final adult height (Cox *et al.* 2019; Martiniano *et al.*, 2017). Estimates of stature heritability have been reported to be as high as 80-90% (Silventoinen *et al.*, 2003), however, final adult stature has also been shown to be influenced by non-genetic factors, such as developmental stress and growth impairment, as well as adaptive life history traits (for reviews see Wells & Stock 2011, 2020). The analysis of estimated stature and body mass at Xagħra therefore provides a means of investigating these themes, which are complementary to palaeopathological analysis presented elsewhere (Chapter 4, Chapter 8).

Another important element of this study was overcoming the considerable methodological challenges that were encountered during the analysis of the highly commingled and fragmented Xagħra assemblage. The acquisition of reliable and accurate osteometric data is one of the fundamental challenges of working with fragmentary and commingled human bone, and therefore this chapter also introduces the various approaches used in the analysis. The application of 3D surface scanning technology particularly aided in the reconstruction and estimation of bone dimensions that were necessary for the acquisition of CSG properties.

Few studies have attempted to analyse long bone CSG properties from commingled and fragmentary skeletal material because of the difficulties of acquiring the necessary osteometric data. Stock & Willmore (2003) investigated broad patterns of habitual activity through the application of skeletal biomechanics in a large fragmented and commingled Iroquoian burial assemblage, successfully illustrating the validity of such studies. Palaeoanthropological studies have also demonstrated the wealth of information that can be extracted from small samples of fragmented fossil hominin remains (Ruff 2008b; Trinkaus & Ruff 1999; Xing *et al.* 2018), providing a strong methodological framework on which to build. In particular, recent analysis of a large commingled and fragmented assemblage of *Homo naledi* remains (see Marchi *et al.* 2017) has also addressed many of the issues faced in this research.

7.2. Materials

7.2.1. Sampling strategy

The main period of use at the Circle was during the Tarxien phase (*c.* 2800–2400 cal. BC; Chapter 3), when the site was the setting of an elaborate set of funerary rites, whereby human remains underwent complex and varied processes of disarticulation and dispersal (Malone & Stoddart 2009; Chapter 12 in this volume). The natural cave system was elaborated with megalithic architecture and periodically restructured throughout the Tarxien period, where burial deposits functioned as structural deposits (§3.4.2). The combination of these site formation processes with the funeral rituals performed on site resulted in the formation a large commingled and highly fragmentary skeletal assemblage.

The large size and complexity of the Xagħra assemblage therefore required a targeted sampling strategy aimed at contexts containing high frequencies of long bones as reported in the original study by Malone *et al.* (2009d). Sampling was initially targeted at both the earlier rock-cut tomb (*c.* 3500–3200 cal. BC) and the main Tarxien phase burial complex (*c.* 2975–2250 cal. BC), although material from the rock-cut tomb was eventually excluded from the final analysis owing its small sample size and extreme level of fragmentation. Furthermore, extensive concretion obscured much of the cortical surface of the long bones from the rock-cut tomb, limiting the potential to retrieve accurate CSG properties. Sampling of the Tarxien phase deposits was directed towards three articulated individuals from contexts (799), (960) and (1241), in addition to three large commingled mortuary deposits, Contexts (783), (1206) and (1268). Contexts (1206) and (1268) from the 'Shrine' area were specifically targeted for their high frequencies of humeri, femora and tibiae, and because they presented the clearest record of a stratified sequence within the site that spanned the Tarxien phase (Stoddart *et al.* 2009c). The nature of the Xagħra assemblage was such that complete skeletons could not be reconstructed, eliminating the potential to explore sex-based or whole-body trends in skeletal robusticity, and restricting the analysis to an exploration of broad patterns in body size and physical activity.

7.2.2. Comparative sample

Comparative data for Copper Age central Italy from Parkinson (2019) were included in the analysis in order to place the Maltese data within a broader central Mediterranean regional context. The comparative sample consists of 32 individuals from Ponte San Pietro (Latium) and Fontenoce-Recanati (Marche) dated to the Italian early Copper Age (3600–3300 cal. BC) (Dolfini 2010; Silvestrini *et al.* 2004). Both sites are associated with the Rinaldone burial tradition (Cazzella & Moscoloni 2012; Dolfini 2006b, 2006a), and are traditionally considered as agro-pastoralists that navigated the mountainous and hilly terrain of the central Italian Apennines (Cocchi Genick 2009; Manfredini *et al.* 2009; Skeates 1997). The comparative central Italian sample consists almost entirely of fully articulated skeletons, thus enabling a more detailed exploration of patterns across the skeleton. One major benefit of this comparison is the ability of the more detailed results from central Italy to help tease out underlying trends in the Xagħra sample.

7.3. Methods

7.3.1. Long bone cross-sectional geometry

Long bone solid CSG properties were captured at the mid-shaft (50% of bone length) of the femur and tibia, and at the mid-distal (35% of bone length) point of the humeral diaphysis thereby avoiding the morphology of the deltoid muscle attachment (Ruff 2019). Given the relationship between endosteal (internal) and periosteal (external) contours, capturing both internal and external cross-sectional properties is preferred (Larsen 2015; Ruff & Hayes 1983a). However, solid CSG properties based on external contours alone have

