Sexual division of labour in early agricultural Central Europe: an argument against androcentric bias in bioarchaeology

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Abstract

A common assumption in anthropology is that agricultural intensification involves increasing male labour contributions. This assumption is affected by substantial androcentric bias, and bioarchaeological investigations of past populations do not always support it. In Central Europe, previous studies have shown marked differences in terrestrial mobility and upper limb manipulative behaviours between males and females, as well as consistently high levels of female humeral loading. However, humeral loading and relative interlimb loading in contemporaneous males have not been investigated. This study analysed humeral and tibial cross-sectional geometric properties (J and I_{max}/I_{min}) in Neolithic, Bronze Age, Iron Age, and early Medieval Central European males. The results show a lack of significant change in the intensity and directionality of upper limb loading over time, but significant declines in tibial loading in all time periods relative to the Neolithic. The first ~6150 years of agricultural intensification in Central Europe can thus be characterized as having disproportionately affected male lower limb relative to upper limb loading, likely related to increasing sedentism following the introduction of agriculture. This contrasts with previous findings in contemporaneous females, among whom interlimb loading patterns document very high levels of manual labour relative to terrestrial mobility through to the early Medieval period. This research offers insight into sexual divisions of labour in early Central European farming populations, and addresses the androcentric and methodological biases that affect perceptions of agricultural labour in the bioarchaeological record.

Keywords

Sexual division of labour; bioarchaeology; androcentrism; agriculture; Central Europe

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Table of Contents

1. Introduction……..4

2. Definitions and terminology of sex and gender……7

3. Sexual division of labour in agricultural populations……..8

3.1. Ethnographic investigations……..……9

3.1.1. Androcentric bias in agriculture……...11

3.2. Biomechanical investigations……12

3.2.1. Methodological issues……15

4. Central Europe from the Neolithic to the early Medieval period……17

4.1. Agricultural and social change……17

4.2. Evidence for a sexual division of labour……21

4.2.1. Bioarchaeological……...21

4.2.2. Biomechanical……21

5. Materials and methods……...23

5.1. Quantification and size-standardization of CSG properties…..……24

5.2. Statistical analysis……..25

6. Results……26

7. Discussion……26

7.1. Sexual division of labour in early agricultural Central Europe……26

7.2. Implications for androcentric assumptions of agricultural labour……29

7.3. Implications for bioarchaeological methodology……32

8. Conclusion……33

9. Tables and figures……35

10. References……..……...42

1. Introduction

Agricultural intensification has long been associated with changing sexual divisions of labour. The advent of the plough, in particular, is widely understood as marking a shift to male-dominated farming systems and reduced agricultural contributions of females (Boserup, 1970). However, this assumption is affected by androcentric biases with regards to what constitutes agricultural labour and, as a result, largely focuses on the physical tasks performed by men (Brandth, 2002). Additionally, bioarchaeological studies of past populations during periods of agricultural intensification do not always support this assumption of reduced female labour (Bridges, 1989; Bridges et al., 2000). While some do (for example, see Sparacello et al., 2011 and Cameron and Pfeiffer, 2014), their interpretations result from directly comparing male and female cross-sectional geometric (CSG) properties. Due to sex differences in bone biology, male bone responds to mechanical load in a more advantageous manner than does female bone and, as such, direct comparisons likely underestimate female levels of physical activity. In order to accurately interpret physical activities from skeletal material, it is necessary to use appropriate sex-specific comparative frameworks.

The research presented here examines the sexual division of labour in Central Europe during the first ~6150 years of agricultural development, from the Neolithic (~5300–4600 cal BCE) to the early Medieval period (~800–850 CE). It builds on previous biomechanical investigations into these early Central European farmers that document changes in relative levels of manual labour and terrestrial mobility, as inferred by humeral and tibial CSG properties respectively. These studies demonstrate that,

while terrestrial mobility gradually declines in both sexes over time (Macintosh et al., 2015), tibial loading only decreases significantly in males (Macintosh et al., 2014a). Additionally, humeral loading remained consistently more important than tibial loading in females (Macintosh et al., 2017) but relative interlimb loading was not analysed in contemporaneous males. Males also exhibit much less variable humeral symmetry through time than females (Macintosh et al., 2014b), but male CSG properties were not analysed independently in each limb as they were in females (Macintosh et al., 2017).

This analysis thus addresses two specific questions: 1) do changes in male right and left humeral CSG properties suggest changes in the intensity or type of manual labour; and 2) do changes in relative limb loading among males indicate shifts in the importance of manual labour relative to terrestrial mobility? Temporal trends in male humeral and tibial CSG properties reflecting bone rigidity and shape were analysed in order to infer changes in manual labour and relative upper limb loading through time. Inferred behavioural changes among males were then compared to trends identified by Macintosh and colleagues (2017) among contemporaneous females. Male CSG data was also directly compared to data on living male athletes (Shaw and Stock, 2013) in order to contextualize levels of load in relation to known behaviours.

This research undertakes a sociocultural analysis using biological methods, and provides a new line of evidence as to the sexual division of labour in Central Europe during a period of considerable agricultural intensification. The results challenge the androcentric biases that inform perceptions of agricultural labour in both living and past

populations. Additionally, they highlight the methodological issues that affect bioarchaeological interpretations of sexual divisions of labour in past populations.

The essay begins with a brief discussion of the use of gendered terminology in bioarchaeological studies. Section 2 explains the differential use of the terms that occur throughout, namely ‘men’ and ‘women’ when referring to ethnographic evidence, and ‘male’ and ‘female’ when referring to bioarchaeological data.

Section 3 provides background information on perceptions of changing sexual divisions of labour during periods of agricultural intensification. This occurs first through ethnographic investigations of living populations, and then bioarchaeological approaches in past populations. This section outlines both the androcentric biases that alter perceptions of agricultural labour, as well as the methodological issues that affect interpretations of labour from skeletal remains.

Section 4 is an overview of the study area. It begins with a brief synopsis of the agricultural, technological, and social changes that occurred in Central Europe from the Neolithic to the early Medieval period. This provides a foundation for the subsequent review of bioarchaeological and biomechanical evidence for a sexual division of labour in these populations.

Following this is an analysis of male humeral and tibial CSG properties that investigates temporal changes in the intensity of upper limb loading, and the relative importance of upper limb compared to lower limb loading. The results are discussed in light of implications for androcentric assumptions of labour in agricultural populations, as

well as appropriate methodology for future bioarchaeological investigations of sexual divisions of labour in past populations.

2. Definitions and terminology of sex and gender

Contemporary Eurocentric interpretations of sex and gender are constantly undergoing revision. However, they are largely founded on biomedical perceptions of a static binary system in which sex (male or female) correlates to gender (man or woman) (Geller, 2009; 2017). Sex and gender, though, are distinct concepts (Geller, 2017) and their expressions can vary widely between societies.

Investigations in sexual divisions of labour are largely situated within these Eurocentric notions (Geller, 2005; 2009). This has carried into bioarchaeology, where (predominantly European or Euro-descended) researchers might use the basis of sex to make inferences about gender according to their specific viewpoints (Geller, 2008). Nevertheless, sex estimation cannot always inform on a culture's concept of gender and bioarchaeologists should not begin an investigation with predetermined assumptions of the two (Geller, 2006). All that can be gathered from skeletal material of past populations is that some individuals were biologically male, and others were biologically female. As such, these are the terms used throughout this essay when referring to skeletal samples.

Ethnographic accounts of divisions of labour often refer to them as being on the basis of sex. However, many of these investigations occurred prior to the widespread reconceptualizations of sex and gender that have developed over the last few decades,

and associate a sexual division of labour with gender identity (for example, see Boserup 1970). Additionally, these interpretations are further complicated because the culture in question is often studied within the Eurocentric binary of men and women, without any discussion as to whether or not these gender expressions apply. While addressing these issues specifically is beyond the scope of this essay, the gendered terms ‘men’ and ‘women’ are used throughout when referring to ethnographic works on living societies. This is done even when the original source in question considered sex and gender as interchangeable.

