Essays on Humans and Resources in a Long-Term Perspective

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Curriculum Vitae

Nicholas J. Meinzer was born in Kassel in 1986. After finishing vocational training as an industrial mechanic, he studied Economics and Business Administration at Eberhard Karls Universität Tübingen, graduating with a B.Sc. in 2011. In 2013, he received a M.Sc. in International Economics and Finance from Eberhard Karls Universität Tübingen after studying there and at the University of Western Australia in Perth. He works as a research assistant in Project B06: Humans and Resources in the Migration Period and the Early Middle Ages of the SFB 1070 RESSOURCENKULTUREN, funded by the German Science Foundation (DFG) at Eberhard Karls Universität Tübingen.

Colophon

This document was typeset using the XeLaTeX typesetting system created by the Non-Roman Script Initiative, the memoir class created by Peter Wilson, and a template by Frederico Maggi. The body text is set 12pt with EB Garamond. Other fonts include `Source Code Pro` and Lato Regular.[1] The figures were drawn using *Stata Statistical Software: Release 13.1* by StataCorp LP, except for the maps which were drawn using *QGIS Geographic Information System*, of the Open Source Geospatial Foundation Project.

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[1] This is the sans-serif fontface used for the figures. Unfortunately, there were technical difficulties printing text set in this font outside the graphs.

Preface

First and foremost, I thank my advisor, Jörg Baten, for constant encouraging support, and my second advisor, Heinrich Härke, for introducing me to the archaeology of the Middle Ages and giving valuable comments on drafts of some of the chapters and on data collection strategies.

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I am grateful to Richard H. Steckel, Clark S. Larsen, and other collaborators in the *Global History of Health Project* for giving me the opportunity to contribute to the ongoing endeavour and gather experiences with such a large-scale project.

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Other colleagues from the SFB and the Tübingen economic history department, Daniel Steinberg, Jörg Widmaier, and Christina Vossler-Wolf contributed to a stimulating office environment, improved my understanding of their field's literatures, or were available for discussions, and provided feedback. Thank you!

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I have also benefited from valuable comments and questions by editors and anonymous referees of academic journals.

Last but not least, I thank my family and friends.

Nicholas Johannes Meinzer
Tübingen, April 2017

Abstract

Human remains are at the centre of the study of living conditions, physical well-being, and their development in the very long run with heights estimated from long bones allowing insights into the biological standard of living that can be complemented with evidence from skeletal markers related to illness and physical activity.

The first three studies focus on a key transition period in European history, the Merovingian era (5th– 8th century), when state-like structures re-emerged after the decline of the Roman Empire in the West. Social status, insofar as it was expressed through lavishly furnished burials and exquisite grave-goods, appears to have been accessible to some who were not privileged during childhood. This is shown to be a potential problem for assessments of inequality between groups of people identified by the grave-goods they were buried with. To apply the coefficient of variation of heights as a measure of inequality of biological living standards, the suitability of a range of height estimation formulae commonly used in the anthropological literature for estimations of this measure are assessed. Estimated height inequality in a sample of about 2,200 adult individuals, compiled for these studies from published excavation reports and unpublished anthropological records, was higher in the latter half of the study period. Male estimated heights are, to some extent, correlated with agro-ecological indicators of suitability for permanent pasture, similar to heights of 19th-century conscripts that have been documented as being on average taller in administrative districts with a higher number of cows per inhabitant.

Another study documents degenerative joint disease as an indicator of biomechanical stress related to workload and activity patterns over the past two millennia, based on the *Global History of Health Project*'s dataset that covers more than 15,000 individuals excavated from 103 burial sites. The analyses of osteoarthritis also demonstrate fluctuating intensity of physical activity over time and sexual division of labour.

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Introduction

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Human remains are at the centre of the study of living conditions and their development in the very long run. Since the seminal volume on *Paleopathology at the Origins of Agriculture*, edited by Cohen and Armelagos (1984), mortuary evidence has been used to study health conditions in the Americas (Steckel and Rose 2002), Europe (Steckel 2004; Koepke and Baten 2005, 2008), and other regions (cf. Mummert et al. 2011).

As the coefficient of variation of heights turned out to be a useful measure of inequality of living conditions (Baten 2000; Moradi and Baten 2005; Blum 2013, 2014), the concept has also been applied to heights estimated from the lengths of excavated long bones. Boix and Rosenbluth (2014), for example, assess developments of height inequality to investigate the relationship between social and political organisation and inequality of living standards.

The research presented here contributes to the exploration of long-run trends of biological well-being in Europe, assessing indicators of workload and physical activity in a sample of more than 15,000 individuals from diverse backgrounds who died over the course of the last two millennia.

Against this backdrop, the importance of social change and regional characteristics of the environment are taken into focus in three studies of a key transition period, the (re-) emergence of state-like structures in Central Europe during the Merovingian era (5th–8th centuries CE), after the collapse of the Roman Empire in the West.

1.1 Humans and Resources in the Migration Period and the Early Middle Ages

Chapters 2, 3, and 4 analyse mortuary evidence from Early Medieval southwestern Germany and adjacent regions that has been compiled for these works from published catalogues of archaeological excavations of *Reihengräberfelder* that detail grave-goods deposited in the excavated graves as well as age, sex, and basic metrics of the skeletal remains, and unpublished anthropological theses and reports containing individual-level data where the publications only report aggregates. Additional anthropometric data comes from Eva Rosenstock's *Lebensbedingungen und biologischer Lebensstandard in der Vorgeschichte Europas und Südwestasiens (LiVES)* database, the *Mainzer Datenbank für prähistorische und historische Anthropologie*, and the Geneva *ADAM base de données au service de l'anthropologie physique*. In all, the sample contains data on more than 7,600 burials on 40 cemeteries in the region. Deducting children and youths who had not reached their terminal height before they died, and individuals whose skeletal remains were not well-enough preserved to allow measurement of long bones leaves a total of 2,200 adults for the analyses of average estimated heights.