Table 7.1. *Cross-sectional geometric properties used in the study.*

Property	Definition	Biomechanical relevance
TA	Total cross-sectional area	Correlate of compressive strength
J	Polar Second Moments of Area (SMA)	Sum of $I_{max}+I_{min}$, correlate of torsional strength and average bending rigidity
I_x/I_y	Cross-sectional shape ratio	Distribution of bone about the anterior-posterior and medio-lateral axes, indicator of cross-sectional shape and direction of mechanical loading
I_{max}/I_{min}	Cross-sectional shape ratio	Distribution of bone about maximum and minimum axes, indicator of cross-sectional shape

been shown to correlate strongly with true cross-sections and likely reflect the most mechanically relevant bone tissue (Davies *et al.* 2012; Macintosh *et al.* 2013; Stock & Shaw 2007). The solid cross-sectional properties used in this study are total cross-sectional area (*TA*), a correlate of compressional strength, the Polar Second Moments Area (*J*), a correlate of bending and torsional rigidity, and the cross-sectional shape ratios I_{max}/I_{min} and I_x/I_y, which give an indication of cross-sectional shape and the direction of mechanical loading (Table 7.1). Solid CSG properties were derived from 3D laser surface scans of individual bones captured with a NextEngine object scanner using AsciiiSection v.3.2 (Davies *et al.* 2012). All 3D scans were processed in Rapidform XOR and aligned to standard anatomical axes defined by Ruff (2002). As body size itself constitutes a mechanical force, CSG properties must be body size standardized using a combination of bone length and body mass (Ruff 2000, 2019). Body mass estimations were derived from femoral head diameter using regression equations developed for European Holocene populations (Ruff *et al.* 2012), whereas knee breadth was used to estimate body mass from isolated tibiae (Squyres & Ruff 2015). The bones of the upper limb have also been shown to scale with body mass, and therefore humeral CSG properties must also be standardized for the influence of body size (Pomeroy *et al.* 2018; Ruff 2002; Ruff *et al.* 1993). Upper limb CSG properties are typically standardized using body mass estimates derived from associated femora, however, the commingling of the Maltese sample makes this impossible. Instead, CSG properties for isolated humeri were standardized using powers of bone length, as recommended by Ruff (2019). The recommended power of bone length for standardizing *TA* is maximum length^^{3}, whilst the recommended powers for Second Moments of Area (*I* and *J*) are maximum length^$^{5.33}$ (Ruff *et al.* 1993).

7.3.2. Approaches to fragmented material

A series of adapted and original approaches were used to overcome the methodological challenges that were posed by the fragmented and commingled Xagħra assemblage. The use of 3D scanning to acquire long bone CSG properties in this study was particularly useful in enabling the application of digital reconstruction techniques to overcome some of the methodological challenges of working with fragmented skeletal material. Specific to this study was the need for estimates of complete bone length and femoral head diameter from fragmentary long bones. Maximum bone length is not only required to establish accurate, standardized cross-section locations along the diaphysis, such as the femoral and tibial mid-shaft (50% of bone length) and mid-distal humerus (35% of bone length from the distal end) (Ruff & Hayes 1983a), but it is also a vital component in size standardization of CSG properties (Ruff *et al.* 1993).

Ruff (2008a, 2019; §7.3.1) recommends the use of estimated bone lengths when working with fragmented and isolated skeletal elements, and estimated bone lengths are widely used in the analysis of fragmentary fossil hominin material (Day & Molleson 1976; Haeusler & McHenry 2004; Korey 1990; Ruff 2008b; Trinkaus & Ruff 1989, 1996; Trinkaus *et al.* 1998). Slight misplacement of cross-section location within 5% of bone length has been shown to have little effect on CSG properties of the femur and humerus (Ruff 2008b; Sládek *et al.* 2010), enabling biomechanical analysis of these elements with confidence. However, CSG properties of the tibia have been shown to be most sensitive to cross-section misplacement because of the irregular and angular morphology of the tibial medial and lateral surfaces (Sládek *et al.* 2010). For this reason, extra care was taken to screen CSG data from tibiae, and only elements that were more than approximately 75% complete were selected for analysis.

7.3.2.1. Estimation of maximum bone length: 3D reconstruction and superimposition

Estimation of maximum bone length was achieved primarily through 3D digital reconstruction and 3D superimposition. Forensic anthropologists have developed a range of methods to estimate complete maximum bone length from fragmented long bones for the purposes of stature estimation (Jacobs 1992; Simmons *et al.* 1990; Steele 1970; Steele & McKern 1969; Wright & Vasquez 2003), but available methods are problematic in that they are often exclusively developed for the lower limb and often calculate stature directly rather than provide an estimate of bone length. Considerable doubt has also been placed over the accuracy and repeatability of current methods for estimating complete length from fragmented long bones, which are population specific and often rely on highly variable anatomical landmarks (Bidmos 2009).

A major benefit of the 3D scanning approach, however, is the opportunity to manipulate skeletal elements digitally in virtual space, enabling the use of techniques in 3D digital reconstruction and 3D superimposition (Fig. 7.1). Both 3D digital reconstruction and 3D superimposition provide accurate estimates of complete long bone length, which have advantages over traditional visual approaches (Sylvester *et al.* 2008). Long bone reconstruction was performed in Rapidform XOR using the Interactive Alignment function, where individual fragments were aligned and positioned according to anatomical landmarks, estimated anatomical axes and fracture congruence (Benazzi *et al.* 2014; Grine *et al.* 2010; Gunz *et al.* 2009; Senck *et al.* 2015). Once reconstructed, the individual 3D scanned meshes of each fragment were fused to form a single mesh using Rapidform's Combine tool (Fig. 7.1). As with any analysis involving fragmentary skeletal material, digital reconstruction relies on careful documentation during the initial data collection stage and reference to, whenever possible, excavation notes. 3D digital reconstruction also offsets the need to undertake restoration and reconstruction of the physical skeletal element, which often requires the use of adhesives that can lead to serious long-term conservation issues (Caffell *et al.* 2001; Johnson 1994).