My use of both of these types of terms does not suggest that they are synonymous, or even that there is a link between them. I also do not mean to suggest that the androcentric biases faced by living women agriculturalists, as discussed in Section 4.1, are the same as those experienced by females in the past. My argument is solely that androcentric bias influences perceptions of labour in living agricultural populations, and that these same biases affect how behavioural signatures are interpreted from skeletal remains.

3. Sexual division of labour in agricultural populations

While this essay is primarily concerned with androcentric bias within bioarchaeology, such investigations into the divisions of labour in past populations are a fairly recent phenomenon. Ethnography, conversely, has been used to investigate sexual divisions of labour in living groups for quite some time. These sociocultural interpretations are

often applied to past societies, and have broadly informed understandings of early agricultural intensification as well.

3.1. Ethnographic investigations

A marked division of labour is common throughout the ethnographic record in horticultural and agricultural societies. Often this division is considered to be natural simply on the basis of sex or gender, where men and women become responsible for different tasks (Boserup, 1970). However, the nature of the division of labour and the tasks performed by each party can vary between groups, based on climate and geography, as well as within groups, due to changing societal pressures over time (Murdock and Provost, 1973; Leibowitz, 1975; Bridges et al., 2000).

Some researchers have argued that agricultural intensification, as a result of new technological adaptations, is associated with the increasing labour of men (Boserup, 1970; Martin and Voorhies, 1973; Burton and White, 1984). This notion is based on analyses of ethnographic accounts which suggest that women's contribution is highest in horticultural groups that practice smaller-scale hand cultivation, but decreases substantially in societies that practice more intensive plough-based agriculture. Some societies do not perform in this anticipated manner, but they are generally dismissed as exceptions to this otherwise global rule (for example see Boserup, 1970, p. 33).

There are a few proposed explanations to justify this shift from women-dominated farming to men-dominated farming. Martin and Voorhies (1973) suggest that horticultural practices stem from earlier women-led gathering activities, and

that later farming practices only become monopolized by men as growing populations require more agricultural labour than can be performed solely by women. This suggestion stems from belief that the superior physical strength of men makes them more capable of “mobilizing… in brief bursts of excessive energy” (Martin and Voorhies, 1973, p. 211).

Alternatively, another suggestion is that this decline instead results from women becoming more responsible for domestic work, rather than agricultural work. While men are apparently more suited to physical labour in the fields, women are conversely at a disadvantage when performing tasks that take them away from the home due to their “burdens of pregnancy and infant care” (Martin and Voorhies, 1973, p. 211). The perceived decline in women’s agricultural labour might then be due to an increase in food processing tasks and childcare (Ember, 1983; Sanday, 1973). Brown (1970) even suggests that a woman’s agricultural contributions will be most substantial when she is able to remain at home, doing monotonous work that does not require steady concentration, and which can be easily resumed after being interrupted by children.

These androcentric biases seem to stem from earlier ethnographic accounts, whose physiological explanations for sexual divisions of labour equated male strength with the superiority of men, and female capacity for reproduction with enhanced domestic abilities of women (for example, see Durkheim, 1933 and Murdock, 1949). Even Margaret Mead, a renowned feminist anthropologist who wrote extensively on sex and gender, described the role of men as that of a provider, while women and children are to be provided for (Mead, 1949, p. 190).

3.1.1. Androcentric bias in agriculture

Anthropology was largely developed, and initially pursued, by men. As such, androcentric bias is an inherent problem within the field as a whole (Slocum, 1975). The concept of 'Man the Hunter', for example, assumed that the hunting behaviours of men were fundamental to human social organization while women, as gatherers, were insignificant (Washburn and Lancaster, 1968; Slocum, 1975). That this hypothesis has prevailed for so long is a clear indication of anthropology's focus on men.

Within agricultural frameworks, androcentric biases are still very prevalent today. The focus remains directed towards men farmers, and women's labour has largely been treated as irrelevant (Brandth, 2002). Allen and Sachs (2007) describe modern agrarian ideology as one that encourages and enforces women's subordination and, according to Whatmore (1991), this invisible status of women agriculturalists affects perceptions of agricultural labour as a whole.

Despite the fact that women agriculturalists perform myriad tasks directly associated with the farm itself (Whatmore, 1991), this work is often completed in addition to domestic labour imposed on them on the basis of gender specific stereotypes (Brandth, 2002). This 'domestic sphere' is treated as a separate domain even though the labour involved, such as household maintenance and childcare, is often integral to the efficient running of a farm (Whatmore, 1991). In Bangladesh, for example, women agriculturalists often work longer hours to balance the double burden of field work and domestic work. While their involvement in agriculture is widely considered to be limited to post-harvest processing, Bangladeshi women spend several

hours a day in the fields alongside men yet are still less likely to be hired as workers (Rahman, 2010). Rice producing regions in India demonstrate a similar disparity where, even though women have always played significant roles in the cultivation process, they earn substantially less than their men counterparts. This is, at least in part, due to inherent beliefs that women are weaker and thus less efficient and productive farm workers (Mencher and Saradamoni, 1982).

Because their labour is so flexible and variable, women farmers are often reluctant to describe themselves as such because 'real' farm work is associated with physical tasks, such as those performed by men (Brandth, 2002). However, understanding agricultural labour solely as what occurs in the field completely downplays women's participation (Reimer, 1986 cited in Whatmore, 1991). Thus, in order to fully understand the farming labour process, it is necessary to include the frequently ignored realm of 'women's work' in relation to subsistence production (Whatmore, 1991).

3.2. Biomechanical investigations

Bone is a highly responsive tissue, and can quickly respond to changes in external mechanical load. The reaction will vary based on biological factors such as age, sex, and genetics but, generally speaking, bone cells will deposit more tissue in areas that frequently experience high mechanical load. When a bone no longer experiences high load, that extra tissue is no longer needed and will subsequently be removed (Ruff et

al., 2006). Highly active individuals should therefore exhibit increased bone strength and rigidity relative to more sedentary individuals.

Bone biomechanics is the application of engineering principles to long bones to study their dynamic response to external stimuli. This type of quantitative analysis allows for an estimation of the types of mechanical loading a bone was subjected to during life, as inferred by particular cross-sectional geometric (CSG) properties. Different CSG properties can be used to measure a bone's strength and rigidity during multiple types of loading (see Ruff, 2008 for a detailed explanation) and, when applied to bioarchaeological samples, biomechanical investigation can estimate habitual physical behaviours performed by individuals in the past. While there are relatively few studies that use CSG properties to address changing sexual divisions of labour during periods of agricultural intensification, biomechanics is an effective approach to infer behavioural differences between the sexes using skeletal remains.

Bridges (1989) argues that Archaic and Mississippian period groups in what is now Alabama show increasing female labour during agricultural intensification. She documented higher humeral and femoral bending rigidity in Mississippian agriculturalists, which suggests that this later period of maize cultivation was more physically demanding than what was experienced by Archaic hunter-gatherers. These trends are greater in females than males, though, which was interpreted as females taking over "a greater proportion of the subsistence activities associated with agriculture" (p. 392). The same can be said for populations from similar time periods in what is now Illinois (Bridges et al., 2000).

Sparacello and Marchi (2008) assert that Neolithic and Medieval period populations from Italy show a different pattern. The authors document a decline in humeral bending and torsional rigidity over time in the Liguria region, although this was more significant in males. No significant temporal changes occurred in the femur although there was a slight decline in females during the Medieval period. However, the researchers documented marked sexual dimorphism in both samples, in that male humeral and femoral CSG values were consistently higher than those of the females. This was interpreted as "males [being] involved in more physically demanding tasks than females" (Sparacello and Marchi, 2008, p. 490) and, during the Medieval period in particular, females being "overall involved in more sedentary activities than… males" (Sparacello and Marchi, 2008, p. 492). A similar study of an Iron Age population from the Abruzzo region suggested a similar division of labour where, according to consistently higher values of bending strength, "males performed most of the production and status-related activities and females were relegated to time-consuming sedentary tasks" (Sparacello et al., 2011, p. 128).

With regards to the sexual division of labour, notwithstanding changing agricultural practices, Stock and Pfeiffer (2004) argue that Later Stone Age males from what is now South Africa demonstrate consistently higher upper and lower limb strength and rigidity than contemporaneous females, regardless of regional differences in geography and ecology. Cameron and Pfeiffer (2014) demonstrated similar humeral and femoral results in an additional group from the same time period, which they

interpreted as males “participat[ing] in activities that increased humerus and femur biomechanical loading as compared to [females]” (Cameron and Pfeiffer, 2014, p. 10).