The research underlying these chapters was conducted as part of the collaborative research centre (SFB) 1070 RESSOURCENKULTUREN's project *B 06: Humans and Resources in the Migration Period and the Early Middle Ages*, that set out to explore the biological standard of living and nutrition, analysing estimated body heights and ratios of stable carbon and nitrogen isotopes in bone collagen, in early medieval southwestern Germany. The main topics were the exploration of associations of nutritional and health status of individuals with details of their burials such as grave-goods deposited in their graves, analyses of possible differences in well-being between early settlers and later populations in the region, and an inquiry into differences in living standards that may be related to agricultural specialisation.

1.2 Global History of Health

The dataset analysed in chapter 5 is a subset of a larger source that contains information on the skeletal remains of 15,119 individuals excavated from 103 European sites. The individual-level evidence has been collected and coded according to the protocol laid out in Steckel, Larsen, Sciulli, et al. (2011). This data collection codebook is at the core of the *Global History of Health Project* which aims to extend the effort that resulted in *The Backbone of History* (Steckel and Rose 2002), a collection of studies on health in the Americas between 5000 BCE and the 19th century, to Europe.[1]

After hundreds of years in the soil, most of the skeletons are not complete and in a pristine condition, so that not every element could be scored for all individuals. As detailed in table 1.1, almost three quarters of the adults with at least one measurement of a femur or humerus also have at least one scorable

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[1] The project is described in detail in Steckel, Larsen, and Roberts (2017), the proposed first chapter of *The Backbone of Europe*.

joint or vertebral body while less than a fifth of them are in the osteoarthritis-sample but lack both humerus and femur lengths, to provide a comparison with the skeletal data used in the studies of heights in the Early Middle Ages.

The contextual covariates, however, are defined on the level of excavated sites or samples of skeletons. The time variables capture the earliest and latest burial dates for each cemetery. While these can be very precise, especially for sites from military contexts, where the people died within a short period of time, the median individual's skeleton has been excavated from a cemetery with a 200-year gap between those two dates. While many cemeteries have been used to bury many generations of inhabitants of a settlement, the broad ranges of dates are to some extent due to the limited precision of the applied archaeological dating methods. The socio-economic structure of the buried populations and the size of their settlements are also typically inferred from the archaeological finds. Small *rural* settlements were typically homes to *farming communities*, while *craft or artisan workers* often lived in *towns* or small *small cities*. Similarly, *farming communities* are more common in some categories of the geographical context variable, such as on *plains* or in *rolling hills*. However, since collinearity between the covariates is far from perfect, and they are conceptually distinct, it is warranted and instructive to explore the datasets along the lines of the different categories of the socio-economical and geographical context variables.

As figure 1.1, a map of the sites, shows, the observations are widely distributed, although some areas such as the Apennine peninsula, the Balkans, the *Hexagone*, or the central Iberian peninsula are unfortunately not covered. These larger blank spaces on the map are due to issues with data availability, as sites were selected for inclusion by contributors to the project who were more familiar with the material in their home countries. At the scale of the map, a few clusters of sites cannot be further differentiated since the distance between the constituting sites is smaller than the apparent size of the markers.

The development of average estimated heights, or 'raw' lengths of *femora* and *humeri* for that matter, of the people in the dataset corresponds remarkably well to trends described in analyses based to some extent on compilations of aggregate data (Koepke and Baten 2005), as figure 1.2 from the chapter on "Height trends, Urban Penalty and Workload in Europe over the Past Two Millennia"[2] shows.

Other chapters of *The Backbone of Europe* for which I have analysed and visualised data are concerned with markers of unspecific systemic stress dur-

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[2] The authors of this chapter of *The Backbone of Europe* are Nicholas J. Meinzer, Joerg Baten, and Richard H. Steckel.

ing early childhood (linear enamel hypoplasia),[3] reactions of the bones to injury or infection (periostitis),[4] and a combination of indicators of early life stress (cribra orbitalia and porotic hyperostosis)[5] and am tasked to do so for the chapter on anemia and related nutritional deficiencies.[6]

1.3 Summary

The first of the chapters drawing on the early medieval dataset compiled for the RESSOURCENKULTUREN project (chapter 2), discusses potential challenges that the mortuary evidence – estimated heights and grave-goods – poses to analyses of inequality. Since long-bone lengths can only be influenced as long as an individual is still growing, i.e. during their childhood and youth, but burial rites and grave-goods deposition can reflect changes of their social status or situation that occurred during their adult life, inequality cannot easily be assessed by grouping people according to details of their burials. The observed advantage of 3 centimetres of estimated height of men buried with a long sword over the others corresponds to a level of social mobility that is compatible with the intergenerational correlation of certain forms of wealth described in the literature for more recent small-scale societies.

Chapter 3 studies differences in inequality of living standards between an earlier period, from the first burials on *Reihengräberfelder* in the region to about 600 CE, and a later one ending with the last burials of that type in the 8th century. The question is approached using the coefficient of variation of estimated heights as a measure of inequality of living standards to avoid the potential challenges of analyses of the material based on differences between groups discussed in chapter 2. An important contribution of the study is a comparison of various regression formulae used in the literature to estimate heights from long-bone lengths regarding not only the mean but also the standard deviation of estimated heights. Grave-goods data is used to augment the main result, that inequality of estimated heights was apparently higher in the later part of the study period, with observations of declining inequality

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[3] The authors of the chapter on *Growth Disruption in Children: Linear Enamel Hypoplasias* are Zsolt Bereczki, Maria Teschler-Nicola, Antonia Marcsik, Nicholas J. Meinzer, and Joerg Baten.

[4] The chapter on *Nonspecific Indicators: Periostitis* will be authored by Carina Marques and Vito Matos, and Nicholas J. Meinzer.

[5] Charlotte A. Roberts and Richard H. Steckel will be the authors of the chapter on *The Developmental Origins Hypothesis: Evidence from Skeletal Remains*.

[6] The authors of the chapter on *Anemia and Related Nutritional Deficiencies: Evidence from Cribra Orbitalia and Porotic Hyperostosis* will be Anastasia Papanthanasiou, Clark S. Larsen, Nicholas J. Meinzer, and Kimberly D. Williams.

of the number of different artefact types deposited alongside the dead. Together, these observations fit in with narratives that the elite no longer needed to impress the populace with demonstrations of wealth and power in order to secure their position in society as stratification became more rigid.

