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Manuscript

Is the evaluation of millennial changes in stature reliable? A study in southern Europe from the Neolithic to the Middle Ages

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Abstract

Analyses of stature variation in prehistoric and historical populations encounter considerable problems of reliability of the comparisons. To properly compare the results of different studies, it is necessary to conduct a systematic review of the chronological and cultural context of the skeletal series used and identify the most approprriate method to calculate stature values, since stature reconstruction formulae are specific for certain times and places.Stature variations in the population of Sardinia (a Mediterranean island now part of the Italian republic but considered separately given its unique genetic structure) from the Neolithic to the Modern Period were studied to evaluate the intensity of millennial changes.

The results were then compared with the values of coeval skeletal series reported in the literature for other Southern European countries (Italy, Spain, Portugal). We used

Sardinian skeletal series with radiocarbon dates of from culturally well-defined archaeological contexts.

The osteometric measurements were taken on femora of adults who had completed growth and who did not present evident pathological conditions. The data we collected and analyzed indicate that the conditions are lacking to reliably identify a common trend in millennial changes among the considered populations of Southern Europe.

Keywords
Stature – Millennial changes – Southern Europe – Neolithic – Middle Ages

Introduction

Stature is the somatometric character most frequently used in studies of past populations because it is ecologically sensitive. Although stature is ≥80% under genetic control (Sanna et al. 2008; Lettre 2009; McEvoy and Visscher 2009), the final phenotype is greatly influenced by environmental and socioeconomic factors (Danubio and Sanna 2008). The estimation of stature and its variations in time and space provide an important 16 contribution to knowledge of the living and health conditions of past and current populations (Larsen 2002; Formicola and Holt 2007). Indeed stature plays an important role as an indicator of health status (Pietrusewsky and Tsang 2003; Maat 2005), nutritional status and hygienic-sanitary conditions (Steckel 1995; Larsen 1997), micro-evolutionary trends in body size and proportions (Formicola and Giannecchini 1999; Steckel 2004; Gerhards 2005; Giannecchini and Moggi-Cecchi, 2008), and sexual dimorphism (Gustafsson et al. 2007). Stature estimates also allow reconstruction of body mass, skeletal robusticity and activity levels (Holt 2003; Ruff et al. 2005).

However there are methodological limitations to the analysis of stature and its variations over time in past populations due to the inherent difficulty of reconstructing the height of the living individual from his skeletal remains (Giannecchini and Moggi-Cecchi 2008). The two main methods for stature estimation are the anatomical method and regression equations. The anatomical method proposed by Fully (1956) and Fully and Pineau (1960) and reviewed by Raxter et al. (2006;

2007) requires the complete skeleton, since the stature estimate is based on all the skeletal components contributing to stature: skull, vertebral column and lower limb bones. This procedure provides the most reliable reconstruction of stature since the source of error, typically ± 2.05 cm, is reduced to the thickness of the soft parts and the degree of spinal curvature (Vercellotti et al. 2009). Since archeological excavations do not usually yield complete skeletons, this method is rarely used for stature estimates. Hence it is necessary to employ alternative methods based mainly on regression equations such as those of Pearson (1899) and Trotter and Gleser (1952; 1958) which use the long bones of the limbs. The intrinsic difficulties in sex determination, particularly of a skeleton represented only by the long bones, should also be noted (Krogman and Işcan 1986). Therefore the choice among the many methods available for stature estimation must be based on theoretical grounds, practical utility and technical aspects (Formicola 1989).Among the methods based on long bone lengths, the tables of Manouvrier (1892) and the formulas of Pearson (1899) produce values that are on average 4 cm lower than those produced by the Trotter and Gleser equations (1958) for "whites" (Cardoso and Gomes 2009). The different results are explained by the fact that the formulas were obtained from samples with different limb/trunk proportions and by different estimation procedures (Trotter and Gleser 1952; 1958; 1977; Formicola 1983; 1989). Therefore the choice of the method to apply to past populations is important given that the limb/trunk ratio is not known for them.

The aim of the present study was to determine height variations in populations of southern Europe and Asia Minor from the Neolithic to the Middle Ages to compare the intensity of millennial changes in stature. The samples used, although from specific sites, are identified with the current names of the regions. Sardinia (a Mediterranean island currently part of Italy) is analyzed separately from Italy because of its insularity and unique gene pool, demonstrated by numerous genetic studies with classic non-DNA and DNA markers. This differentiates the Sardinian population from the others of Europe and the circum-Mediterranean area, as well as from other Italian populations (Francalacci et al. 2003; Vona and Calò 2006; Capocasa et al. 2014). These peculiar characteristics are most likely related to the earliest settlements in the Upper Paleolithic (Varesi et al. 2000; Vona and Calò 2006; Francalacci et al. 2013), the geographical isolation, the marginal position of the island with respect to the main currents of economic development and the substantial absence of significant migration flows

(Sanna 2006). The peculiar biological and biodemographic history of Sardinia make the island an ideal place to study the impact of bio-socio-cultural factors on secular and millennial changes.

Materials and methods

Samples

The Sardinian database includes measurement values of femora of skeletal series from various periods from the Neolithic to the Modern Period (fifteenth to nineteenth century CE). These data, measured following Martin and Saller (1957), were used to estimate the stature of the living individuals. The mean statures of Sardinians were compared with those reported in the literature for three other southern European regions: Italy (Giannecchini and Moggi-Cecchi 2008), Spain (Lalueza-Fox 1998), and Portugal (Cardoso and Gomes 2009). To create this database, we considered Sardinian skeletal series with radiocarbon dates (Sanna 2006; Lai 2009; D′Amore et al. 2010) or from culturally well-defined archeological contexts. These series, mostly belonging to the collection of the Sardinian Museum of Anthropology and Ethnography, University of Cagliari, or temporarily housed there for study purposes, are listed in Table 1. The material was the subject of a recent study by one of the authors (PM), who measured the specimens and reanalyzed the data.