These studies highlight the fact that, more often than not, biomechanical investigations into sexual divisions of labour in past populations are done by directly comparing male and female CSG properties. Such an approach assumes that higher indicators of bone strength and rigidity correlate to greater physical loading sustained during life. In practice, it consistently leads to the conclusion that males participated in more laborious activities than females.

3.2.1. Methodological issues

Responses to agricultural intensification were regionally variable as a result of different environments, geography, and cultural practices (Bridges et al., 2000). However, Macintosh and colleagues (2017) suggest that sex differences in bone biology might have a serious impact on interpretations of changing agricultural labour because male and female bone respond differently to mechanical load. The humeri of male tennis players, for example, exhibit more responsiveness to repetitive side-to-side movements than female tennis players (Kannus et al., 1995; Haapasalo et al., 1996). Male runners have also been found to exhibit more anteroposterior expansion of cortical bone and higher bending and torsional rigidity than females, in both endurance and recreational athletes (Macintosh et al., 2017). Deere and colleagues (2012) likewise suggest that females see a reduced skeletal response to high-impact activity relative to males.

The fact that males are, on average, larger than females does not explain this disparity in bone strength parameters, as it persists even when size differences are

accounted for (Looker et al., 2001). The more advantageous response to mechanical loading seen in male bone could instead result from sex differences in growth trajectory (Tanner, 1989) or the secretion and receptors of growth hormone and insulin-like growth factors (Callewaert et al., 2010). There is also the question of differential effects of sex hormones on bone deposition (Gosman et al., 2011), specifically the role of estrogen in bone accumulation. Järvinen and colleagues (2003a) found that, in rats, higher estrogen levels lead to more dense bones in females than males in response to mechanical load. That human females accumulate extra bone mineral during puberty in response to increased estrogen secretion (Järvinen et al., 2003b) might limit the ability of female bone to respond to mechanical load while no such phenomenon is seen in males (Järvinen et al., 2003a).

In light of this, interpreting the behaviours of past populations by directly comparing the mechanical properties of male and female bone will likely underestimate female levels of physical activity. As such, the studies described in Section 3.2 that argue for the presence of a male-dominated sexual division of labour in past Italian (Sparacello and Marchi, 2008; Sparacello et al., 2011) and South African (Stock and Pfeiffer, 2004; Cameron and Pfeiffer, 2014) groups may be inaccurate because they employed this flawed method. A more appropriate approach for investigating changes over time would be to compare male and female trends in order to infer relative differences in mechanical load. Alternatively, values could be directly compared to sex-specific frameworks of living males and females to assess levels of physical activity in relation to known behaviours.

4. Central Europe from the Neolithic to the early Medieval period

Modern-day central Europe is a multinational entity comprising Germany, Poland, the Czech Republic, Serbia, Slovakia, Hungary, and Austria, and includes numerous languages, cultures, and political affiliations. It is a contemporary designation but the area also shares broad geographic and ecological similarities and, as such, a comparable history of agricultural development (Milisauskas, 2011). Central Europe was chosen as a study region because biomechanical investigations of labour in female agriculturalists, from the Neolithic to the early Medieval period, have already been performed using an appropriate sex-specific interpretive framework (Macintosh et al, 2017). Analysing contemporaneous males will therefore allow for a better understanding of the presence and extent of a sexual division of labour. The resulting Central European model can then be used to investigate the assumption that agricultural intensification is associated with increasing male labour.

4.1. Agricultural and social change

There have been several investigations into farmers from the Central European Neolithic, but fewer conducted into later time periods. As such, the summary presented below only conveys a broad understanding of regional agricultural subsistence patterns and how they respond to new technological adaptations and changing social structures. It focuses on aspects of life that exert enough force to mark bone in a way that can be

analysed using a biomechanical approach. Such activities include farming and livestock practices, as well as tool use and manufacture.

The first farmers in Central Europe, known as the *Linearbandkeramik* (LBK) culture, appeared during the Neolithic between ~5500 cal BCE and ~5000 cal BCE (Bickle and Whittle, 2013). These groups are generally understood to consist of sedentary agriculturalists who practiced small-scale manual garden cultivation (Bogaard, 2004; Bickle and Whittle, 2013). Faunal remains of various livestock species are commonly found at LBK sites which suggests that animal husbandry was also practiced. However, there appears to have been a greater emphasis on cattle which would have provided large quantities of milk and meat (Bickle and Whittle, 2013). While it is difficult to determine exact animal husbandry practices, there was likely more of a reliance on pastoralism in which herds of animals were moved throughout the larger region surrounding a settlement in order to graze (Greenfield, 2001).

Preserved agricultural implements are rare and were probably made out of organic materials, such as wood, that are more prone to degradation (Harding, 2000). However, farmers would have needed hand-operated tools to break the ground, clear away weeds, and till the soil, and fieldwork would be associated with substantial use of the upper limbs. Food preparation, such as the grinding of grains using a saddle quern, would have involved up to five hours a day of consistent bilateral humeral loading (Sládek et al., 2016).

The mixed agricultural strategy of crop cultivation and animal husbandry persisted into the Bronze Age (Harding, 2000), with similar types of cultivated crops as

seen during the Neolithic (Greenfield, 2001). At this point, though, agriculture becomes more intensive, in terms of increased crop production and livestock rearing, as well as extensive, in that this increased production required larger areas of land (Greenfield, 2001). Farmland expansion was achieved by clearing forests with axes, which required considerable use of the dominant arm. However, settlements remained small and focused on food production and livestock tending (Harding, 2011). Abundant cattle remains and preserved pottery strainers suggest an increase in dairy production, and preserved weaving materials provide evidence of an important textile industry (Coles and Harding, 1979).

The Neolithic to Bronze Age transition sees the first evidence of important new technologies, namely the plough and metalworking. The plough is a more efficient method of preparing fields for crops, and its use likely facilitated the intensification of agricultural practices seen in the Bronze Age (Greenfield, 2001). That said, steering and operating a plough still involves high levels of bilateral humeral loading. The exploitation of copper mines to produce metal tools and other implements was performed on a small scale, but mining and smithing are also both physically intensive activities that require considerable use of the dominant upper limb.

The transition from the Bronze Age to the Iron Age saw a continued trend of agricultural development, both in terms of extensions to farmland (Dreslerová et al., 2013) as well as more intensified crop cultivation (Pollmann, 2014). Metallurgy continued to develop as well and, while bronze implements remained in circulation, iron exploitation became more commonplace (Wells, 2001). The addition of iron allowed for

even more efficient agricultural implements, but working in the fields still would have required substantial manual labour to provide for increasing populations. Food processing, though, became less intensive with the emergence of the rotary quern used to prepare cereal crops (Sládek et al., 2016).

Population growth was marked during the Iron Age, and settlements during this period were often much larger than the farmstead communities seen previously (Wells, 2011). These urban centres were able to take on particular roles in manufacturing, politics, and extensive trade and, as such, task specialization increased during this time (Wells, 2011). Non-agricultural production, such as goods made of glass, bone, leather, and antler, increased during this time.

The early Medieval period saw notable changes to social order, specifically the beginnings of aristocracy and distinct social stratification. Agricultural practices were largely defined by private land ownership (Hammer, 2002) but the majority of information from this period pertains to the church and ruling class. Despite written accounts of agriculture and production, very little is known about farming practices for the rest of the population (Reuter, 1991). In general, though, the early Medieval period saw an increase in human impact on the surrounding environment. Settlements continued to grow in size and agriculture became more important due to the high energetic needs of large towns and castles (Rösch, 2013). Farming practices did not change greatly from earlier times; similar tools and technologies were employed, and dairying and other livestock-related industries remained important (Schutkowski and Herrmann, 1999).