Figure 7.1. *Examples of digitally reconstructed humeri: a) 3D superimposed humerus; b) 3D digitally reconstructed humerus (E. Parkinson).*

3D digital superimposition was undertaken to estimate complete bone length for incomplete fragmented long bones, such as those without epiphyses. Similar to visual pair matching, which is used widely in forensic (Adams & Byrd 2006; Adams & Konigsberg 2004) and palaeoanthropological (Marchi *et al.* 2017; Trinkaus *et al.* 1998) research, this approach compares the diaphyseal contours and anatomical landmarks of a fragmented skeletal element with a complete element from a reference collection. The combination of the incomplete and complete elements can then be used to make a reliable estimation of complete bone length (Fig. 7.1). Traditional visual comparison methods are more subjective, in that they rely on comparison between two bones positioned next to one-another, whilst 3D digital superimposition allows for clearer and more accurate comparisons to be made *in silico*, thus limiting subjectivity. In a test of this approach, Karell *et al.* (2016) showed that manual 3D superimposition outperformed automated matches and traditional visual comparison methods in 100% of comparisons. The application of 3D digital superimposition has also been effectively employed in analysis of very fragmented fossil hominin material (Xing *et al.* 2018). 3D superimposition was performed in Rapidform XOR by importing a 3D mesh of a complete bone of similar size and morphology, on the basis of approximate length estimations made during initial data collection. Incomplete bones were then positioned and orientated over the complete reference bone, on the basis of a comparable morphology, using the Interactive Alignment and Datum Match functions in Rapidform XOR. Whilst this approach requires experience in handling 3D data, as well as access to specialist software and 3D scanning equipment, 3D superimposition achieves reliable estimations of complete bone length and can be replicated using open-source software alternatives (Fig. 7.1). In the case of fragmentary elements belonging to articulated individuals (i.e., two humeri from the same individual, the left missing a distal epiphysis and the right missing a proximal epiphysis), both sides were scanned and used to create 'hypothetical' reconstructions whereby the individual models where mirrored and superimposed on to the corresponding skeletal element.

7.3.2.2. Estimating femoral head diameter: shape fitting

Femoral head diameter was required for the estimation of body mass (*i.e.*, Ruff *et al.* 1997) and the standardization of CSG properties. Whilst the femur is one of the best surviving elements in archaeological contexts

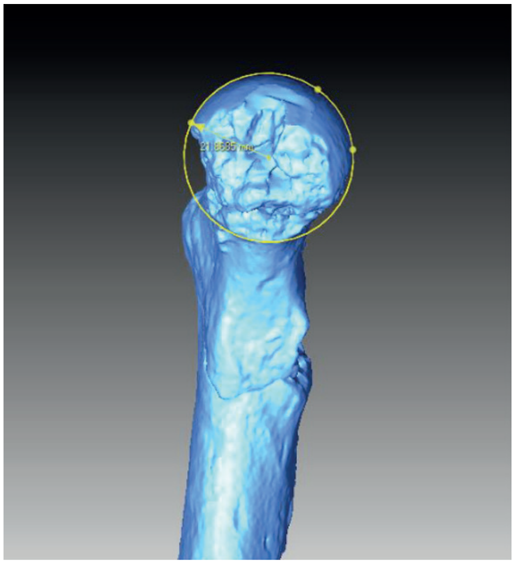

Figure 7.2. *Example of shape fitting method applied to fragmented femoral head. The femoral head is modelled as a sphere and the curvature of the surviving surface is then extrapolated to achieve an estimated diameter (E. Parkinson).*

(Stojanowski *et al.* 2002; Waldron 1987), long bone epiphyses are often damaged in commingled assemblages (Adams & Byrd 2006). In these cases, shape fitting can be used to estimate the diameter of fragmented femoral heads. By modelling the femoral head as a sphere and extrapolating the curvature of the surviving surface with the Measure Radius tool in Rapidform XOR, it was possible to estimate the complete diameter (Fig. 7.2). The estimated radius was then multiplied by two to achieve an estimated femoral head diameter. Whilst this approach does assume perfect sphericity of the femoral head, clinical and experimental research has shown that the femoral head can be confidently modelled as a sphere (Cereatti *et al.* 2010; Hammond & Charnley 1967; Kim 1989) or partial sphere (Parkinson 2014; Ruff 1990, 2002; Rafferty & Ruff 1994). Similar approaches applied to fossil hominin acetabula have proved an effective means of estimating femoral head size in palaeoanthropological literature (Berger *et al.* 2010; Hammond *et al.* 2013; MacLatchy & Bossert 1996; Plavcan *et al.* 2014a, 2014b).

7.3.3. Statistical approach

Independent *t*-tests were used to compare CSG properties between the Xagħra and central Italian Early Copper Age groups and between the left and right humeri from the Xagħra assemblage. Box-and-whisker plots are used here to visualize the data, with the box component depicting the first and third quartiles and the whiskers representing the maximum and minimum values, with the exception of outliers which are plotted as separate points. The threshold for statistical significance was set was $p<0.05$ for all analysis and statistical tests were conducted in SPSS 25.