We considered only individuals who had completed growth of the long bones and who did not present evident pathological conditions. The material is not in anatomical connection and often comes from multiple burials. Therefore, we only considered measurements of the femora to estimate the stature since the lower limb bones give a more accurate estimate of stature than the upper limb bones and the proximal parts of the limbs are more accurate than the distal ones (femur with respect to tibia and fibula, humerus with respect to ulna and radius; Trotter and Gleser 1958; Krogman and Iscan 1986; Vercellotti et al. 2009). Moreover, when the equations for the estimation of stature are based on single long bones, lower limb bone lengths produce smaller standard errors of estimate (SEEs) of stature than do upper limb bones lengths (Sjøvold 1990; Formicola and Franceschi 1996; Ruff et al. 2012).

Sex determination

Sex determination was initially performed by analysis of the discriminant analysis of the femur: diameter of the femoral head (Pearson and Bell 1917-1919; Stewart, 1979), bicondylar width (Pearson and Bell 1917-1919) and mid-shaft circumference (Black 1978). Moreover, for a few specimens from the Roman Period, sex determination was confirmed by visual analysis of pelves and crania, as proposed by Acsádi and Nemeskéri (1970) and Ferembach *et al.* (1977).

The following method was developed to evaluate the correct attribution of sex. Let X_1, X_2, X_3, X_4 and X_5 be the five anthropometric variables considered (X_1,= diameter of the femoral head, X_2 = bicondylar width, X_3 = mid-shaft circumference of the femur, X_4 = maximum femoral length, X_5 = physiological femoral length). The gender, initially assessed by the analysis of the femoral discriminant characters, was controlled by the procedure described below, based on the fact that female measures are systematically smaller than male ones for all the considered variables. For each specimen *j,* we reassessed the gender by a score function F_j, defined as follows: let X_{hj} be the observed value of the variable X_h in the *j-th* specimen, and let C_h *(h= 1, 2, ..., 5)* be the 5th percentile of the overall distribution of the variable X_h. We put F_{hj} =+1 if $X_{hj} > C_h$ and F_{hj} = -1 if $X_{hj} \leq C_h$ (giving a value F_{hj} = 0 only when the datum is missing). The final value of the score function is

$$F_j = \sum_{h=1}^{5} F_{hj} = \text{n° of} \{F_{hj} = +1\} - \text{n° of} \{F_{hj} = -1\}$$

If the final value F_j has a positive (negative) value, the find is more likely male (female); the absolute values shows the strength of confidence in the gender attribution. For instance, if $F_j=+1$, the classification is “probably male”; if $F_j=-2$, the classification is “very probably female”, and so on. As the score function is based on five variables, the possible range of F_j is from -5 to +5.

This classification, derived from anthropometric measures, was compared with the results of the analysis of the femoral discriminant characters. In the few discordant cases, sex was attributed by means of the new procedure.

Stature analysis

The Sardinian mean statures per period were calculated based on the maximum femoral length (measure 1 of Martin and Saller 1957) according to some of the most commonly usedmethods for stature estimation of European archaeological skeletal material (Giannecchini and Moggi-Cecchi 2008; Ruff *et al.* 2012): Pearson (PEA) (1899), Trotter and Gleser for Whites and Afro-Americans (TGW and TGA) (Trotter and Gleser, 1952, 1977; Trotter 1970) Sjøvold (SJO) (1990) and Ruff et al. (RUF) (2012). We also considered the Trotter and Gleser formula for African-Americans because it has previously been proposed to be the most reliable methodto derive stature in a prehistoric Italian sample (Formicola 1983). It was found to be more suitable than TGW in the estimation of stature for the population of central Italy from the Iron Age

to the medieval period (Giannecchini and Moggi-Cecchi 2008).

We used the results obtained by the Pearson method to compare the Sardinian mean statures with those of the other regions. This method allows a direct comparison of the Sardinian skeletal series with those reported in the literature for the same period for the Italian and Spanish series and for the Portuguese series recalculated based on the mean femoral lengths published by Cardoso and Gomes (2009) (see Table 2). It should be noted that Cardoso and Gomes (2009) estimated the Pertuguese stature according to the Mendonça method (2000) created for forensic purposes to estimate stature in present-day Portuguese.

For the Italian series, we include in Table 2 the mean statures from the Neolithic to the Bronze Age. However, to avoid errors of interpretation of Italian mean statures over time, the values reported by Borgognini-Tarli (1992) are not included in the following analyses since they were estimated by the method of Trotter and Gleser for Whites, which would produce an overestimation of about 4 cm with respect to the Pearson method (Cardoso and Gomes 2009).

To make the mean statures comparable in time among Sardinia, Italy, Spain and Portugal, we compared the values of coeval skeletal series following the chronological indications of the various authors (Table 3). In various cases, the same periods overlap or partially overlap (Table 3). An example is the transition from the Neolithic to the Chalcolithic: in Sardinia, the Late Neolithic is dated between 4000 and 3200 B.C.E. and the Chalcolithic between 3200 and 2200 B.C.E. (Tykot 1994); in Italy, the chronological subdivision puts the Late Neolithic between 4500 and 3500 B.C.E. and the Chalcolithic between 3500 and 2100 B.C.E. (Rottoli and Castiglioni 2009); for Portugal, Cardoso and Gomes (2009) indicate the period from 3500 to 2100 B.C.E. as the Late Neolithic/Chalcolithic, while in Spain the Late Neolithic is dated between 3800 and 3000 B.C.E. and the Eneolithic between 3000 and 2200 B.C.E. (McClure et al. 2011).