4.2. Evidence for a sexual division of labour

4.2.1. Bioarchaeological

Bickle and Whittle (2013) note a number of skeletal differences between Central European males and females during the Neolithic. Adult males showed more evidence of traumatic postcranial injury, as well as having suffered higher levels of childhood stress, than females. Female dentition, though, shows evidence of specific wear patterns that correspond to teeth being used during rope or cord making in order to free both hands for use. Together, these disparities were interpreted as a sexual division of labour in which males and females were exposed to different levels of stress during early life, and later engaged in distinct tasks that put them at divergent risks of injury (Bickle and Whittle, 2013). However, similar investigations have not occurred in Central European populations from different time periods. These interpretations can only inform understandings of sexual division of labour during the Neolithic, and not during subsequent eras.

4.2.2. Biomechanical

Macintosh and colleagues (2015) demonstrate clear temporal trends towards diminishing terrestrial mobility in both males and females from the Neolithic to the early Medieval period. This does not necessarily mean that individuals were confined to the home, and it is more likely that they began to perform more general tasks that loaded their tibiae in a reduced way. However, tibial loading only decreased significantly in Iron Age and Medieval males relative to the Neolithic. The authors suggest that Neolithic

and Bronze Age males relied on higher levels of lower limb loading to plough fields, till the land, and attend to livestock. Later declines in terrestrial mobility were interpreted as an increasing reliance on wheeled vehicles for long-distance trade during the Iron Age, and the emergence of a specialized merchant class in the Medieval period. Females, though, showed no pronounced changes in tibial loading (Macintosh et al., 2014a) but consistently maintained higher levels of humeral loading relative to the lower limbs (Macintosh et al., 2017). However, relative interlimb loading was not assessed in contemporaneous males and it is unclear how their declines in lower limb loading correspond to upper limb behaviours.

In the upper limbs, Macintosh and colleagues (2015) have demonstrated a marked divergence in handedness between males and females over time. Both of these sexes exhibited right-biased humeral loading during the Neolithic, but which was generally much stronger in males. This is likely associated with construction and woodworking tasks using stone axes, given that these tools are found disproportionately in male graves during this time period. However, beginning in the Bronze Age, females maintained largely bilateral loading while males became significantly more right biased. The authors suggested that males were predominantly performing woodworking, land clearance, mining, and metalsmithing tasks that relied more on the right limb, whereas females maintained the use of both arms while performing tasks such as grinding grain and weaving. That females returned to more right-dominant humeral loading during the Iron Age was suggested to result from an increasing importance on tasks that required more unilateral labour (Macintosh et al., 2015).

Finally, Macintosh and colleagues (2017) have demonstrated that, from the Neolithic to the Iron Age, females maintained extremely high levels of manual labour. Humeral bending and torsional rigidity was similar to that of living female semi-elite athletes, and only dropped to levels more consistent with a living sedentary control sample during the early Medieval period (Macintosh et al., 2017) However, similar indices were not examined in contemporaneous males so it is unclear how levels of physical activity differed between these sexes.

5. Materials and methods

If agricultural intensification in Central Europe truly was characterized by increasing male contributions, this would be reflected in their bones. As such, this analysis asked two specific questions: 1) do changes in male right and left humeral CSG properties suggest shifts in the intensity or type of manual labour; and 2) do changes in relative limb loading among males indicate changes in the importance of manual labour relative to terrestrial mobility?

Skeletal data was previously collected by Alison Murray and comprises male tibiae and humeri from Central European agricultural populations across four time periods: early Neolithic (~5300–4600 cal BCE), early and middle Bronze Age (~2300–1450 BCE), early through late Iron Age (~850 BCE–100 CE), and early Medieval (~800–850 CE). These individuals were excavated from cemeteries in Serbia, Slovakia, Germany, Hungary, and the Czech Republic (Figure 1), and are now housed in university and museum collections. Age and sex were estimated using standard

methods outlined by Buikstra and Ubelaker (1994) and only skeletally mature individuals, as indicated by fully fused epiphyses, were included in the analysis (Macintosh, Pinhasi, and Stock, 2017).

5.1. Quantification and size-standardization of CSG properties

There were two CSG properties of interest in this analysis: the tibial and humeral polar second moment of area (*J*), and humeral I_{max}/I_{min}. *J* is a quantification of torsional and twice average bending rigidity, and can generally be interpreted as an indication of overall loading intensity. Higher *J* values in a bone thus suggest higher levels of mechanical load. I_{max}/I_{min} is a ratio of the maximum and minimum bending strengths which indicates loading directionality. A higher value corresponds to a less circular bone shape in cross-section, and is associated with greater loading in one particular direction. Conversely, a lower I_{max}/I_{min} value corresponds to a more circular shape in cross-section which indicates adaptation to variable loading directions.

All data were previously collected by Alison Murray following the methods described below. Tibial data were quantified from three-dimensional laser scans of each individual's best preserved side obtained using a portable NextEngine laser scanner, but preference was given to the right limb if both sides exhibited equal preservation. Laser scanning was also used for Medieval humeri, but humeri from all other time periods were measured using silicone moulds. CSG properties were calculated from the periosteal contour at 50 percent of the maximum length of the tibia, and 35 percent of the maximum length of the humerus (Macintosh et al., 2017).

Left and right humeral *J* values were standardized to account for variation in body size between individuals following Ruff's (2007) method: (*J* / (body mass × bone length^2). Maximum bone lengths were measured with an osteometric board parallel to the long axis of the bone. Body mass was estimated using Ruff and colleagues' (2012) equation for European Holocene populations derived from femoral head measurements. Femoral head diameter was measured with sliding calipers for the Neolithic, Bronze Age, and Iron Age individuals, and from 3D scans generated from Rapidform XR software for the Medieval sample (Macintosh et al., 2017).

5.2. Statistical analysis

All statistical tests were performed using SPSS version 23, where an alpha value of 0.05 or less was treated as statistically significant. Kolmogorov-Smirnov tests were used to check each group for normality, and three were found to not follow a normal distribution: Neolithic left humeral I_{max}/I_{min} (p=.007), Neolithic left humeral size-standardized *J* (p=.045), and Bronze Age right humeral I_{max}/I_{min} (p=.02). As a result, differences between all data groups were examined using Kruskal-Wallis tests, and Mann-Whitney two-tailed post hoc tests. The proportion of lower to upper limb loading was evaluated using linear regression standardized residuals of raw tibial *J* and average left and right raw humeral *J*. The standardized residuals were also tested for normality and group differences using the approaches outlined above. This method mirrors that taken by Macintosh and colleagues (2017) during their analysis of contemporaneous females and will thus allow the results to be accurately compared.

6. Results

Summary statistics for all properties are presented in Table 1, and Kruskal-Wallis test results are given in Table 2. There was no statistically significant temporal change in left or right size-standardized humeral *J* (Figure 2a), or in right humeral I_{max}/I_{min} (Figure 2b). This suggests that the intensity of upper limb loading and directionality of right upper limb loading do not change greatly over time. In the left humerus, however, Medieval I_{max}/I_{min} values are significantly higher than the Neolithic and Bronze Age populations (Figure 2b). This indicates significantly less circular diaphyses in cross-section and thus that the performance of loading occurred predominantly in one particular direction. Neolithic males exhibited significantly lower mean standardized residuals of humeral to tibal *J* than males from all other time periods, indicative of relatively higher tibial loading (Figures 3 and 4).

7. Discussion

7.1. Sexual division of labour in early agricultural Central Europe

The lack of significant change in humeral polar second moments of area (*J*) through time in either the left or right limb among Central European males suggests that the intensity of loading associated with manual activities did not change drastically during the first ~6150 years of agricultural development. However, the directionality of left humeral loading (I_{max}/I_{min}), did significantly change in the Medieval period relative to the Neolithic and Bronze Age. These humeri are significantly more non-circular in

cross-section, indicating that loading occurred in predominantly one direction. This consistency in upper limb loading from the Neolithic through Iron Age followed by change in the Medieval period is paralleled among contemporaneous females, as documented by Macintosh and colleagues (2017). Female humeral polar second moments of area also exhibited no significant change from the Neolithic to the Iron Age, but the Medieval period saw a significant decline in the left humerus, relative to the Bronze Age, and the right humerus, relative to the Iron Age.