7.4. Results

7.4.1. Upper and lower limb CSG properties

Descriptive statistics and results of the independent *t*-tests comparing solid CSG properties of the humerus, tibia and femur of Xagħra and Italian Copper Age groups are displayed in Table 7.2 and Table 7.3. Box-and-whisker plots comparing the solid CSG properties of the humerus, femur and tibia between the Xagħra and central Italian groups are displayed in Figure 7.3, Figure 7.4 and Figure 7.5 respectively. The results show a significant difference in both *TA* ($p<0.001$) and *J* ($p=0.002$) in the humerus between the two groups (Table 7.2), where the Xagħra group has lower average values (Fig. 7.3; Table 7.3). The comparison of humeral cross-sectional shape also shows a significant difference between groups ($p=0.004$), with the Xagħra group having more elliptically shaped humeral cross-sections, as indicated by average greater I_x/I_y values (Table 7.2). A consideration of the standard deviations (Table 7.3) and box-and-whisker plots (Fig. 7.3), which reflect the degree of variability within a sample, shows constrained variation in both measures of upper limb robusticity and cross-sectional shape among the Xagħra group. The results for the lower limb, however, show a considerably different pattern to that observed in the upper limb in that no statistical difference was observed between both groups in any of the comparisons in CSG properties of the femur and tibia (Table 7.3). The descriptive

Table 7.2. *Summary statistics and results of independent t-test comparing cross-sectional properties of upper limb (humerus) between Xagħra and Copper Age Italy.* [a]*Sample contains individuals that have determined biological sex, but are included as a pooled-sex sample here.* [b]*Significant difference,* p = <0.05.

Cross-sectional property	*N*	Mean	St.D.	*t*-test *p* [b]
Humerus TA (35%)				
Xagħra	32	808.56	121.76	<0.001[b]
Copper Age central Italy[a]	61	917.92	143.99	
Humerus *J* (35%)				
Xagħra	32	5114.34	1388.71	*0.002[b]
Copper Age central Italy[a]	61	6335.67	1908.11	
Humerus I_x/I_y (35%)				
Xagħra	32	1.19	0.13	*0.004[b]
Copper Age central Italy[a]	61	1.09	0.16	

Table 7.3. *Summary statistics and results of independent t-test comparing cross-sectional properties of lower limb (femur and tibia) between Xagħra and Copper Age Italy. [a]Sample contains individuals that have determined biological sex, but are included as a pooled-sex sample here. [b]Significant difference,* p = <0.05.

Cross-sectional property	*N*	Mean	St.D.	*t*-test *p* [b]
Femur TA (50%)				
Xagħra	31	882.84	108.56	0.658
Copper Age central Italy[a]	32	871.84	87.06	
Femur I_{max}/I_{min} (50%)				
Xagħra	31	1.31	0.18	0.893
Copper Age central Italy[a]	32	1.31	0.17	
Femur *J* (50%)				
Xagħra	31	4097.77	958.26	0.508
Copper Age central Italy[a]	32	3947.53	827.85	
Tibia TA (50%)				
Xagħra	27	713.15	106.45	0.866
Copper Age central Italy[a]	32	717.5	90.29	
Tibia *J* (50%)				
Xagħra	27	4419.78	939.48	0.552
Copper Age central Italy[a]	32	4264.19	1039.61	
Tibia I_{max}/I_{min} (50%)				
Xagħra	27	2.29	0.51	0.269
Copper Age central Italy[a]	32	2.42	0.44	

statistics (Table 7.3) and box-and-whisker plots (Figs 7.4 & 7.5) for the lower limb also display remarkable consistency in CSG properties of the femur between the central Italian and Xagħra groups. In particular, both Xagħra and the central Italian group have identical femoral I_{max}/I_{min} values of 1.31. However, all CSG properties in the tibia, except *TA*, are numerically greater at Xagħra, and the Xagħra group generally exhibits greater variation in CSG properties of the lower limb (Table 7.3).

Table 7.4. *Descriptive statistics for CSG properties of the humerus (35%) by side and results of independent samples t-test comparing left and right CSG properties of humerus from Xagħra. [a]Significant difference, p = <0.05.*

Cross-sectional property	Left (*N*=11)		Right (*N*=21)		
	Mean	**St.D.**	**Mean**	**St.D.**	***t*-test *p*** [a]
J	220.19	57.03	249.82	92.97	0.363
TA	786.98	107.44	824.79	161.11	0.507
I_{max}/I_{min}	1.27	0.16	1.26	0.09	0.818
I_x/I_y	1.2	0.17	1.18	0.13	0.628

Although it is not possible to examine upper limb bilateral asymmetry within single individuals from Xagħra, comparisons between the left and right humeri were made on a group-wide basis in order to explore broad patterns in hand preference. Summary statistics and results of the independent *t*-tests comparing differences between the CSG properties of the left and right humeri within the Xagħra group are presented in Table 7.4. Figure 7.6 and Figure 7.7 display box-and-whisker plots for the CSG properties of the left and right humerus for the Xagħra sample. No significant difference between the any of the CSG properties of the left and right humeri were observed, although interesting numeric differences are apparent (Table 7.4). In TA and *J*, right humeri display considerably more variation (Fig. 7.6), whereas the shape ratios (I_{max}/I_{min} and I_x/I_y) show a slightly different pattern. In particular, I_{max}/I_{min} in right humeri exhibits extremely limited variability (Table 7.4; Fig. 7.7). These results suggest different patterns of mechanical loading and habitual behaviour between the left and right upper limb and indicate preference for the right side, at least on a sample wide basis.