To determine the temporal trend of stature, we adopted a simplified chronological scheme as follows: Late Neolithic (4000 – 3200 B.C.E.), Chalcolithic (3200 – 2000 B.C.E.), Bronze Age (2000 – 1000 B.C.E.), Iron Age (1000 – 300 B.C.E.), Roman Period (300 B.C.E. – 500 C.E.) and Medieval period (500 B.C.E. – 1500 C.E.).

The mean statures of the Spanish series for the Bronze Age, Talaiotic culture, and Middle Ages (Lalueza-Fox 1998) were obtained by calculation of the weighted means (Table 2). The Portuguese mean statures were obtained by applying the Pearson method to the weighted means of the values of maximum femoral length.

For graphical purposes, the mean stature for time periods in which data were not availabel was obtained by interpolation mathod (Marascuilo and Serlin 1988) (in particular the Sardinian

Chalcolithic 3200 – 2000 B.C.E. and the Iron Age 1000 – 300 B.C.E. for both sexes and the Portuguese Bronze Age 2000 – 1000 B.C.E. and Iron Age 1000-500 B.C.E. for both sexes).

Statistical analyses

Given the very low sample sizes for periods to evaluate whether the different methods used to determine stature produce significantly different values, we adopted the non-parametric Kruskal-Wallis test (KW) and the post hoc Wilcoxon test (WIL) (for paired data) with the Bonferroni-Dunn correction (BD), assuming α=0,01.

To determine if there is a significant difference between Sardinian males and females of the same time period, we used the Welch test. To evaluate if there is , within the same sex, a significant difference between the means of two contiguous periods, we applied the Mann-Whitney test (M-N), using the Bonferroni-Dunn correction (B-D), assuming α=0,01 for any pairwise comparison.

Results

Sardinian Data

The Sardinian stature data (Table 4) were used to construct Figs. 1 and 2, for males and females, respectively, illustrating the possible trend of mean stature from the Neolithic to the Modern Period as shown by the PEA, TGW, TGA, SJO and RUF methods.

The K-W test reveaòed that the differences in the values produced by the various methods are always statistically significant for both sexes ($p<0,001$). The pairwise comparisons with WIL as post hoc test with the B-D correction, assuming α=0.01, are also always significant ($p<0,001$).

In males, the stature trend for the Sardinian population does not change based on the method used; there is only a difference in the value of the stature estimation calculated for period. The highest estimetes are observed for TGW, followed by SJO, PEA, TGA and RUF. The difference between the method producing the highest estimate (TGW) and the one yielding the lowest estimate (RUF) is on average 3.6 cm

Figure 1 shows an increase in mean male stature from the Late Neolithic (4000 – 3000 B.C.E.) to the Bronze Age (1600 – 850 B.C.E.) followed by a decrease, with the minimum recorded by all the methods during the Roman Period (238 B.C.E. – 476 C.E.). Then, there is an increase in stature, with the maximum recorded with all the methods in Medieval period (5th to 15th century C.E.).

However, no significant differences are seen in pairwise comparison between the values of the period by means of the M-N test with B-D correction, assuming $\alpha=0.01$.

In females, the stature trend for the Sardinian population does not change substantially according to the method used (Fig. 2), except for PEA. With TGW, TGA, SJO and RUF, there is a slight increase from the Late Neolithic (4000 – 3000 B.C.E.) to the Roman Period (238 B.C.E. – 476 C.E.) and there is a slight decrease until the Modern Period (15th to 19th century C.E.). Instead, PEA showsthat the increase does not stopin the Roman period (152.6 cm), but continues until the Medieval period (152.9 cm) followed by a slight decrease in the Modern Period (151.2 cm). The highest estimates are produced by SJO, followed by the TGW, RUF, TGB and PEA. With RUF, we obtain the lowest value of mean stature (150.6 cm) for the Late Neolithic, whereas PEA records the lowest value for the remaining periods. The difference between the highest mean female stature values (SJO) and the lowest values (PEA and RUF for the Late Neolithic) is on average 5 cm.

In the pairwise comparison between the values of the periods by means of the M-N test with B-D correction, assuming $\alpha=0{,}01$, there are no significant differences for either males or females. With Welch test, the differences between males and females of each period are always statistically significant ($p<0{,}01$).

Comparison of European samples

The stature data (Table 2) and interpolations were used to construct Figs. 3 and 4, for male and females respectively, illustrating the possible trend of mean stature from the Neolithic to the Middle Ages in each country.