Regional differences in average estimated heights that might be associated with variation in agricultural specialisation depending to some degree on environmental conditions are the subject of chapter 4. For the 19th century, when official statistics begin to cover many facets of life, Baten (1999, 2009) and others observed a link between regional agricultural specialisation, especially dairy farming, and average heights. Since data on agricultural production in the Early Middle Ages is not available with the necessary temporal and spatial resolution, and identifying suitable proxies from modern data relating to agricultural suitability from the multitude of promising candidates is challenging, height data from 19th century conscription records and agricultural data are used as a test case for the modern indicators. Starting from the link between biological living standards and "proximity to protein production" (cf. Meinzer and Baten 2016, for a brief review) the modern proxies are first related to the historical data. Agricultural specialisation on dairy farming in 19$_{\text{th}}$ Bavaria, Baden, and Württemberg is associated with modern-day indicators of agro-environmental indicators of suitability for permanent pasture, especially relative to suitability for the cultivation of food crops. A second step regresses the historical height data on the modern agricultural and environmental indicators obtaining baseline results to which the analyses of the early medieval dataset can be compared. While the signs of standardised coefficients from regressions of the share of tall conscripts and average estimated heights from the Early Middle Ages, respectively, on each of the variety of modern indicators used in the study are mostly the same, further analyses of early medieval female heights and the share of short conscripts in the 19th-century statistics caution against downplaying technological and societal change over the centuries.

The analyses of long-term trends of degenerative joint disease in Europe, presented in chapter 5 at first seem to stand out insofar as they are not directly concerned with biological living standards, but with a more narrowly defined phenomenon. To a large extent, the conditions scored under this category in the skeletal material documented collected the *Global History of Health Project's* European database result from 'wear and tear' of articulating joint surfaces. Therefore, they are a reflection of activity patterns and can add to a more nuanced understanding of these complex parts of human lives. As one of the studies of the *Global History of Health Project* that describe and explore a wide range of health indicators based on a large sample of skeletal remains that have been analysed using a common reporting scheme, this chapter exemplifies the benefits of such a coordinated approach to data preparation.

1.4 Conclusions

Together, the chapters contribute to the ongoing effort of giving a voice to the silent majority[7] who did not leave much behind that can inform us about their daily lives except their mortal remains. The large dataset of the *Global History of Health Project* and the 2,200 individual observations compiled for the studies of the early medieval populations help to make these accessible.

The chapters on inequality in the Early Middle Ages are cases in point for the notion that political power and elevated social status are readily used to secure advantageous living conditions, and that increased state capacity often comes at the expense of poorer segments of the population. Apart from that, they stress the importance of carefully considering details of the data, pointing out that 'diluting' effects of social mobility also have to be taken into account in the context of skeletal data and grave-goods, and assessing the suitability of different height-estimation regressions for measuring inequality. The analyses also highlight that the experiences of men and women, insofar as they were imprinted on their bones, were markedly different in the Early Middle Ages and throughout the last two millennia.

In the larger context, given by the analyses of the European dataset, the side effects of urbanisation and population growth on physical well-being in pre-industrial times become clearer, adding detail that is otherwise hard to grasp. Rising average heights after Late Antiquity and a decline that began in the later part of the Merovingian era and lasted throughout the Late Middle Ages and the early modern period stand in contrast to indicators of living standards based on the flourishing of commerce and culture. These findings and the detailed results on social mobility, rising inequality, differentiated responses to environmental constraints, and patterns of workload and physical activity add nuance to the understanding of the past, serving as a reminder that the struggles of 'ordinary' people can easily be overlooked.

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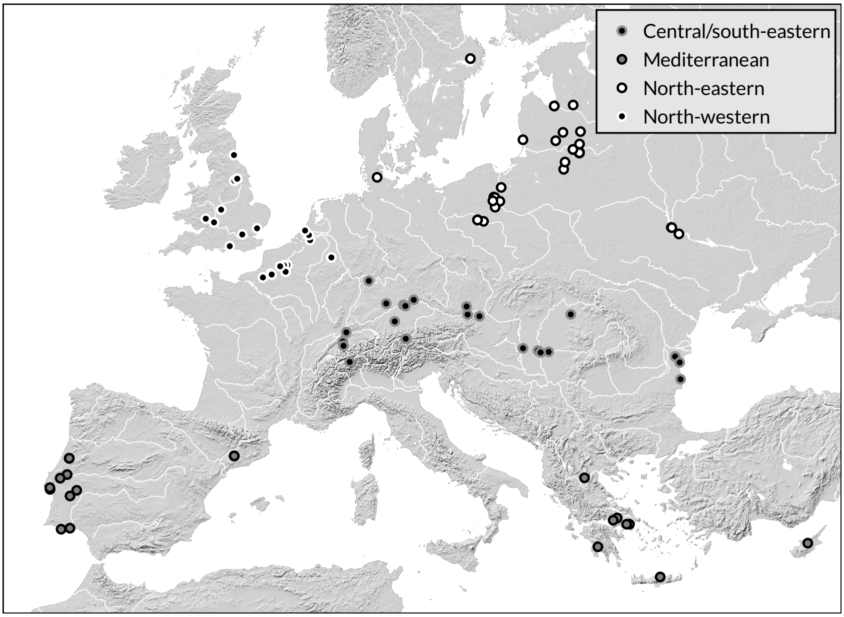
[7] Before coming to describe large groups of people who do not publicly express their opinion, the phrase apparently referred to the dead, who have outnumbered the living since very early in human history (cf. `https://en.wikipedia.org/wiki/Silent_majority#Euphemism_for_the_dead`).