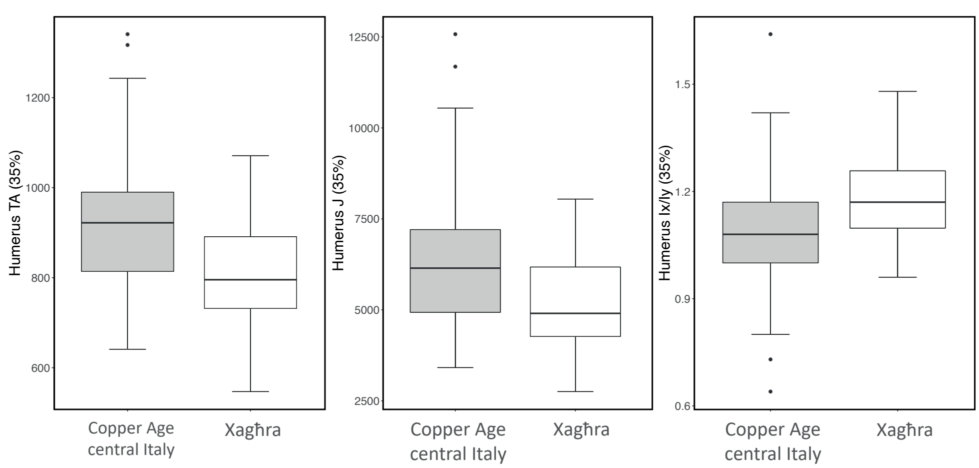

Figure 7.3. *Comparison of solid CSG properties of the humerus between Xagħra and central Italy.*

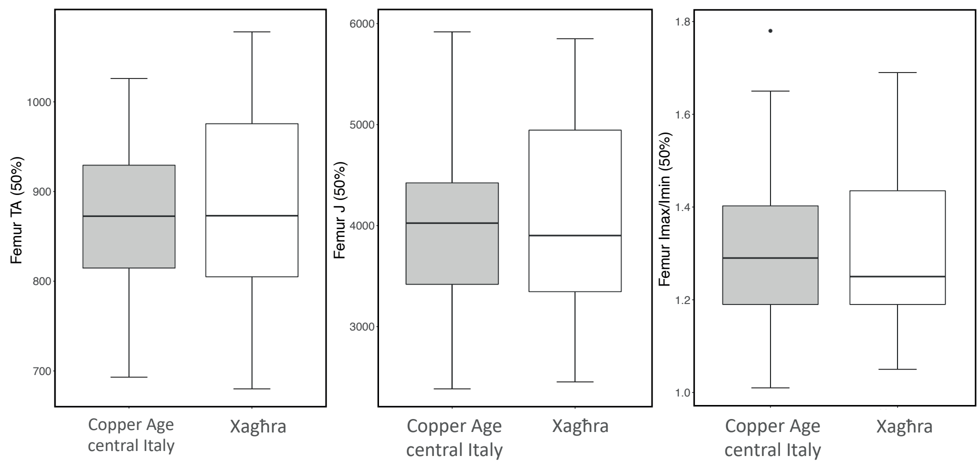

Figure 7.4. *Comparison of solid CSG properties of the femur between Xagħra and central Italy.*

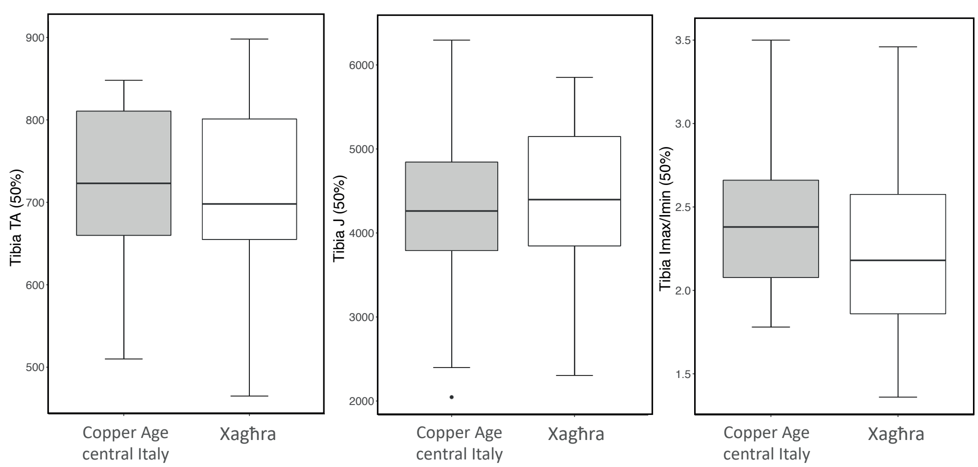

Figure 7.5. *Comparison of solid CSG properties of the tibia between Xagħra and central Italy.*

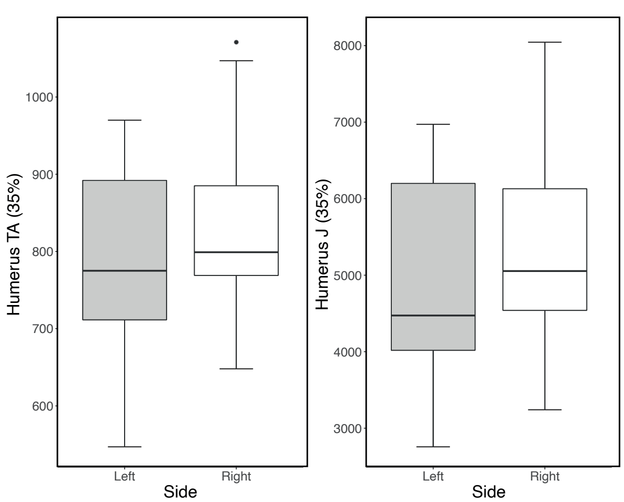

Figure 7.6. *Side differences in TA (left) and J (right) of the humerus at Xagħra.*