It can be seen immediately that there are different temporal trends of stature in Sardinia and Portugal between male and females from the Iron Age (1000 – 300 B.C.E.) to the Medieval Period (5th to 15th century C.E.). With regard to the trend of the four populations (not considering the data obtained by linear interpolation), only the males of Italy, Spain and Sardinia show a common trend, characterized by a decrease from the Iron Age (1000 – 300 B.C.E.) to the Roman Period (300 B.C.E. - 500 C.E.), followed by an increase in the Medieval Period (5th to 15 th century C.E.). The Italian males decrease in stature by 2.2 cm from the Iron Age to the Roman Period (from 166.6 to 164.4 cm), before increasing to 166.9 cm in the Middle Ages (an increase of 2.5 cm). The Spanish males decrease by 2.3 cm between the Iron Age and Roman period (from 165.5 to 163.2 cm) and then increase by 1.6 cm (to 164,8 cm) in Medieval period. In the Sardinian males, there is a decrease of 1.7 cm between the Bronze Age and Roman Period, folowed by an increase of 2 cm (to 165.2 cm) in the Medieval Period. The data of Portuguese males indicate a different trend, characterized by an increase from the Chalcolithic (3200 – 2000 B.C.E.) to the Medieval period (5th to 15th century C.E.), from 160.2 to 165.4 cm (Fig. 3)

The female sample does not show similar trends in the various regions, with the exception of the Iron Age (1000 – 300 B.C.E.), Roman Period (300 B.C.E. - 500 C.E.), and Medieval Period (5th to 15 th century C.E.) for Italy and Spain. Both series show a trend similar to those of the corresponding male series. The Italian female sample decreased by 2.2 cm from the Iron Age to the Roman Period (from 154.3 to 152.1 cm) and then increases by 2.4 cm (to 154.5 cm) in the Middle Ages. The Spanish sample decreases by 1.8 cm between the Iron Age and Roman Period (from 153.6 to 151.8 cm) before increasing by 1.1 cm (to 152.9 cm) in the Medieval Period. The Sardinian and Portuguese females show an increase in stature from the Neolithic to the Middle Ages, respectively from 151.2 to 152.9 cm and from 149.2 to 154.7 cm

It shuold be noted that the estimation of stature for the Iron Age in Spain was calculated from the skeletal series of the Talaiotic Period (600 – 200 B.C.E.) (Table 2), referring to a population of the Balearic Islands and thus not representative of the whole Spain.

Discussion

In a comparison of the temporal trend of stature among coeval populations, various problems that hinder a clear interpretation of the data must be addressed:

- The use of different measures to estimate stature
- The dating of skeletal remains
- The absence of mean stature values and/or standard deviations in some time periods
- The small sample sizes used for stature estimation
- The single sites of origin of the skeletal material or the small numbers of specimen, not indicative of the entire region.

The first problem involves the use of different methods for stature estimation, especially when several methods are used for the same region. For example, if we had considered the data from the Neolithic to the Bronze Age of the Italian skeletal series (Borgognoni-Tarli 1992), obtained with the Trotter and Gleser method (1952), which results in an overestimation of about 4 cm (Cardoso and Gomes 2009) with respect to the Pearson method (1899) used by Giannocchini and Moggi-Cecchi (2008) to evaluate millennial changes in Italy, there would have been possible distortions in the analysis of the trend and also strong differences in the mean stature values.

In fact, the analysis of the Sardinian stature values over time by means of tke K-W test and WIL as post hoc test with B-D correction assuming α=0.01 resulted in significantly different values, depending on the estimation method used ($p<0.001$). The differences between the methods producing the highest values and the lowest values of mean stature are on average ca. 3.6 cm for males and 5 cm for females.

Another problem concerns the dating and cultural attribution of the material. The dating of skeletal remains is often not performed by the radiocarbon technique but by an analysis of the cultural context provided by archaeological specimens (e.g. the Sardinian Eneolithic samples not considered by us). This dating method is very imprecise for a burial site in which there was reuse of graves belonging to prior cultural periods or if the site was not sealed when discovered and had been violated racently or in ancient times. The absence of radiocarbon dating makes comparisons among coeval populations from different regions difficult and imprecise.

One of the main difficulties in the analysis of millennial changes among past populations is the absence in some time periods of mean stature values (e.g. the Spanish series from the Neolithic and the Eneolithic) and standard deviations (e.g. Portuguese and Spanish series with standard deviations only for Middle Ages). The lack of these values together with the small sample sizes (often only a few individuals, as in the Sardinian Neolithic and Medieval Period, and in the Portuguese series, Table 2) prevents a continuous analysis of the trend of stature and its temporal variability, as well as a statistical evaluation of the differences between the means.

Also important is the number of sites providing the skeletal samples. In fact, the examined material may not be representative of the entire region, since it may come from a small number of sites or even from a single site per time period (e.g. the Sardinian Neolithic and Medieval Period), thus preventing the definition of stature changes representative of the entire population.

Millennial changes in Sardinia

In the Sardinian males, the stature trend does not change with the methods used and there is only a significant difference in the value of stature estimation calculated per period (Table 4). For the females, instead, there is a discrepancy in the trend when the PEA method is used (Fig. 2).

We observe two different trends ofr Sardinian males and females. It is possible to infer a millennial trend for males involving an increase in mean stature from the Late Neolithic (4000-3200 B.C.E.) to the Bronze Age (1600-850 B.C.E.), during which there occurred the expansion of the Nuragic culture exclusive to the Sardinian population, following by a decrease in the Roman period (238

B.C.E. – 476 C.E.) and a subsequent increase until the Medieval Period followed by a resumption of the negative trend in the Modern Period. The females present different trends if we consider the values obtained with PEA versus those provided by TGW, TGA, SJO and RUF (Fig. 2). While with TGW, TGA, SJO and RUF there is a slight increase from the Late Neolithic (4000 – 3000 B.C.E.) to the Roman Period (238 B.C.E. – 476 C.E.) and then a slight decrease until the Modern Period (5th to 15th century C.E.), with the PEA the increase does not stop in the Roman Period (152.6 cm) but continues until the Medieval Period (152.9 cm), after wich there is a slight decrease in the Modern Period (151.2 cm). This may be related to the small samples overall of the Roman periods and consequently their potentially more erratic estimates.