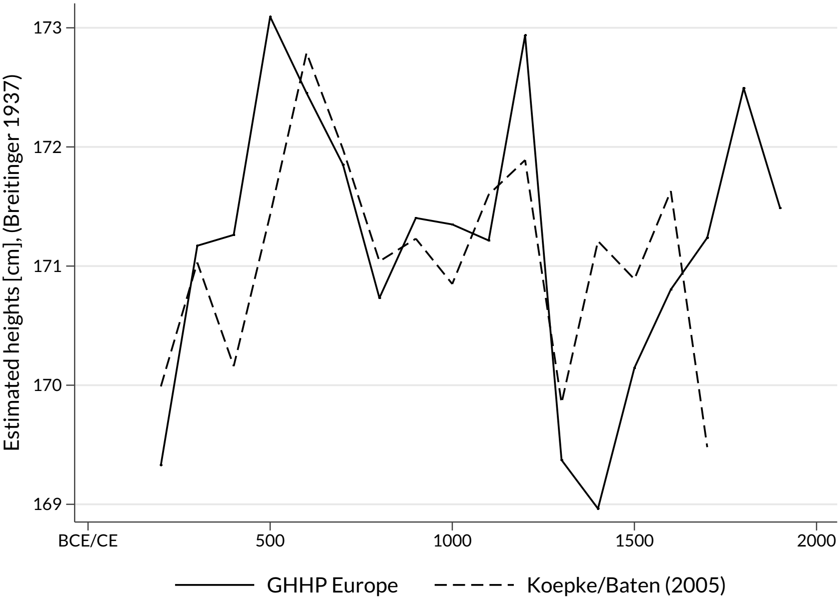
1.5 Figures and tables

Figure 1.1: Map of the sites and European regions



– The relief is based on the *GTOPO30* global digital elevation model by the U. S. Geological Survey (USGS), river centerlines are from *Natural Earth*.

Figure 1.2: Comparison of estimated height trends



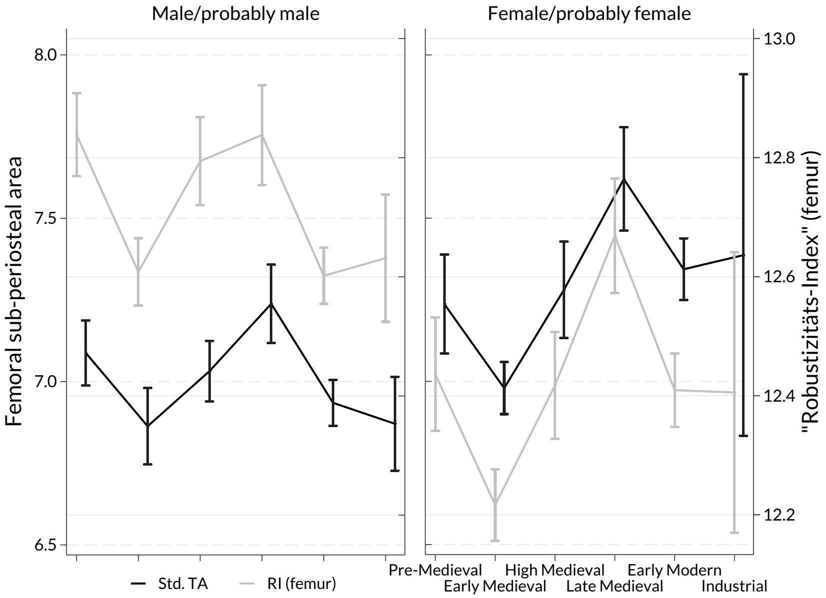
– Figure 3 of Meinzer, Baten, and Steckel (2017).
– Based on Koepke and Baten (2005) and the sample of femur lengths, applying the Breitinger/Bach estimation formulae which were used by Koepke and Baten (2005).

Table 1.1: Sample sizes *Global History of Health Project*

	No DJD score	⩾ 1 score	Total
No long-bone measurement	1,950	2,047	3,997
Femur OR humerus	1,245	5,493	6,738
Total	3,195	7,540	10,735

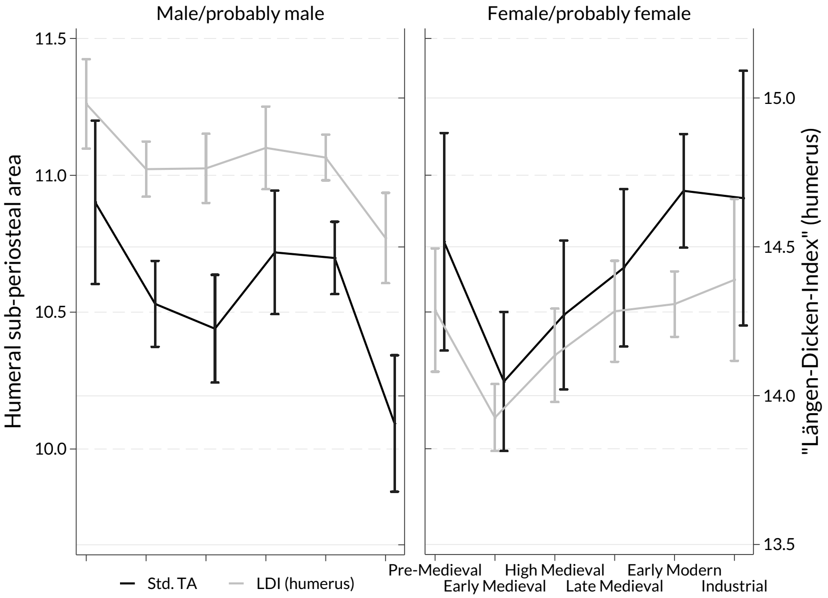
- *Sub-adult* individuals and individuals of *unclear* anthropological sex are excluded.
- The 7,540 people with "⩾ 1 score" for osteoarthritis or osteophytosis of joint or vertebral body are analysed in chapter 5.
- Meinzer, Baten, and Steckel (2017) is concerned with the 6,738 individuals with at least one measurement of the length of their *femora* or *humeri*.

Figure 1.3: Comparison of femoral robusticity indicators, with 90 % confidence intervals



– Based on figures from Meinzer, Baten, and Steckel (2017).
– The standardised sub-periosteal area of the femur at midshaft (Std. TA) and its *Robustizitäts-Index* (robusticity index, RI) are calculated and scaled as described there.
– The vertical scales apply equally to both panels, as indicated by the solid (right) and dashed (left) grid lines.

Figure 1.4: Comparison of humeral robusticity indicators, with 90 % confidence intervals



– Based on figures from Meinzer, Baten, and Steckel (2017).
– The standardised sub-periosteal area of the humerus at midshaft (Std. TA) and its *Längen-Dicken-Index* (length-thickness-index, LDI) are calculated and scaled as described there.
– The vertical scales apply equally to both panels, as indicated by the solid (right) and dashed (left) grid lines.