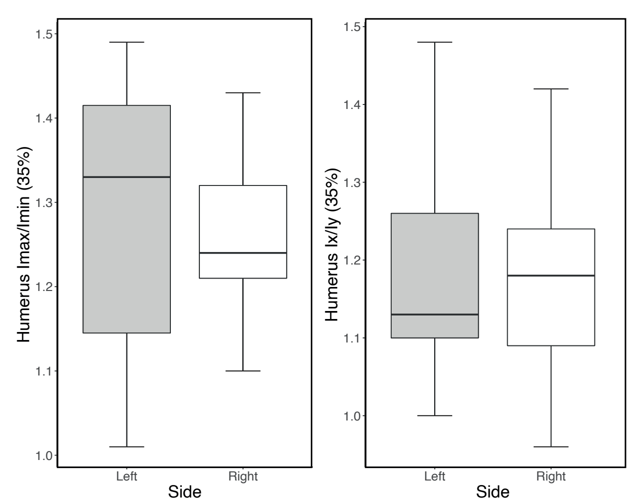

Figure 7.7. *Side differences in cross-sectional shape of the humerus (left, I_{max}/I_{min} and right I_x/I_y) at Xagħra.*

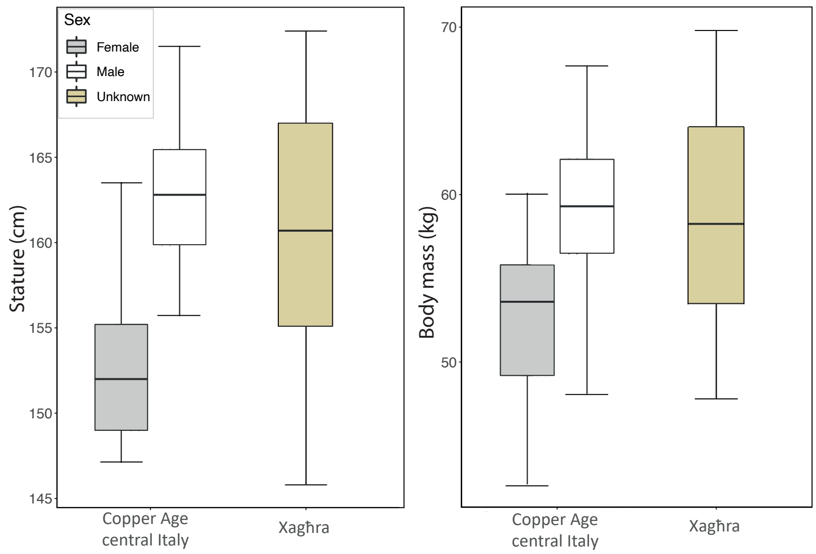

Figure 7.8. *Comparisons of estimated stature (cm) and body mass (kg) between Xagħra and central Italy.*

7.4.2. Body size

Table 7.5 contains descriptive statistics and independent *t*-test comparisons of estimated stature (cm) and body mass (kg) between the Xagħra and central Italian groups. Box-and-whisker plots showing body size variables for the Xagħra (pooled-sex) and central Italian (by sex) groups are displayed in Figure 7.8. Whilst no significant difference in either stature or body mass is observed, the summary statistics and box-plots indicate that the Xagħra group exhibits greater overall body size. Although the analysis presented here only offers one comparison, the results follow a broader central Mediterranean trend were late Neolithic Malta exhibits larger body size than contemporary and near-contemporary groups (Parkinson 2019). The greater range of variation in body size variables at Xagħra is reflective of this group being a pooled-sex sample, where males and females cannot be identified because of commingling. This is highlighted by the clear body size differences between males and females in the central Italian group, where males have a numerically greater average body size than females.

Table 7.5. *Descriptive statistics and results of independent t-tests comparing body mass and stature. [a]Significant difference, p = <0.05.*

	Estimated stature (cm)			Estimated body mass (kg)			
Group	***N***	**Mean**	**St.d.**	***N***	**Mean**	**St.d.**	***t*-test *p*** [a]
Late Neolithic Malta	22	160.72	7.71	28	58.63	6.76	0.159
Copper Age central Italy	25	158.34	6.85	30	56.19	6.27	0.268

7.5. Discussion

The results of the biomechanical analysis of the humerus, femur and tibia indicate that the late Neolithic population of the Maltese Islands had gracile upper limbs, but that the mechanical profiles of the lower limb were similar to Copper Age populations in central Italy. The results also demonstrate preferential use of the right hand within the Xagħra sample, alongside limited variability in CSG properties of the upper limb in stark contrast to the greater variation observed the lower limb. The data are interpreted here as reflecting evidence for reduced levels of physically demanding manual activity in late Neolithic Malta, relative to near-contemporary groups, in contrast to adaptations in the lower limb to heightened levels of terrestrial logistical mobility around the rugged terrain of Gozo. A further interesting feature of the Xagħra assemblage was the constrained variation of upper limb CSG properties.