However, we did not find statistically significant differences in the pairwise comparison of the values of the different periods performed with the M-N test with B-D correction, assuming assuming α=0,01.

Comparing millennial changes among populations

While bearing in mind the interpretative difficulties and the extreme diversity of the trends shown by the males and females of the different regions, we can note for the noninterpolated periods that the three regions of the

Mediterranean, i.e., Italy, Spain, and Sardinia, show the same trend in males, characterized by a decrease from the Iron Age (1000–300 B.C.E.) to the Roman Period (300 B.C.E.–500

C.E.) followed by an increase in the Medieval Period (fifth to fifteenth century C.E.). Instead, the Portuguese males show a different trend characterized by an increase from the Chalcolithic (3200–2000 B.C.E.) to the Medieval Period (fifth to fifteenth century C.E.). The female sample does not show similar trends except from the Iron Age (1000–300 B.C.E.) to the Medieval Period (fifth to fifteenth century C.E.) for Italy and Spain.

It is noteworthy in this regard that Koepke and Baten (2005a, b) analyzed the biological standard of living in Europe and the impact of climate from the first to the eighteenth century CE and recorded a stature trend similar to the one we found. They observed a period of stature stagnation in central, southern, and western Europe during the Roman Empire (27 B.C.E.–476 C.E.), a drastic increase in Europe in the fiftth and sixth century C.E. and again in the eleventh and twelfth century C.E.

The end of the Roman Period—beginning of the Early Middle Ages—was a period of political, social, and economic transition (Giannecchini and Moggi-Cecchi 2008) that saw Europe, and especially the regions under Roman rule, undergo changes that led to an increase in mean stature after Roman domination ceased. The Early and High Middle Ages, despite the epidemics and famines, do not seem so Bdark^ when we consider the increase in stature. Indeed for regions like Portugal, these were periods of relative economic prosperity (Marques 1980). According to Montanari (1988, 1994), the farmers in northern Italy ate better and in greater quantities during the Early Middle Ages than in the Roman Period or from the Late Middle Ages up to the first decades of the nineteenth century. The changes in agriculture, climate, economy, and population density (Steckel 2004; Gherards 2005; Koepke and Baten 2005b, 2008; Barbiera and Dalla Zuanna 2009) in the Middle Ages may have contributed to an improvement of nutritional status.

However, the changes in stature recorded in our study must be interpreted with extreme caution, given the previous remarks concerning the absence of data; the small sample sizes in some periods; the long time period under study (ca. 5500 years) characterized by important social, cultural, and economic changes; and the fact that the examined material may not be representative of the entire region since it comes from a small number of sites not uniformly distributed over the territory or in some cases from a single site per period.

The stature variations may have been influenced by several factors, but nutrition and health status are those that directly influence the expression of the genetic potential for growth (Danubio and Sanna 2008). For the interpretation of past stature changes to be reliable and complete, there must be an understanding of the environmental conditions during the period under study, an examination of the indicators of stress and diet, an analysis of possible delays in growth, and the addition of biocultural information (Vercellotti et al. 2014). At present, it is difficult to arrive at an exhaustive explanation of the stature changes observed in the various periods since data on nutrition, health status, and eco-socio-biocultural factors in the observed populations are fragmentary.

Variations in the mean stature of past populations have often been related to indirect indicators of factors influencing growth, such as climate change and changes in population density (Koepke and Baten 2005b; Gerhards 2005; Özer 2011). Climate could indirectly influence stature in the short term on the assumption that warmer temperatures favor crop yields and the production of more protein-rich nutrients (Koepke and Baten 2005b).

One of the indirect factors conditioning the intensity of secular changes in stature is social status (Danubio and Sanna 2008). However, it is very difficult to assess this in the analysis of millennial changes since the social status of the individuals is not usually reported for the skeletal series under study. Nevertheless, the nature of the sites indicates that most of the skeletal series are composed of individuals representative of the overall population (e.g., prehistoric collective burials, historical public cemeteries, churchyards). Therefore, none of the samples seems to represent a particularly privileged or underprivileged social group.

In summary, we believe that with the data collected and analyzed thus far, it is not possible to determine a common millennial trend for the considered populations and any interpretation of millennial changes is very approximate due to the lack of data that would allow a somewhat continuous and nonfragmentary analysis of the temporal trend. It should be noted that there is also a difference in the trend between the sexes of the same country.

The discrepancy in the possible millennial trends among the populations and between the sexes and the difference in the stature variations among the populations could be explained by differences in the environmental and socioeconomic contexts over time between regions and within regions.

Conclusions

Analyses of stature variations of prehistoric and historical populations encounter significant problems of reliability of the comparisons.

The data we have collected and analyzed indicate that the conditions are lacking to reliably identify a common trend in millennial changes among the considered populations of southern Europe.

Therefore, to properly compare the results of different studies, it is necessary to conduct a systematic review of the chronological and cultural context of the skeletal series, identify the most appropriate method to calculate the stature values, and analyze and provide new data on the characteristics indicative of the nutritional, health, and ecological conditions of the populations in different periods. It is equally essential to create an open-access database to allow the sharing of primary data sets (sex, age at death, osteometric measures) which are the basis of analyses of past populations. Data sharing, increasingly necessary in biological and biomedical research (Milia et al. 2012; Congiu et al. 2012), is also essential in osteoarcheology. The increased availability of basic data made possible by data sharing would allow more rapid and efficient progress in research, better exploitation of data, optimized use of resources, opportunities for data quality control, and promotion of scientific creativity.