Social Mobility in the Early Middle Ages

2

Abstract

Estimates of inequality of living standards based on average height differences between socio-economic strata are likely biased if the social status of some individuals changed during their lifetime. Height differences estimated from skeletal remains, reflecting living standards during childhood and adolescence, are probably too small if social status is inferred based on grave-goods which are associated with the individuals' social status at the time of their death. The higher the level of social mobility, the more distinguished individuals will not have had a privileged childhood and, therefore, the biological characteristics of the disadvantaged group. In a newly assembled sample of individual level anthropometric data from 26 early medieval row grave cemeteries in southwestern Germany, men buried with a long sword in their grave were on average about 3 centimetres taller than the others. In a simple model of the mechanics of the social-mobility bias, this height difference, together with parameters from the literature, implies a level of social mobility typical of small-scale agricultural or pastoral societies.

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I have benefited from comments and suggestions by Jörg Baten, Heinrich Härke, Daniel Steinberg and other colleagues at the SFB 1070 and the Tübingen economic history seminar, participants of the NWO ClioInfro-Workshop 2014, the EMASS Conference 2015, an editor of the journal, and two anonymous referees.

2.1 Introduction

Ever since the neolithic revolution, elites in hierarchical societies have often successfully managed to redirect resources to themselves and their families, with lasting results (Boix and Rosenbluth 2014). While for most of this time neither the underlying social and economical differences nor the resulting unequal outcomes were recorded in writing, other sources of data are available. Mortuary evidence, such as skeletal remains which can be used to estimate body heights and accompanying grave-goods which are likely to have reflected social status, is available for long periods of the past.

Nutrition and health conditions during childhood are a major influence on average heights of populations (Bogin 2001). The children of the elite tend to grow up into, on average, taller adults due to their advantageous material condition. This inequality of living standards is reflected in an average-height difference between people with elite and ordinary background.

Analysing social gradients of adult heights in a British cohort study, Power et al. (2002) stress that social mobility introduces a bias into such measures of inequality. If children from poorer homes rise into the ranks of the elite later in life, the average height of the elite will be lower than it would have been otherwise. The shorter average heights of socially upwardly mobile people reduce the average height of all adults with elite status taken together. Conversely, the ordinary people will be on average (ever so slightly) taller if some children of the elite cannot retain their social status as adults.

Only in a rigidly ranked society would the average height differences reflect the true underlying inequality of living standards. In a society with maximum social mobility, where all children have a similar chance to rise to the top, there would be no measurable differences in heights between the (adult) elite and the others, regardless of differences in childhood health and nutrition.

Like many other historical sources, the mortuary evidence from the Early Middle Ages analysed below represents the state of things as they were at one point in time. As potential markers of social status are not directly related to childhood circumstances, between-group differences are likely biased, while the actual level of social mobility cannot be measured directly. Making assumptions about underlying height differences based on the literature, a simple model of the mechanics of the social-mobility bias can be used to obtain ballpark estimates of the level of social mobility, or vice-versa.

The next section presents a simple model of average heights in a society with two social strata, spelling out the effects of social mobility. A third section reviews relevant literature on average height differences between members of various social strata, gives some background information on south-western Germany in the 5th to 8th centuries, and argues that some grave-goods deposited during burial, namely large swords and objects made of precious metals, can be used to tentatively identify an individual's social standing. The fourth section introduces a new dataset of 926 adult individuals excavated from 26 cemeteries. Before coming to a conclusion, another section discusses the observed difference of almost 3 centimetres between the men buried with special grave-goods and the others and applies the simple model presented in the second section to the dataset. Assuming an underlying height difference of 4 centimetres, the model implies that between 58 and 95 percent of the individuals who received an elite burial grew up under privileged conditions.

2.2 A simple model of social mobility and heights

Consider two generations of people in a society with two social strata, ordinary people and an elite. The elite has preferential access to resources and generally enjoys a higher standard of living. Children growing up in households of the elite enjoy the higher living standard of those households and grow up to be on average b centimetres taller than those who grew up in ordinary households. The heights of children of the elite, h_e, and ordinary people, h_o, are distributed normally

$$h_o \sim \mathcal{N}(\mu_h, \sigma^2) \tag{2.1}$$

$$h_e \sim \mathcal{N}(\mu_h + b, \sigma_e^2) \tag{2.2}$$

Over the courses of their lives, some m people born and raised in ordinary households somehow become members of the n_E people strong elite stratum. Conversely, m people born to elite parents move down the social ladder so that the numbers of the elite remain constant. How and why specific individuals maintain or gain their elite status cannot be observed, therefore, it is sensible to treat the process as exogenous for reasons of parsimony. People then die and are buried according to the rites applicable to deceased of their status, i.e. from the social stratum they belonged to when they died. The expected height of people buried as members of the elite μ_{h_E} is a function of the average height of ordinary people μ_h, the height benefit b of people raised in elite homes and the share of members of the elite who retained their childhood status.

$$\mu_{h_E} = \mu_h + \frac{n_E - m}{n_E} b \tag{2.3}$$

Assuming further that the outcomes, having an elite childhood and becoming part of the elite as an adult, are drawn from two correlated Bernoulli distributions, the fraction of individuals who were not socially mobile in formula (3) can be regarded as the conditional probability of a successful draw from the second distribution given a successful draw from the first. In the most simple case, where the probability of success p is the same for both outcomes with a correlation coefficient ϕ between growing up in an elite household and becoming an elite adult, this conditional probability, corresponding to the fraction f of members of the elite who have retained their childhood status, is

$$f = \frac{n_E - m}{n_E} \xrightarrow{p} \phi + p - \phi p \tag{2.4}$$

The second panel of figure 2.8 depicts the outcome of such a simple mixing model, using the parameters estimated from the data or assumed below.[1] While the distribution of the ordinary adults has been shifted to the right only ever so slightly, the downward bias for the adult elite is more pronounced.