The changes that occur in the Medieval period, for both males and females, are likely related to increasing task specialization and technological efficiency. The production and trade of non-agricultural goods was an important part of Medieval societies, and textile implements such as spindle whorls, loom weights, and needles can be found in the graves of both sexes at this time (Gleba and Pásztókai-Szeőke, 2013). As such, it is possible that both males and females could have been engaging more frequently in tasks that did not require substantial loading of the upper limbs. Additionally, as tools became more productive, individuals during the Medieval period would not have had to exert as much manual labour when performing agricultural-related tasks, such as operating a plough or processing cereal crops.

Tibial loading, relative to humeral, is significantly higher among Neolithic males relative to all other time periods. Terrestrial mobility thus appears to have been most important for males immediately following the Neolithic shift to farming, during which males exhibited similar levels of lower limb loading to living male athletes, but declined considerably beginning in the Bronze Age (Macintosh et al., 2014a; 2015). Female

relative interlimb loading, however, consistently demonstrates greater humeral loading than tibial loading and does not change greatly over time (Macintosh et al., 2017).

Considering that both males and females maintained fairly consistent levels of manual labour, early Central European agricultural intensification appears to have disproportionately affected male terrestrial mobility. In some LBK communities, such as the Neolithic site of Schwetzingen, strontium isotope analysis demonstrates that some males spent considerable periods of time in other regions (Bentley et al., 2012) which Macintosh and colleagues (2014a) suggest could indicate a primary responsibility of supervising herds of grazing livestock instead of involvement with other farming or land clearance activities. Another possible explanation is that some males from LBK farming populations partially subsisted on resources from different regions (Bentley et al., 2002 as cited in Macintosh et al., 2014a; Smrčka et al., 2008), and thus early Neolithic farming practices might have seen an influx of individuals who otherwise followed hunting and gathering subsistence strategies in areas with steeper terrain (Macintosh et al., 2014a).

Additional information can be obtained by comparing mean humeral *J* values to appropriate sex-specific frameworks. Relative to living females, Central European females from all time periods demonstrated similar levels of upper limb loading to semi-elite athletes. Neolithic females, in particular, were most similar to living rowers who trained up to 21 hours, rowing up to ~190 km, per week (Macintosh et al., 2017). In comparison, male mean humeral *J* from all time periods is closest to that of living sedentary males and never approaches that of living male athletes (Shaw and Stock,

2013) (Figure 5). Early Central European males clearly maintained consistently low levels of upper limb loading relative to females, regardless of changing agricultural practices.

Furthermore, males also exhibit reduced variation in upper limb asymmetry than females. While males maintain consistent right-dominant humeral loading over time, females started off as right-dominant in the Neolithic before shifting to significantly more bilateral manual labour in the Bronze Age, and then returned to right-dominant loading during the Iron Age (Macintosh et al., 2014b). The consistent right-dominated upper limb loading in males suggests that they performed similar habitual behaviours that relied predominantly on the right upper limb, such as woodworking during the Neolithic and metalworking during the Bronze and Iron Ages. Female changes, however, might be related to changing technologies such as the introduction of the plough or an increasing importance of weaving or textile industries (Macintosh et al., 2014b). Thus, in addition to performing relatively higher levels of upper limb loading than males, females also appear to have performed more variable manual labour during agricultural intensification.

7.2. Implications for androcentric assumptions about agricultural labour

Clearly, the assumption that male contributions to farming practices increase alongside agricultural intensification does not apply to this study sample. However, it very well might not apply to any regions or time periods once its foundational androcentric biases are considered. As discussed in Section 3.1.1, ethnographic accounts of divisions of

labour within living societies largely focus on physical activities performed by men, and consider work done by women as less important in part because it is not as physically demanding.

This is no different to the experiences of many living women agriculturalists today, who are often faced with a dual burden of agricultural tasks and domestic work related to household maintenance and childcare (Whatmore, 1991; Brandth, 2002). In many regions it is still assumed that women are weaker, and thus cannot perform as efficiently or productively as men (Mencher and Saradamoni, 1982). Brandth (2002) argues that women farmers are “defined by their biology and marital contract irrespective of what work they do in the production on farms” (p. 184) while men are associated with the physical tasks that comprise ‘real’ agricultural work.

These androcentric biases remain prevalent today, and have unfortunately been imposed into ethnographic accounts of societies worldwide. Boserup (1970), for example, suggests that intensive agriculture becomes the domain of men by comparing women-dominated horticultural groups in Africa to men-dominated farming populations in Asia. She notes a shift in Asian farming populations following the introduction of the plough, after which clearing the fields becomes men’s work and argues that women in such intensive farming systems “may have little agricultural work to do” (Boserup, 1970, p 34). Instead, women contribute mainly through “harvest work and… the care of domestic animals (p. 25).

However, caring for domestic animals and harvesting crops should absolutely be considered agricultural labour. Simply sourcing food for livestock can account for up to

five hours of work per day (Hoffpauir, 1978) and other related tasks, such as milking animals, processing meat and textiles, and sourcing and carrying water, can be equally labour-intensive (Blumberg, 1979; Geere et al., 2010). Food processing is also strenuous work - manually grinding grains for a single family requires hours of consistently intensive bimanual upper limb loading every day (Sládek et al., 2016). Finally, childcare is extremely physically demanding and, moreover, essential on family farms because older children and adolescents are often brought up to work and assist in cultivation (Whatmore, 1991). This 'domestic' labour is integral to farming populations but largely goes unrecognized because it is considered part of the invisible realm of women's work (Whatmore, 1991).

Additionally, claims that women simply cannot contribute to agricultural populations as much as men because of childcare and reproductive responsibilities are inherently flawed. Humans are cooperative breeders and often rely extensively on parenting help from both related and unrelated group members (Kramer, 2010). It is unreasonable to assume that, in living or past populations, mothers would be required to stay at home following the birth of their first child.

While clearing a field with a plough is necessary, physically demanding labour, it is certainly not the only component of an agricultural economy. Crops then need to be planted, protected, harvested, processed, and prepared for consumption. Maintaining herds of animals that feed and clothe a population is also an important facet of farming communities, and there is no viable reason to consider these tasks as external to the agricultural process simply because they are perceived as less physically intensive than

operating a plough. Additionally, women's role in childcare and reproduction is foundational to agricultural production, not irrelevant. Perceptions of the agricultural labour process are seriously distorted by disregarding the wealth of work achieved by women as the focus is placed solely on physical tasks performed by men.

7.3. Implications for bioarchaeological methodology

Despite its flawed foundation, this androcentric assumption of declining female labour has been inappropriately applied to past societies (Surovell, 2000; Gifford-Gonzalez, 1993). Bridges and colleagues (2000) have noted how results from bioarchaeological investigations into past populations have yielded conflicting results; some suggest that males maintained higher levels of physical activity than females (Stock and Pfeiffer, 2004; Marchi, 2008; Sparacello and Marchi, 2008; Sparacello et al., 2011; Cameron and Pfeiffer, 2014), whereas others indicate the inverse (Bridges, 1989; Bridges et al., 2000). Interestingly, though, the studies that suggest males performed more labour-intensive activities than females are the ones that directly compare male and female bone. Those that compare temporal trends between males and females instead find that males often demonstrate a marked reduction in loading when new agricultural technologies are adopted.

As discussed in Section 3.2.1, male bone responds in a more advantageous manner to mechanical loading than does female bone. Directly comparing the two thus likely underestimates female levels of physical activity, and it is possible that the use of this method in previous studies has resulted in inadequate interpretations of sexual

divisions of labour in past populations. For example, as described in Section 7.1, early female agriculturalists from Central Europe appear to have been performing consistently higher levels of manual labour than contemporaneous males when compared to sex-specific samples of living athletes. However, male humeral *J* values are consistently higher than those of females throughout the Neolithic, Bronze Age, Iron Age, and Medieval period (Figure 6). Directly comparing these values would have resulted in a very different interpretation, in which males are incorrectly presumed to have regularly performed more intensive manual labour than females throughout these time periods. This case study thus highlights the need for bioarchaeologists to use appropriate sex-specific interpretive frameworks when analysing the physical behaviours of past populations.