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Tables and figures

Table 1

Sardinian skeletal material: archaeological sites. Dating and provenance of samples

Archeological site	Dating or period (reference)	Provenance of samples
San Benedetto-Iglesias	Late Neolithic 3978–3648 cal. BC 2σ (Lai 2009)	MSAE
Is Aruttas-Oristano	Nuragic 1433–1130 cal. BP 2σ (Lai 2009)	SASAR
Capo Pecora-Arbus	Nuragic 1261 ± 105 cal. BP (Sanna 2006)	MSAE
Tueri Cave-Perdasdefogu	Nuragic 2880 ± 60 BP no cal. (Sanna 2006)	MSAE
Lu Maccioni Cave-Alghero	Nuragic 2800 ± 60 BP no cal. (Sanna 2006)	MSAE
Li Muri-Arzachena	Nuragic (Germanà 1995)	MSAE
Ingurtosu Mannu-Donori	Nuragic 1205–910 cal. BP2σ (Martella et al. 2014)	MSAE
Sa Serra Masi-Siliqua	Nuragic 1690–1400 cal. BP2σ (Martella et al. 2014)	SASAR
Mitza Salida-Masullas	Imperial Roman (Manos and Floris 2005)	SASAR
Genna Cuccureddu-Baunei	Roman Period (personal communication R. Floris)	SASAR
San Saturnino Church, Cagliari eighth to tenth century C.E.	Early Medieval Period (Floris and Usai 1997)	SASAR
San Michele Church, Bono (Sassari) sixteenth to nineteenth century C.E.	Modern Age (Maxia and Fenu 1963)	MSAE

MSAE Sardinian Museum of Anthropology and Ethnography, SASAR Archaeological Superintendence of Sardinia

Table 2

Summary of the archaeological sites yielding the skeletal material and mean stature values collected or calculated by one of the authors (PM)

Table 2 Summary of the archeological sites yielding the skeletal material and mean stature values collected or calculated by one of the authors (PM)

Region	Time period/dating (if present)[a]	Site or localities of provenance	Male			Female			Reference for metric data, cronological data and note	Bone/variable	Methods
			N	Average	SD	*N*	Average	SD			
Sardinia (Italy)	Neolithic late (4000–3200 B.C.E.)	*San Benedetto* d'Iglesias	3	163.5	4.6	3	151.2	3.7	Present study	Femora/maximum length	Pearson 1899
	Bronze Age (1600–850 B.C.E.	*Is Aruttas*-Oristano, *Capo Pecora*-Arbus, *Tueri* Cave-Perdasdefogu, *Lu maccioni* Cave-Alghero, *Li Muri*-Arzachena, *Ingurtosu Mannu*-Donori, *Sa Serra Masi*-Siliqua	32	164.9	3.7	23	151.8	3.8	Present study	Femora/maximum length	Pearson 1899
	Roman Period (238 B.C.E.–476 C.E.)	*Mitza Salida*-Masullas-Oristano, *Genna Cuccureddu*-Baunei	10	163.2	3	18	152.6	4.8	Present study	Femora/maximum length	Pearson 1899
	Early Medieval Period (fifth to tenth century C.E.)	*San Saturnino* Church, Cagliari eighth to tenth century C.E.	11	165.2	3.1	4	152.9	4.9	Present study	Femora/maximum length	Pearson 1899
	Modern Period (XVI–XIX century C.E.)	*San Michele* Church Bono (Sassari)	64	163.8	4.5	41	151.2	4.1	Present study	Femora/maximum length	Pearson 1899
Italy	Middle Neolithic	Central-Southern Italy	–	166.0	–	–	156.0	–	Borgognini 1992[b]	Long bones	Trotter and Gleser 1952
	Chalcolithic	Central-Southern Italy	–	168.0	–	–	156.6	–	Borgognini 1992	Long bones	Trotter and Gleser 1952
	Bronze Age	Central-Southern Italy	–	168.0	–	–	158.0	–	Borgognini 1992	Long bones	Trotter and Gleser 1952
	Iron Age (ninth to fifth century B.C.E.)[c]	Central Italy	220	166.6	4	181	154.3	3.7	Giannecchini and Moggi-Cecchi 2008	Femur, tibia,[d] humerus and radius/maximum length	Pearson 1899
	Roman Period (fifth century B.C.E.–fifth century C.E.)	Central Italy	153	164.4	3.9	130	152.1	3.4	Giannecchini and Moggi-Cecchi 2008	Femur, tibia,[d] humerus and radius/maximum length	Pearson 1899
	Medieval period (fifth to fifteenth century C.E.)	Central Italy	187	166.9	4.3	150	154.5	3.4	Giannecchini and Moggi-Cecchi 2008	Femur, tibia,[d] humerus and radius/maximum length	Pearson 1899
Spain	Neo-Chalcolithic	Meseta, Levante	93	162.6	–	60	150.6	–	Lalueza-Fox 1998	Long bones	Pearson 1899
	Bronze Age (2000–1000 B.C.E.)[e]	Catalonia; Andalusia (Argar Culture)	99	162.4	–	74	151.1	–	Lalueza-Fox 1998	Long bones	Pearson 1899
	Talayotic (600–200 B.C.E.)[e]	Son Real, Majorca; Illot des Porros, Majorca	424	165.5	–	229	153.6	–	Lalueza-Fox 1998	Long bones	Pearson 1899
	Roman (third to fifth century C.E.)	Tarragona	168	163.2	–	88	151.8	–	Lalueza-Fox 1998	Long bones	Pearson 1899
	Medieval (seventh to fourteenth century C.E.)[e]	Catalonia; Montjuich, Barcelona; Palacios de la Sierra, Burgos; La Torrecilla, Granada;	280	164.8	–	152	152.9	–	Lalueza-Fox 1998	Long bones	Pearson 1899