2.3 Background and literature review

2.3.1 Status differentials and intergenerational correlation

In a rigidly stratified society, the share of socially mobile people among elite dead approaches zero. A low estimate of the share of socially mobile people in actual societies is implicit in Clark's recent finding of "a universal constant of intergenerational correlation of 0.75" for "income, wealth, education and longevity" (Clark 2014, p.12 *et passim*) relying on his innovative surname method. However, other methods produce lower intergenerational correlations for a number of outcomes. Borgerhoff Mulder et al. (2009), for example, find an intergenerational transmission coefficient of 0.59 for material wealth and 0.36 for an importance-weighted average of "embodied", "relational" and "material wealth" (Borgerhoff Mulder et al. 2009, p.685) in "small-scale agricultural societies" and 0.61 and 0.43, respectively, in "small-scale pastoral societies"

The height benefit, designated b in the model, is hard to pin down for the Early Middle Ages. Data on height differentials between men buried with or

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[1] Random numbers from correalted Bernoulli distributions can be drawn using Coveney (2007) 'OVBD: Stata module to generate correlated random binomial data' for most of the parameter space, except the edges. The graph shows cumulative results of 10,000 trials. For more details and simulations, see the stata do-file.

without weapons or categorised according to status are not that helpful for this exercise because they cannot take into account the social status of the parents. For the sake of completeness, the differences reported in the literature range from up to 5 centimetres between those buried with and without weapons for the Weingarten cemetery population (Huber 1967, p.13) and fifth to early seventh century Anglo-Saxon burials (Härke 1990, p.39), to just over half a centimetre between men classified as "middle/higher status" and those of the "lower/unknown category" in the fifth to ninth century (Koepke and Baten 2005, pp.83). Some studies based on written sources which include information on the socio-economic status of parents of those measured report height differences between groups distinguished by the characteristics of the measured individuals' parents. Baten (1999, pp.161) finds differences ranging from 0.8 to 2.3 centimetres between conscripts from middle and upper class families and those from the lower classes in various regions of nineteenth century Bavaria. Analysing a sample of Bavarian conscripts born in the last years of the eighteenth century, Tollnek (2016) reports height differences of up to 3.8 centimetres between 19-year-olds whose fathers had professional occupations and those with unskilled fathers, with a sample average height of 164 centimetres.

Longitudinal studies from post World War II Great Britain are the oldest rigorous studies of the subject and consistently show a height difference between children of (upper) middle class and working class or non-working fathers that gradually diminishes in cohorts born in later decades due to improving socio-economic conditions (cf Li and Power 2004, p.1326). Here, Power et al. (2002) also observe that differences in average heights between social groups are smaller when the groups are defined based on the occupations the studied people themselves had aged 33, than they are when their fathers' occupations are the distinguishing factor. The comprehensive longitudinal data also show evidence for health-related social mobility, namely that socially downward-mobile people are on average shorter than those retaining their higher status, and socially upward-mobile people are taller than those who do not make it (Manor et al. 2003).[2] Kuh and Wadsworth (1989, p.666) analyse follow-up measurements of a national sample of children born in early March 1946 and report that male children of upper middle class fathers were on average about 177 centimetres tall, 4 centimetres taller than those of non working

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[2] Mechanically, as illustrated by the simulation exercises below, selective social mobility based on height (or other health outcomes) increases between-group differences and counteracts the equalising potential of social mobility (cf Stern 1983). In the referenced cases from the twentieth century at least, selectivity does not seem to be important enough to compensate much of the effect.

fathers. Taking into account other factors such as maternal education, the number of siblings and living conditions in early childhood, the difference between those in best and worst-off groups is estimated at 6.5 centimetres (Kuh and Wadsworth 1989, p.665). The height difference in the 1947-born Newcastle-upon-Tyne-sample was apparent in early childhood and was measured to average 4 centimetres in the then 22 year-old men (Miller et al. 1972, p.226).

2.3.2 Southwestern Germany in the Early Middle Ages

Most of the early medieval populations contained in the dataset studied in this short paper are identified as *Alamanni* by the archaeologists who excavated their cemeteries or analysed the finds. This name was first mentioned in the early third century, describing *Germanic* war bands that were defeated at the Roman *limes* border fortifications (Geuenich 2005, pp.18). At the turn of the fifth to the sixth century, the *Franks* subjugated a loosely knit alliance of several *Alamanni* kingdoms (Geuenich 2005, pp.82), establishing a dukedom encompassing the *Alamannia* toward the end of the first half of the sixth century (Drinkwater 2007, p.347).

The first comprehensive written sources concerning *Alamanni* society are two legal texts, dating back to the early seventh and early eighth century, that prescribe a strict social order where compensation due for inflicting harm on others was differentiated by the rank of the victim (Schott 1974). However, written centuries after the *Alamannia* came under *Frankish* rule, these laws do not seem to be based on tribal customs and legal traditions from earlier periods (Geuenich 2005, pp.108).

In the absence of written sources, archaeological findings provide a general idea of everyday life from the dwellings people lived in to the garments they wore and the food they produced and ate (e.g. Archäologisches Landesmuseum Baden-Württemberg 1997). The *Alamanni* lived mostly in small settlements of just a few families and relied on agriculture for subsistence.

As in other parts of central Europe on the fringes of the Roman empire, communities in the region harmonised their burial practices in the late third and fourth centuries CE, abandoning various methods of cremation that were practised in earlier times (Fehr 2008, pp.77).[3] They began burying their dead on larger cemeteries, so called *Reihengräberfelder*, dressing them

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[3] Cremation remained a popular choice in Eastern Europe. Pescheck (1996, pp.7) claims that the cremation burials in the cemetery of Kleinlangheim (15) indicate *Slavic* influences in this area on the fringe of the *Frankish* realm.

up and equipping them with armaments, tools, jewellery and other goods (James 1989).

The meaning invested in grave-goods and the burial rite remains open to interpretation, especially since contemporary written sources remain silent on the topic. Härke (2014) discusses a number of better-documented burial customs from historical evidence and the contemporary ethnographic literature, from disposal of items polluted through contact with the deceased to potlatch-style public destruction of wealth, emphasising the complexity of the matter. Recent plausible explanations propose that the surviving relatives used the burial both to demonstrate and to re-assert their importance in local society and politics (Halsall 2010, pp.103, 2013, pp.112). This corresponds to explanations of the burial rite as an expression of the need to demonstrate acquired status that became obsolete when social stratification became more rigid and the "open ranked society", in which not every strongman or locally influential person was the descendant of his predecessor, changed into a society with distinct estates (Steuer 1982, p.531).