8. Conclusion

This study demonstrates statistically nonsignificant change in upper limb loading among Central European males throughout the first ~6150 years of agricultural development, and higher levels of tibial loading, relative to humeral, during the Neolithic. When compared to published accounts of contemporaneous females, it is clear that changing technologies and farming practices in Central Europe were associated with significant declines in male terrestrial mobility, relative to manual labour, but no substantial changes in relative female interlimb loading. Additionally, while both sexes maintained steady levels of manual labour over time, females consistently performed a much higher degree of upper limb loading relative to males. Agricultural intensification in early

Central Europe can thus be characterized as having disproportionately affected male tibial loading but not the female behavioural repertoire.

The results provide a new line of evidence as to how labour was divided between these two sexes in Central Europe during a time of significant technological and agricultural transition. In doing so, they challenge the androcentric biases that inform understandings of labour in agricultural populations. The assumption that agricultural intensification is characterized by increasing male labour requires equating superior male strength with male superiority, and female reproduction with inherent domesticity. Bioarchaeology has been somewhat complicit in maintaining this assumption through the use of inappropriate methodology, and this research highlights the need for appropriate sex-specific interpretive frameworks so as to not underestimate female levels of physical behaviour in past populations.

9. Tables and figures

		Left humerus			Right humerus	
Size-standardized J	**N**	**Mean**	**Range**	**N**	**Mean (SD)**	**Range**
Neolithic	48	19.91 (3.36)	13.67	49	21.66 (3.37)	16.03
Bronze Age	33	20.37 (4.28)	17.56	28	23.56 (4.78)	17.77
Iron Age	12	20.59 (4.60)	13.26	11	22.84 (4.17)	15.04
Medieval	10	20.09 (5.43)	15.55	10	22.43 (4.66)	13.45
I_{max}/I_{min}						
Neolithic	53	1.21 (0.11)	0.5	53	1.23 (0.12)	0.58
Bronze Age	36	1.21 (0.11)	0.4	29	1.23 (0.15)	0.55
Iron Age	13	1.26 (.12)	0.41	14	1.28 (0.13)	0.39
Medieval	10	1.31 (0.13)	0.38	10	1.24 (0.13)	0.4

Table 1. Summary statistics for male CSG properties by group.

	Neolithic	Bronze Age	Iron Age
Left humeral *J*			
Bronze Age	0.78		
Iron Age	0.337	0.758	
Medieval	0.578	0.625	0.598
Right humeral *J*			
Bronze Age	0.112		
Iron Age	0.307	0.876	
Medieval	0.872	0.507	0.673
Left humeral I_{max}/I_{min}			
Bronze Age	0.581		
Iron Age	0.112	0.308	
Medieval	**0.024**	**0.035**	0.457
Right humeral I_{max}/I_{min}			
Bronze Age	0.631		
Iron Age	0.152	0.195	
Medieval	0.638	0.748	0.815
SR humeral:tibial *J*			
Bronze Age	**0**		
Iron Age	**0.013**	0.903	
Medieval	**0.002**	0.239	0.289

Table 2. Results of post hoc (Mann-Whitney) examinations of male CSG properties and linear regression standardized residuals (SR)*. Significant results ($p<0.05$) shown in bold. Left and right humeral J is standardized to account for differences in body size.*

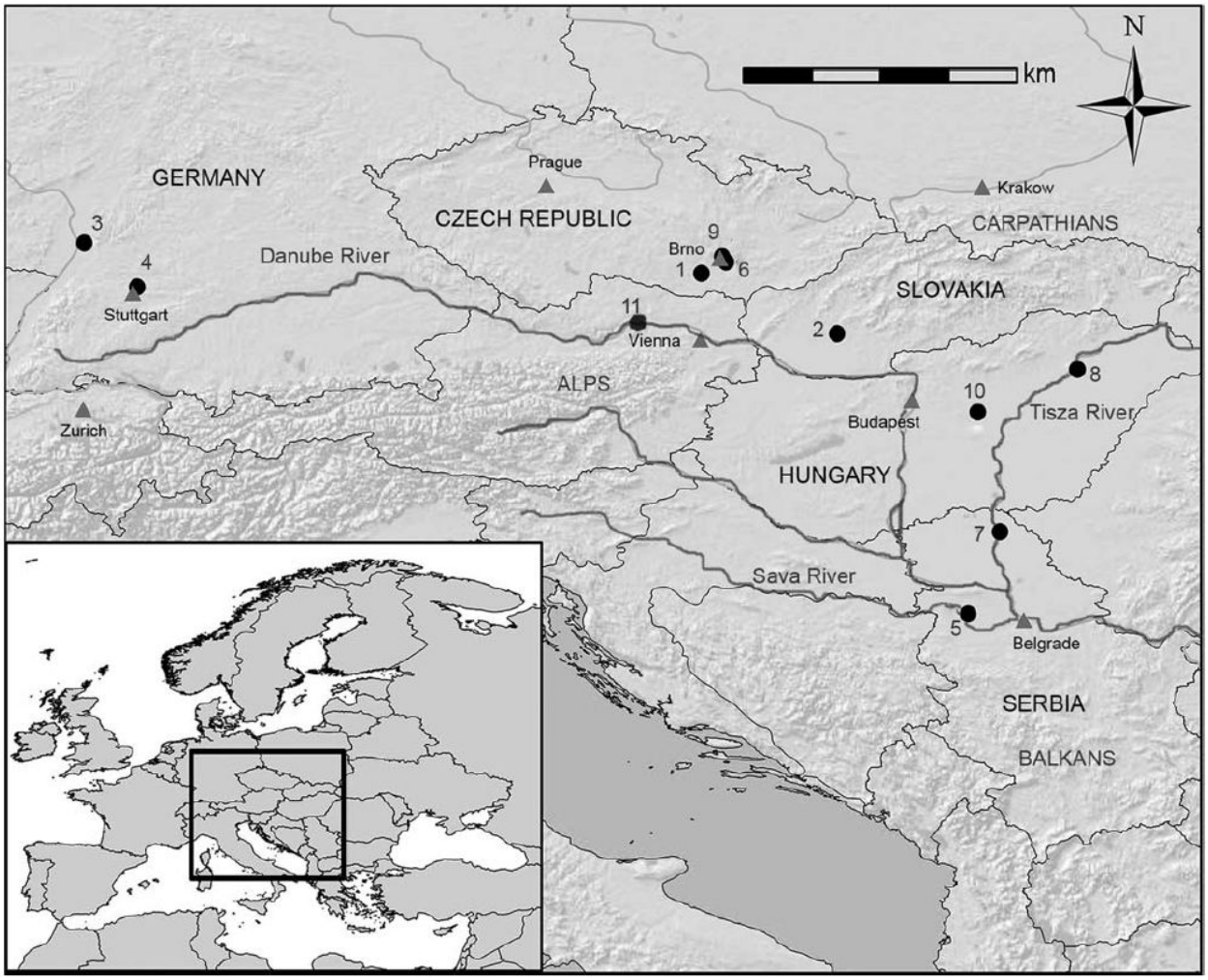

Figure 1. Map of Central Europe with locations of sampled cemeteries. 1. *Vedrovice (Neolithic);* ***2.*** *Nitra Horné Krškany (Neolithic);* ***3.*** *Schwetzingen (Neolithic);* ***4.*** *Stuttgart-Mühlhausen (Neolithic);* ***5.*** *Hrtkovci-Gomolava (Neolithic and Iron Age);* ***6.*** *Brno-Turany (Bronze Age);* ***7.*** *Ostojićevo (Bronze Age);* ***8.*** *Polgár-Ferenci-Hát (Neolithic) and Polgár-Kenderföld (Bronze Age);* ***9.*** *Brno-Maloměřice (Iron Age);* ***10.*** *Tápiószele (Iron Age);* ***11.*** *Pottenbrunn (Medieval). Copied with permission from Macintosh, Pinhasi, and Stock (2017).*