Table 2 continued

Region	Time period/dating (if present)[a]	Site or localities of provenance	Male N	Male Average	Male SD	Female N	Female Average	Female SD	Reference for metric data, cronological data and note	Bone/variable	Methods
		La Olmeda, Palencia; Santa Maria de Hito, Cantabria; Villanueva de Soportilla, Burgos									
Portugal	Late Neolithic and Chalcolithic (3500–2100 B.C.E.)	Poço Velho (Cascais) Eira Pedrinha (Condeixa-a-Nova) Quinta do Anjo (Palmela)	6	158.3	–	20	150.5	–	Cardoso and Gomes 2009	Femora/maximum length	Mendonça 2000
	Roman (second B.C.E. to fourth century C.E.)	Conimbriga (Coimbra) Tròia Setùbal	6	165.5	–	4	151.5	–	Cardoso and Gomes 2009	Femora/maximum length	Mendonça 2000
	Medieval (twelfth to sixteenth century C.E.)	São Manços (Èvora) São Pedro de Canaferrim (Sintra) São Martinho (Leiria)	37	165.7	–	23	157.1	–	Cardoso and Gomes 2009	Femora/maximum length	Mendonça 2000
Portugal[f]	Late Neolithic and Chalcolithic (3500–2100 B.C.E.)	Poço Velho (Cascais) Eira Pedrinha (Condeixa-a-Nova) Quinta do Anjo (Palmela)	6	160.2	–	20	149.2	–	Cardoso and Gomes 2009	Femora/maximum length	Pearson 1899
	Roman (second B.C.E. to fourth century C.E.)	Conimbriga (Coimbra) Tròia Setùbal	6	165.2	–	4	149.9	–	Cardoso and Gomes 2009	Femora/maximum length	Pearson 1899
	Medieval (twelfth to sixteenth century C.E.)	São Manços (Èvora) São Pedro de Caneferrim (Sintra) São Martinho (Leiria)	37	165.4	–	23	154.7	–	Cardoso and Gomes 2009	Femora/maximum length	Pearson 1899

[a] The chronological subdivision used by the authors in their publications is reported

[b] Borgognini-Tarli (1992) data, not used for the analysis

[c] Simplified chronological scheme

[d] The height value for each individual was given by the average of all estimates calculated from single long bones

[e] Weighted means

[f] Portuguese mean statures recalculated from weighted means of the values of maximum femoral length reported in Cardoso and Gomes (2009)

Table 3
Summary of the cultural periods for Sardinia, Italy, Spain, and Portugal

Dating	Sardinia[a]	Italy[b]	Spain[c]	Portugal[d]
1500 C.E.	Medieval Period	Medieval Period	Medieval Period	Medieval Period
500 C.E.	Roman Period	Roman Period	Roman Period	Roman Period
500 B.C.E.	Iron Age	Iron Age	Iron Age	Iron Age
1000 B.C.E.	Bronze Age	Bronze Age	Bronze Age	Bronze Age
1500 B.C.E.				Late Neolithic
2500 B.C.E.	Chalcolithic	Chalcolithic	Chalcolithic	Chalcolitic
3000 B.C.E.				
3500 B.C.E.	Late Neolithic		Late Neolithic	
4000 B.C.E.	Middle Neolithic	Middle and Late Neolithic	Neolithic	Neolithic
4500 B.C.E.				
5000 B.C.E.				

[a]

Table 4
Sardinian skeletal material

	Late Neolithic (4000–3200 B.C.)			Bronze Age (1600–850 B.C.)			Roman Period (238 B.C.–476 C.E.)			Early Medieval Period (fifth to tenth century C.E.)			Modern Period (sixteenth to nineteenth century C.E.)		
Male															
	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
PEA	3	163.5	4.6	32	164.9	3.7	10	163.2	3.0	11	165.2	3.1	64	163.8	4.5
TGA	3	162.6	5.2	32	164.2	4.1	10	162.2	3.3	11	164.5	3.5	64	162.9	5.0
TGW	3	165.4	5.9	32	167.3	4.7	10	165.0	3.8	11	167.6	4.0	64	165.8	5.7
SJO	3	164.9	6.5	32	166.9	5.1	10	164.5	4.2	11	167.3	4.4	64	165.3	6.3
RUF	3	161.7	6.7	32	163.8	5.3	10	161.3	4.3	11	164.2	4.5	64	162.1	6.5
Female															
	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
PEA	3	151.2	3.7	23	151.8	3.8	18	152.6	4.8	4	152.9	4.9	41	151.2	4.1
TGA	3	151.6	4.3	23	152.3	4.4	18	153.3	5.7	4	153.0	5.7	41	151.6	4.8
TGW	3	153.6	4.7	23	154.4	4.8	18	155.4	6.1	4	155.1	6.1	41	153.6	5.2
SJO	3	155.9	5.0	23	156.8	5.1	18	157.8	6.5	4	157.5	6.5	41	155.9	5.5
RUF	3	150.6	5.4	23	152.8	5.2	18	153.9	6.7	4	153.6	6.7	41	152.0	5.6

Figure 1
Mean male stature for each of the regression methods used. Stature in centimeters on the ordinate, time periods on the abscissa