2.3.3 Grave goods and status – inequality in death

Rich and poor may be equal in the presence of death, but the deceased have definitely not all been treated equally in the Early Middle Ages. A comprehensive description and analysis of the various features of the graves, such as the dimensions of the pit or constructions made from wood or stone, as well as the whole range of grave-goods is beyond the scope of this paper. This section argues that some grave-goods can be used to tentatively identify individuals whose significance was emphasised in the burial rite and addresses potential issues of sample selectivity.

Notable among the artefacts buried with anthropologically male individuals are a variety of weapons on which many interpretations of grave-goods inventories and the men buried with them have been based. A double-edged long sword, the *spatha*, is the largest and most conspicuous type of weapon, and the *seax*, a smaller single-edged sword or large dagger, the most common one. Where the older archaeological literature saw the *spatha*, or swords in general, as indicators that the deceased was a "free Germanic man" (Veeck 1926, p.158; Redlich 1948), the long sword was later interpreted as a sign of wealth, not necessarily related to legal status (e.g. Christlein 1973). Gold and silver are often found in a similar share of burial inventories as the *spatha*. These inventories often contain an above-average number of different artefacts of exceptional quality, in the form of coins, rings, and in the ornaments of belt buckles and fittings. The presence of these precious metals is used here as an alternative indicator of social distinction of those responsible for the burial, and the deceased himself. While the archaeological literature has become more cautious with regard to generalising interpretations, the current idea is that furnished burials served the purpose of demonstrating social status. The *spatha* (or remnants of one) or precious metals seem to be reasonable choices to tentatively identify distinguished male burials. The *seax* is used here to identify men buried with weapons more generally and add nuance to the analyses.

Although individuals with evidence of (ritualised) interpersonal violence on their skeletal remains are found to be more likely to have been buried with a weapon than unharmed individuals (Meyer et al. 2014), weapons are occasionally found in graves of individuals that were disabled by diseases or wounds and unable to wield them (Härke 1990, p.34). Studying *Anglo-Saxon* cemeteries of the same time, Härke (1990) further argues that since weapons do not appear to have been more common grave-goods in more violent times and regions, they should be interpreted as markers of ethnic identity rather than as indicating that the deceased was a warrior. In light of the large share of the variation of heights between samples from modern populations that cannot be attributed to shared genetic differences (Robinson et al. 2015), it should be noted that differences in average height between members of ethnic communities do not need to be based in genetics but can also be consequences of different childcare practises and diets. In a setting with an ethnically segmented population, intermarriage is likely to have an effect similar to that of social mobility in the simple model introduced above.

Apart from the difficulties of interpreting grave-goods and using them to identify social strata, there are several other difficulties. If there was selection into burial by social class, the skeletal samples excavated from the cemeteries may not be representative of the early medieval population of the area. While this cannot be ruled out, it has not been suggested in the archaeological or historical literature that substantial parts of the population were not buried but instead left out to rot in a way that prevented their remains from being preserved for posterity. Similarly, scattering of ashes does not seem to have been common when cremation was still widely practised in late Antiquity. Furthermore, even if all dead were buried, not every cemetery was excavated in its entirety and some of the findings, seemingly unimportant, may not have been reported. In this sample, incomplete excavation is typically due to obstacles such as roads or buildings already covering the area or to inattentive construction work destroying some of the evidence before the remnants of a cemetery were noticed. In any case, the catalogue parts of the documentations cover everything that has been unearthed at the site, and in some cases even ditches or pits that turned out not to have been graves after all (e.g. Dohrn-Ihmig et al. 1999, p.181).

The construction of the graves themselves varied both over time and between regions and may have also been related to the importance of the people buried in them. Dry stone walls, for example, became more common in the *Merovingian* lands only in the 7th century (Koch 1996, p.733), and may not be as indicative of the importance of people buried in graves furnishing them as the energy expenses of construction would suggest (cf. Tainter 1975). Regardless of burial type, all of the bones had been directly in contact with the surrounding soil for centuries before they were excavated. Since soil chemistry and groundwater are of paramount importance once skeletonisation is completed as the result of a complex interplay of environmental factors and furnishing of the grave in human decomposition (Dent et al. 2004), it seems unlikely that the bones of people from any social strata are better preserved due to potential differences in grave construction.

A potential problem of endogeneity remains even if the sample is sufficiently representative and the attrition due to the factors discussed above is exogenous. The association of tall people with distinguished grave goods in general or weapons in particular may be due to them having been selected into the ranks of a warrior elite for their physical features, including stature. As a simple example, it can be imagined that from every new generation of a few individuals in each small settlement of the early medieval people, (one of) the physically most able was selected to serve as a warrior or as the leader in battle. The third panel of figure 2.8 shows two height distributions, illustrating such a selection process in which the elite status depends partly on people's height. The elite height distribution is made up from individuals drawn randomly from the taller half of populations of ten individuals drawn from a distribution with the parameters observed in the dataset.[4] Drawing the elite from a smaller number of tallest people from small populations increases the deviation from the normal distribution.[5] Notably, the variation of the height distribution of the elite is considerably smaller than the variation on the population level, and the difference between the averages of the two strata is sub-

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[4] The simulation uses random numbers drawn with stata's `rnormal(168.1, 5.34)`, using the parameters estimated from the data. To simulate the selection of an elite of comparable size to the share of people buried with a *spatha*, one out of every draw of ten random numbers is designated as elite. For the scenario shown in the third panel of figure 2.8, the draws, representing the male population of a small settlement, are first ordered by size, i.e. height. Then, one of the tallest five is randomly selected and assigned elite status. The graph depicts cumulative results of 1,000,000 trials.