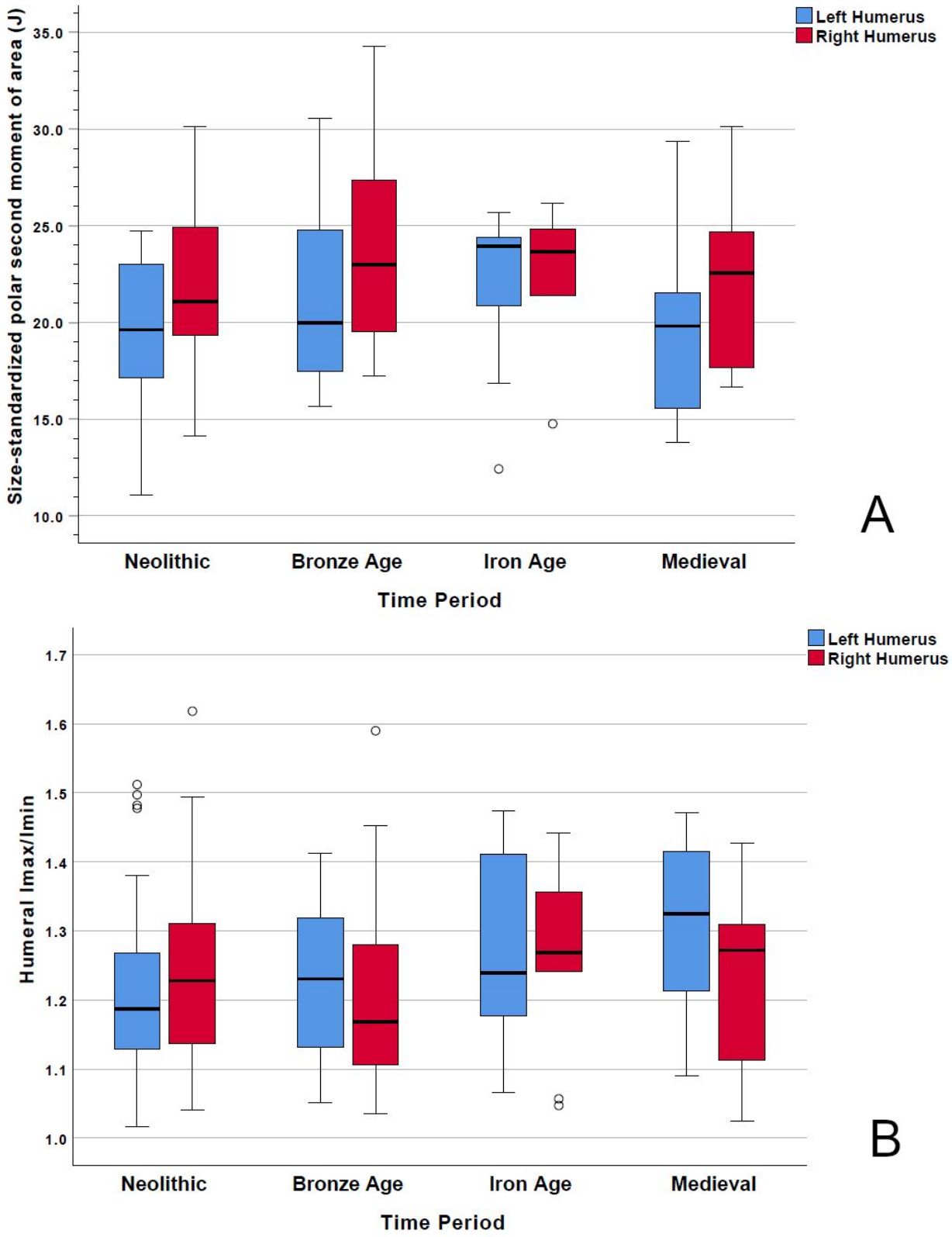

Figure 2. Male humeral CSG properties by group. (A) *Left and right size-standardized J.* ***(B)*** *Left and right* I_{max}/I_{min}.

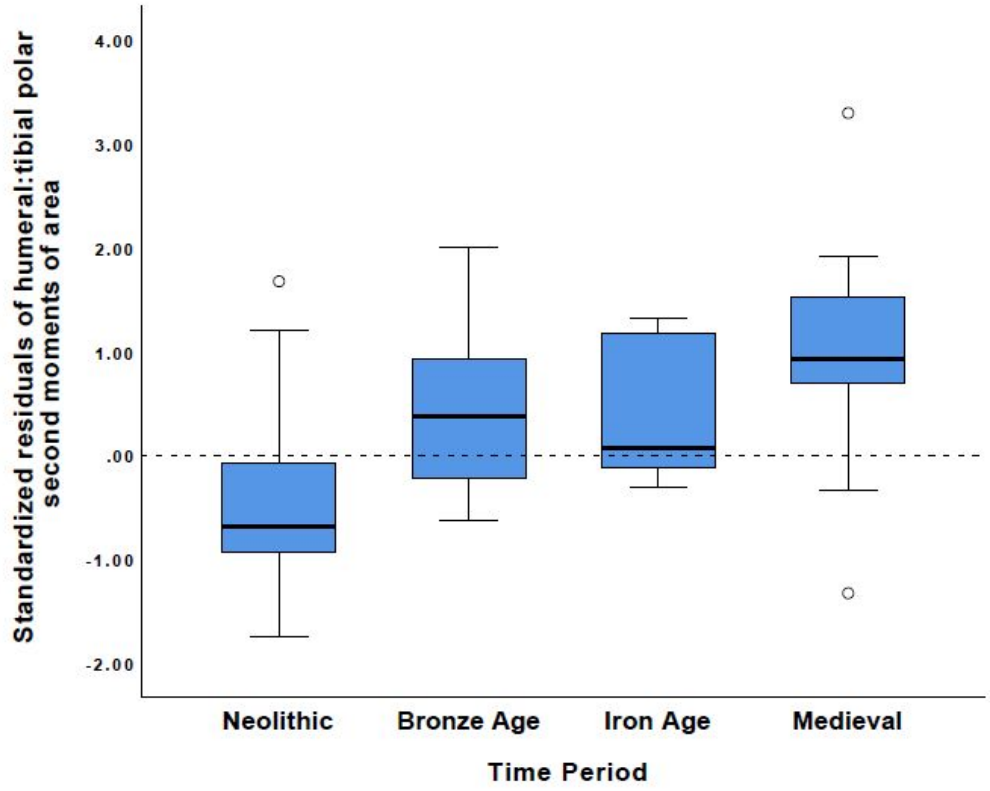

Figure 3. Linear regression standardized residuals by group.

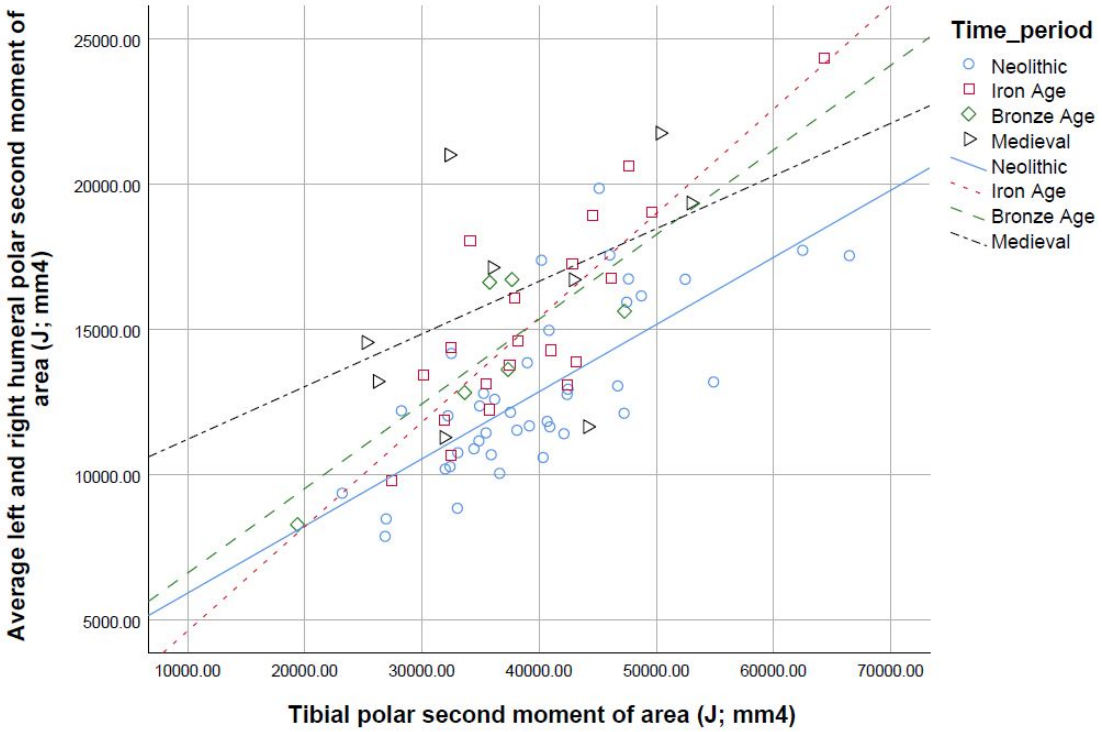

Figure 4. Interlimb strength proportions (humeral relative to tibial) by group.