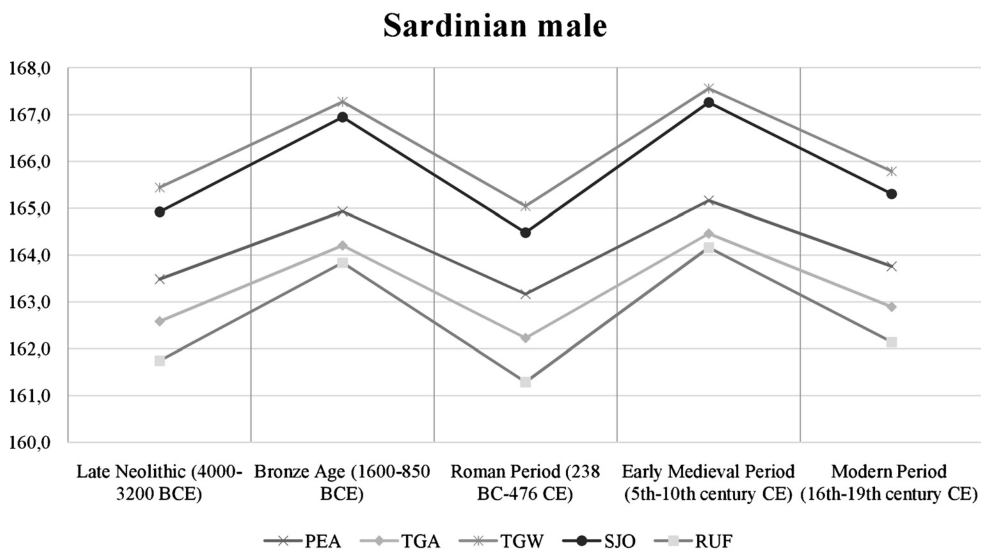

Figure 2
Mean female stature for each of the regression methods used. Stature in centimeters on the ordinate, time periods on the abscissa

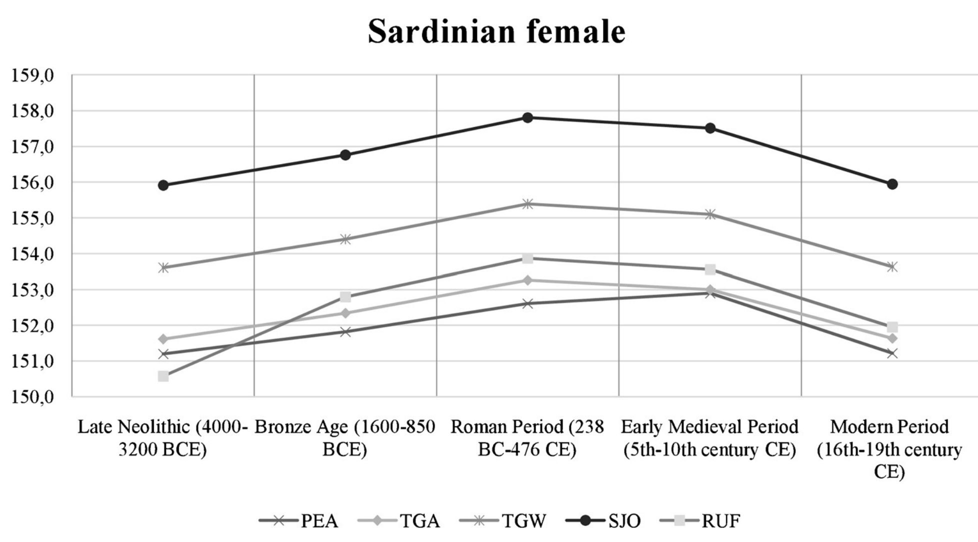

Figure 3

Mean female stature. Stature in centimeters on the ordinate, time periods on the abscissa. *Blank points* represent interpolated average height

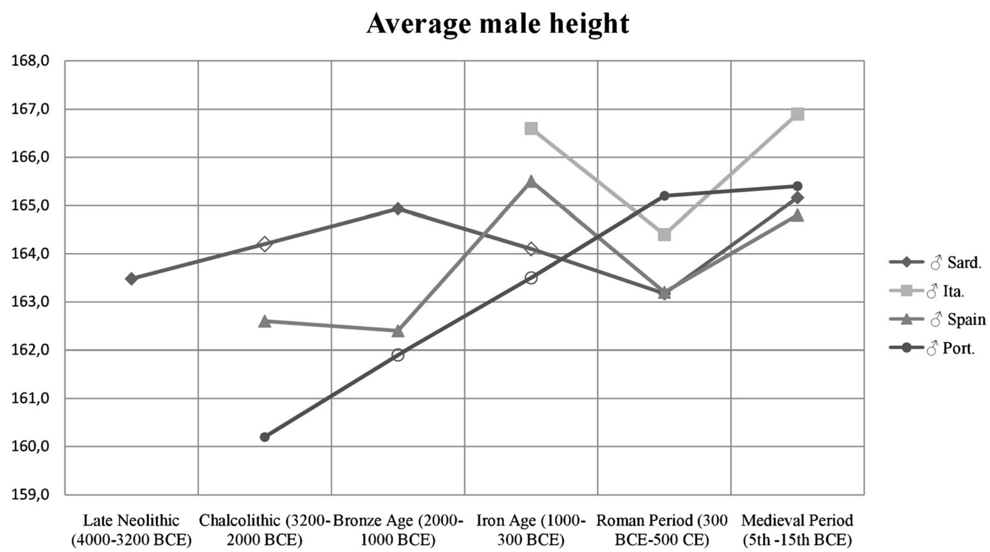

Figure 4

Mean female stature. Stature in centimeters on the ordinate, time periods on the abscissa. *Blank points* represent interpolated average height