Increased I_x/I_y values in humeri indicate an elliptical cross-section shape in the antero-posterior plane and are usually interpreted as evidence for repetitive unidirectional habitual (Ruff 2019; Stock & Pfeiffer 2004) and food processing among early agricultural societies (Larsen 2015; Stock *et al.* 2011). Large numbers of querns are known from late Neolithic Malta (Malone *et al*. 2009a, 264; Trump 1966), and it has been suggested that agriculture intensified during the Tarxien phase under a more controlled system, of which the megalithic Temples formed a focus (Stoddart *et al.* 1993; Trump 1980; Volume 2, Chapter 13). More recent palaeoeconomic models for late Neolithic Malta have added nuance to this view, suggesting that landscape management practices were increasingly employed during the Tarxien phase to offset the diminution of soil cover and aridification (Volume 2, Chapter 5), causing potential dietary changes (Chapter 10). Furthermore, the proliferation of stone masonry on the Maltese Islands during the Tarxien phase (Trump 2002) could also be argued as a plausible explanation for the high I_x/I_y values among the late Neolithic Maltese sample. Experimental studies have shown that such activities would have involved vigorous and repetitive unidirectional manual activity (Caruso 2016; Larocca 2016).

However, the decreased humeral robusticity and rigidity (*TA* & *J*) of the Maltese sample is also important to consider, and an alternative interpretation for the patterning in the data may also be driven by the upper limb gracility of the Maltese sample. Pronounced anterior ridges along the distal humeral diaphysis are an artefact of gracility that may result in a more triangular or elliptical cross-section shape. When viewed alongside the decreased TA and *J* values, this shape suggests that the results for all three CSG properties could be related and reflective of decreased levels of mechanically demanding manual behaviour in late Neolithic Malta. The evidence for decreased mechanical loading in the upper limb is somewhat supported by the lack of activity-related pathology, specifically degenerative joint disease, on the major joints of the limbs (§8.4.3). However, incidences of pathology in the upper extremities (bones of the hands) are indicative that intensive manual activities were part of the lived experience of late Neolithic Malta (§8.4.2), but that such behaviours could have involved repetitive and strenuous fine-motor skills, rather than significant mechanical loading of the upper appendicular skeleton.

Although analysis of humeral asymmetry was not possible with the Xagħra assemblage, comparisons between the left and right humeri from the site showed that right humeri exhibited greater robusticity, allowing for a broad exploration of handedness in late Neolithic Malta. Comparisons of shape ratios did not, however, reveal any differences between the left and right sides. When interpreting these broad results, it is important to consider the full spectrum of potential behaviours in late Neolithic Malta and analysis of the dentition from Xagħra also shows evidence for the use of the mouth as a 'third hand', likely as part of a variety of craft-working or food processing activities (§5.8). Recorded instances of enamel trauma and wear at Xagħra occur most frequently on the right maxillary premolars and left mandibular molars. Such a distinctive diagonal pattern of dental trauma and wear is consistent with repeated clamping and gripping of abrasive materials extending from the right side of the mouth. The biomechanical evidence for preferential use of the right hand among the Xagħra group, although typical for modern (McManus 2009; Raymond & Pontier 2004) and prehistoric populations (Sladék *et al*. 2018), seems to be conducive with the model of habitual activity evidenced through dental wear.

The results of the comparative analysis showed that both the Xagħra central Italian Copper Age groups have similarly robust lower limbs. These results are surprising, given that the Xagħra sample might have been expected to exhibit evidence for decreased terrestrial mobility because of their geographically restricted island context – the Maltese Islands have a combined area of 316 km^2, of which Gozo is only 67 km^2 (Schembri *et al.* 2009). Reduced lower limb loading and terrestrial mobility has been observed in Island groups from the Andaman Islands (Stock & Pfeiffer 2001), but in contrast the Xagħra group show lower limb CSG properties that are comparable with those of the Italian Copper Age. A recent comparison between the central Italian Copper Age sample used in this study and a coeval Copper Age sample from the Po Plain, northern Italy, demonstrated increased lower limb robusticity in the central Italian sample, interpreted as reflecting logistical mobility around the hilly terrain of central Italy (Parkinson *et al.* 2018). The influence of terrain and landscape context on lower limb CSG properties has been well studied in Neolithic Liguria, northern Italy, where high levels of lower limb robusticity and greater bending rigidities were also attributed to an adaptation to rugged terrain and high levels of mobility associated with pastoralism (Marchi *et al.* 2006, 2011; Marchi 2008; Sparacello & Marchi 2008). In these studies, the Neolithic Ligurian population displayed levels of lower limb robusticity closer to highly terrestrially mobile Late Upper Palaeolithic or Mesolithic groups (Marchi 2008; Marchi *et al.* 2011), with similar results seen in 'Ötzi' the Alpine Iceman (Ruff 2006b) and Neolithic groups from mountainous regions of southern France (Lambert *et al.* 2013). In spite of their restricted geographical context, the Xagħra population exhibits evidence for undertaking similarly intensive mobility behaviours to central Italian Copper Age groups. The results therefore seem to suggest that the late Neolithic population of Gozo were engaging extensively with their physical landscape, evidently navigating the harsh and irregular terrain of the island. However, the unique and restricted landscape setting of the Maltese case study may also have future implications for how we define, discuss and interpret mobility behaviour in studies of CSG properties in archaeological populations.