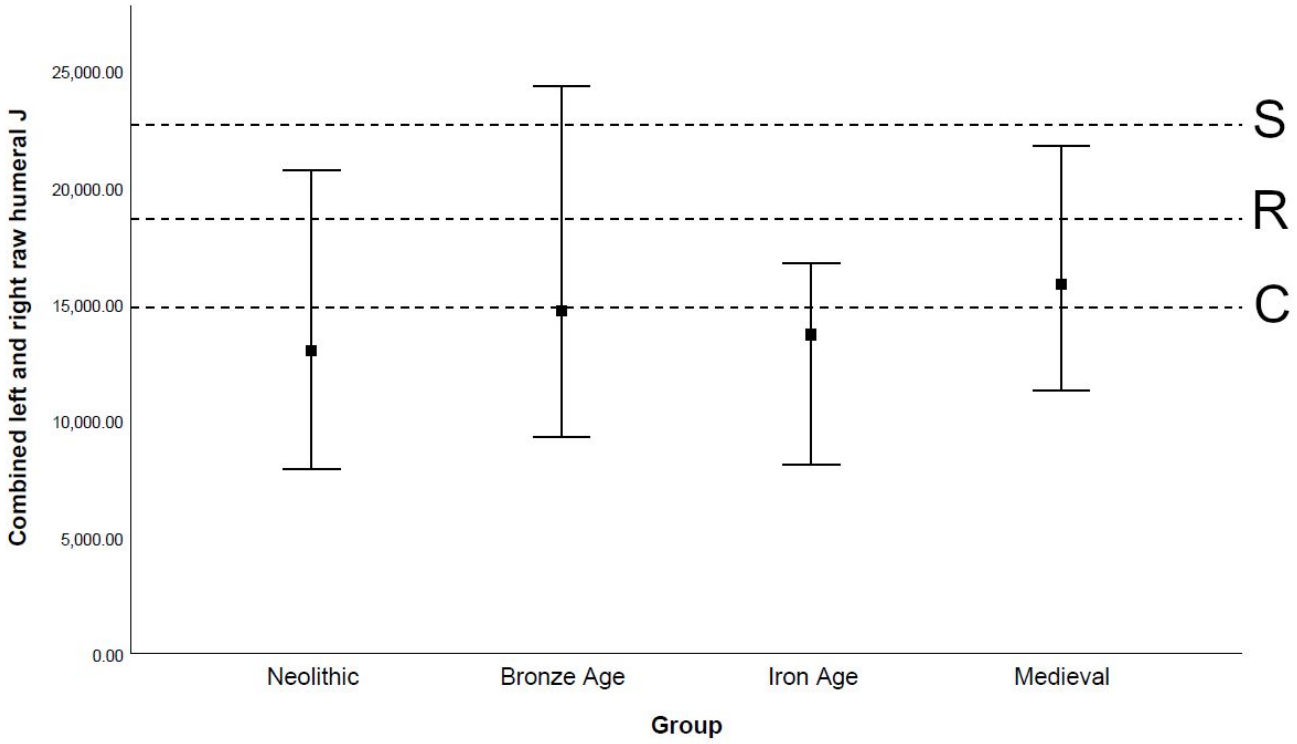

Figure 5. Comparison of mean raw humeral J values between Central European males and living male athletes*. S=swimmers, R=runners, C=sedentary control sample. Male athlete data obtained from Shaw and Stock (2013).*

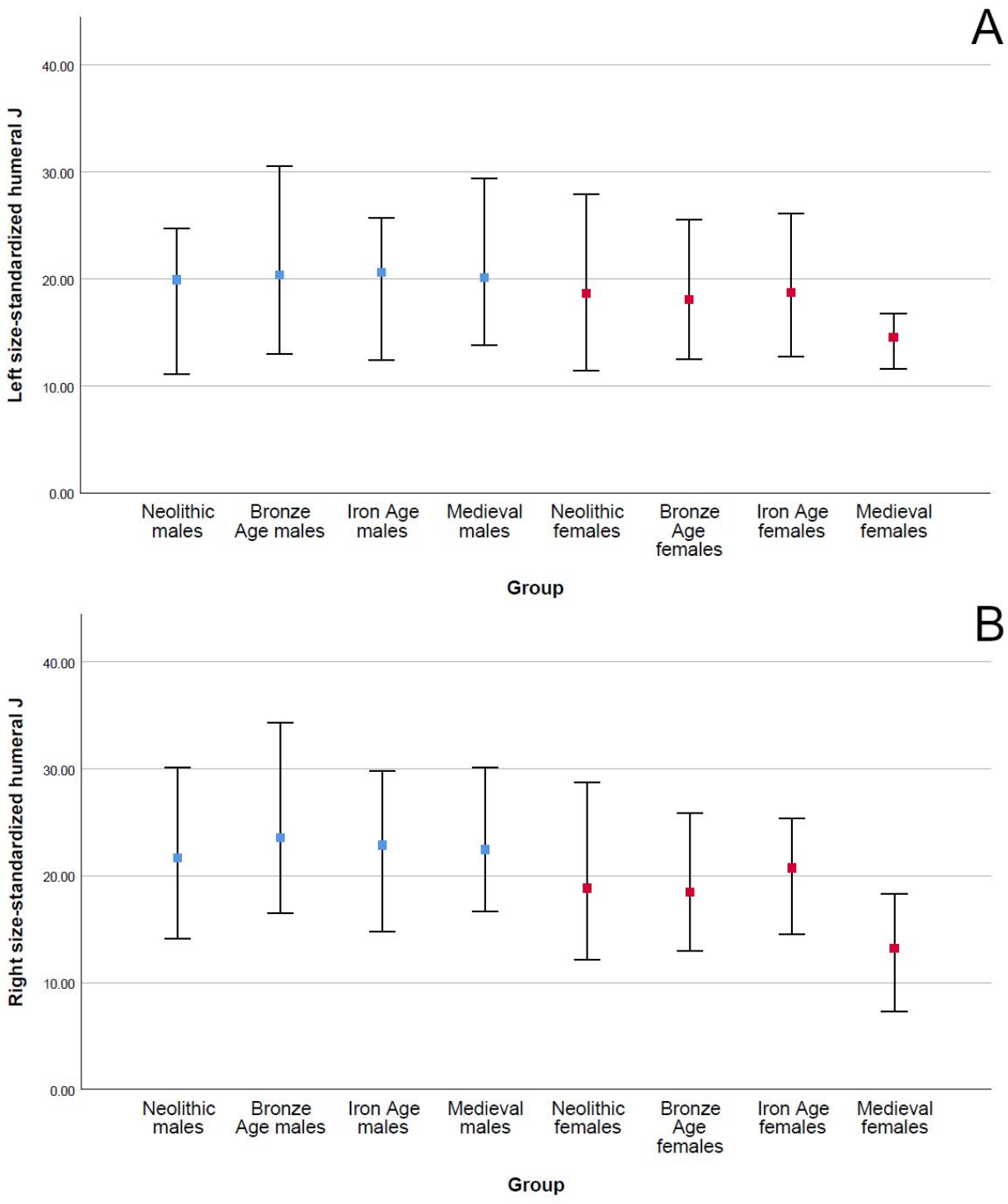

Figure 6. An inappropriate direct comparison of mean humeral J values between sexes over time. (A) *Mean size-standardized left humeral J.* ***(B)*** *Mean size-standardized right humeral J. Female data obtained from Macintosh et al (2017).*

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