The contrasting variability between the CSG properties of upper and lower limb for the Xagħra sample is also interesting. Understanding the precise relationship between the upper and lower limb at Xagħra is difficult in the absence of a larger sample of articulated individuals, although the results do hint at an opposing relationship between patterns physical manual activity and mobility behaviour. The constrained variation in CSG properties of the humerus within the Xagħra sample, when compared to the Italian Copper Age sample, offers useful insights into the division of labour in late Neolithic Malta. Comparison with the humeral CSG properties of the central Italian sample (Fig. 7.3) illustrates how increased variation – at least within that particular archaeological context – can be driven by sexual dimorphism. Considering the Xagħra sample as a commingled assemblage, composed of a mixture of males, females and adult age categories, the limited variation may suggest there was no sex-based division of manual labour during the Tarxien phase. Various social models have been put-forth for late Neolithic Malta that suggest the megalithic temples formed part of structured or hierarchical chiefdom system (Renfrew 1973; see also Cazzella & Recchia 2015, *contra* Bonanno *et al.* 1990 who suggest internal rivalry). The data from the upper limb, with its relative homogeneity, perhaps suggests a more inclusive and heterarchical society and division of labour. Ultimately, attempting to interpret sex-based differences using only CSG values is problematic, however, since post-cranial robusticity has been shown to be heavily influenced by physiological differences between men and women (Macintosh *et al.* 2017, 2019). Examination of sexual dimorphism in the upper limb therefore requires analysis of bilateral asymmetry, which is independent of the physiological factors affecting post-cranial robusticity, although such analysis is simply not possible with the Xagħra commingled assemblage.

The analysis of body size, which revealed a larger average body mass for late Neolithic Malta relative to near-contemporary groups, also has implications for discussions on skeletal growth, stress and development. The averages for body mass (58.6 kg) and stature (160.72 cm) in late Neolithic Malta are at the higher end of ranges obtained from Neolithic and contemporary Copper Age groups in the central Mediterranean (Parkinson 2019) and wider Europe (Macintosh 2016; Niinasken *et al*. 2018), suggesting that the physiological factors affecting skeletal growth and development were less prevalent in Temple Period Malta. In this respect, the higher body size of the Xagħra assemblage lies in apparent contrast to evidence of skeletal stress suggested before (Stoddart *et al*. 2009a) and strengthened in this volume. In particular, the analysis of dental pathology (Chapter 4) and palaeodiet (Chapter 10) shows increasingly marked incidences of linear enamel hypoplasia, decreasing incidences of caries and fluctuating ^{13}N throughout the duration of the Tarxien phase, indicative of developmental stress and changes in diet in the final years of the Temple Period. When viewed together, the evidence therefore appears to present an interesting case whereby the late Neolithic population of Xagħra were clearly faced with increased stress and a changing dietary regimen, but not to the extent that there was a major impact on normal skeletal growth and development. The increased average body size from Xagħra is further surprising given the small island context of the site, where smaller body size might be expected (Foster 1964). Insular dwarfism has been documented in modern human populations (Berger *et al.* 2008; Diamond 2004), although socio-economic factors and life histories have also been shown to affect this phenomenon (Stock & Migliano 2009). When considered alongside the broader archaeological, environmental and palaeoeconomical data for the period (Volume 2, Chapter 12), the Tarxien phase appears to have been a time of considerable changes in diet, behaviour and agricultural practices that suggest the late Neolithic population of the Maltese Islands was grappling with the ever changing environmental instability of their island world.

7.6. Conclusion

Few studies have attempted to analyse long bone cross-sectional geometry in large commingled and fragmented burial assemblages because of the methodological issues they pose, however the results presented here show that meaningful insights into past lifestyles and lived experiences can be gained from such challenging material. This is especially true in cases, such as at Xagħra, where CSG properties and body size data are viewed and interpreted alongside studies exploring diet, health and pathology. The gracile upper limbs of the Xagħra group, when compared with the central Italian group, indicate that levels of manual activity in late Neolithic Malta were perhaps less intensive than in contemporary Copper Age societies in the central Mediterranean. By contrast, the surprising evidence for robust lower limbs among the Xagħra group has shown that despite their geographically restricted island context, the late Neolithic inhabitants of Gozo were actively mobile and engaging with their rugged and hilly natural landscape. The broad patterns of side bias in the upper limb also correspond with side biases in identified dental wear elsewhere in the volume, which when integrated provide exciting glimpses into the lived experience of late Neolithic Malta. The results from the analysis of stature and body mass indicate that average body size among the Xagħra group was greater than that of contemporary groups in the central Mediterranean, suggesting that the physiological factors affecting stature and body mass were perhaps less prevalent in late Neolithic Malta. Interestingly, the body size data presented here shows some contrasts with the palaeodietary and palaeopathological data for Xagħra reported elsewhere, highlighting the complex interplay between skeletal indicators of developmental stress and life history.

Despite the interpretive limitations imposed by the commingling at Xagħra, the broad insights into habitual behaviour derived from the biomechanical analysis presented in this chapter were augmented by the analysis of dentition and palaeopathology presented in Chapters 5 and 8, underscoring the effectiveness of multi-method research programmes in bioarchaeology. However, one particular limitation of this study was that it only considered adult long bones. The evidence from dental wear (Chapter 5) demonstrates that adolescents undertook similar habitual tasks to adults, suggesting a broader division of labour in late Neolithic Malta that integrated younger members of society. It is worth noting, however, that the activity induced bone growth reflected in long bone CSG properties appears to correspond to mechanical loading during adolescence (Haapasalo *et al.* 1996; Kontulainen *et al.* 2002; Pearson & Lieberman 2004). The emphasis on particular contexts also imposes further constraints on the inferences that can be drawn on the data collected here, however; the main contexts that were analysed (from the Shrine, Chapter 3) do offer a representative sample for the entire duration of the Tarxien phase.

The discussions in this chapter also highlight the impact that recent developments in archaeological science have had on the study of complex commingled assemblages, enabling minimal and efficient sampling procedures that provide maximum results. For this study, the application of 3D laser scanning aided the acquisition of osteometric data that would have otherwise been impossible since it enabled a flexible approach whereby study materials could be revisited *in silico*, allowing methodologies to be constantly refined, developed and reapplied.

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