[5] The stata do-file contains code for a graph with nine panels showing this for selections of the n/10 tallest people from populations of ten.

stantial. The issue is made more complicated conceptually by the fact that even if the selection was not due to height but related to social status, it would be taller people ending up in the elite stratum if there were indeed differences in biological living standards between the groups. Incidentally, this was the major concern of Stern (1983) who used numerical examples to make the case that differentials should be measured by class of origin instead of achieved social class, as health-selective social mobility would increase health differences between groups defined by their achieved class. However, it turned out that selectivity was not strict enough in twentieth-century Britain to overcome the equalising potential of social mobility (e.g. Bartley and Plewis 1997; Blane et al. 1999).

This paper argues that even if the data are unaffected by any of these potential problems, and there really were social strata enjoying different biological standards of living, average height differences may not reflect this due to the effects of social mobility on the composition of the groups.

2.4 Data

The main sources of burial data aggregated into my new dataset are publications documenting the analysis of material recovered in archaeological excavations of early medieval row grave cemeteries. While the number of graves excavated in southwestern Germany is huge, most of the retrieved material from the cemeteries has not yet been analysed scientifically. Apart from height estimates or measurements of individual long limb bones and anthropological age and sex, the database contains information about the burial goods and the graves in general. While cemeteries where no anthropometric data is available are not included, archaeological descriptions of the grave-goods are still missing for some of the skeletal series. In all, the database covers 40 cemeteries with more than 6,000 buried individuals of all ages buried with more than 20,000 artefacts.

Excluding individuals who died in their infancy or youth and had not reached their maximum height and those with insufficiently well preserved skeletal remains, leaves about 2,100 individual height estimates. Here, the female half of those are not considered, as well as about 170 men for whom no grave-goods data is available. At the end of this winnowing process, the sample consists of 926 men from the 26 cemeteries shown in figure 2.8, a map of the Central European region. Summary statistics and references to the documentation are provided in table 2.1. Of those, 96 were buried with a *spatha* (long sword) and 197 with a *seax* (short sword), though 52 of the *seaxes* were 'secondary weapons' of men buried with a *spatha*. More detailed information about the grave-goods is available for 800 of the men, 106 of whom had artefacts with at least traces of silver or gold deposited in their grave.[6]

Among the oldest dated burials in the sample are grave 52 from Horb-Altheim, dating to the 460s (Beilharz 2011, p.192), and grave 25 from Hemmingen, dated to the 460s at the earliest (H. F. Müller 1976, p.144), while burials 158 A and 160 A from Dirmstein (Leithäuser 2006, p.208) and grave 408 from Vogelstang (Mannheim) (Koch 2007, p.291), all dating to the last decades of the seventh century or the early eighth century are among the youngest ones. The archaeological dates are necessarily vague, because they are based on relative chronologies for typical grave-goods assemblages. Depending on the circumstances regarding the period of production and use of artefacts of a specific type, the buried individuals' life span, and the time when the artefact was acquired, the average date can be off by several decades (Steuer 1998).

2.5 Long-bone measurements and estimated stature

Where soil conditions were suitable, some of the bones have not decomposed but have been excavated in a condition that allowed measuring their length. Using the four major long bones and regression formulae to reconstruct stature considerably expands the sample from the size it has when only single bones could be compared. Siegmund (2010, p.103) concludes that the method of Pearson (1899) yields the most convincing results of the commonly used estimation formulae in a sample of large sample of prehistoric skeletal samples from central Europe. Whenever possible, estimated body height is calculated directly from long limb bone measurements using Pearson's method. In the few cases where the sources only report height estimates, those according to the Breitinger/Bach methods are converted using a regression formula from Siegmund (2010, p. 79) while others are converted by calculating the length of a hypothetical set of long bones and applying Pearson's method.

The regression formulae can only be applied in a meaningful way to long bone measurements of individuals who had attained their terminal stature prior to their demise, which restricts the sample to those who were anthropologically determined to be at least 20 years old – or *adult* at the time or their death. Since one of the skeletal indicators of this age is that the long bones have stopped growing, problems associated with late catch-up growth of previously deprived individuals are ruled out. Notably, shrinking with age, as it

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[6] Gold alone is part of only 8 grave-goods assemblages, while more than 80 contain silver as the only precious metal. *Spathae* are part of 45 of the 106 inventories with objects made with gold or silver.

has been observed in historical populations when heights of standing or sitting individuals were measured (e.g. Miall et al. 1967; Cline et al. 1989) is of no concern here, since the effect is caused by changes in the soft-tissue of the spinal column whereas the length of the long limb bones does not decrease again. Estimated heights should not be compared to heights of living populations of varying ages or including elderly people.

Due to differences in body proportions, the regression coefficients of the same bones are different in the estimation of male and female stature (Pearson 1899). Given that the skeletal data has to be divided by (anthropologically determined) sex for height estimation anyway, and the archaeological data shows strictly gendered grave-goods assemblages,[7] the exploration of the data is restricted here to male individuals and their grave-goods.[8]

2.6 Results – heights and grave-goods

The first panel of figure 2.8 shows kernel densities of the estimated height of those buried with and without a *spatha*. The impression that both distributions look rather normal cannot be dispelled by Shapiro-Wilk tests ($p = 0.25$ for those without and $p = 0.45$ for those with a *spatha*), while the Kolmogorov-Smirnov test of equality of distribution suggests that the group of men buried with spatha are taller ($p < 0.001$).[9] Comparing the first panel with the empirical densities of the actual observations from the Early Middle Ages and the second panel, depicting the simple mixing model of social mobility with simulated data to the third panel of figure 2.8, which also shows simulation results, reveals two main differences. The height distribution of individuals randomly selected from the taller halves of populations of ten people does not appear to be normal, having substantial negative excess kurtosis and being slightly skewed to the right, and the difference of the means seems to be very large given that heights of both the elite and the ordinary people are ultimately drawn from the same underlying distribution.

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[7] The literature on the German material does not know of any individual buried with armaments that has been reliably identified as female. A recent re-analysis of the prominent case of Niederstotzingen 3c with modern methods of molecular genetic analysis, for example, shows that the individual was indeed male and suggests reasons why he was mis-identified as female fifteen years before (Wahl et al. 2014, pp.378).

[8] Furthermore, the variety of items in womens' graves seems to be larger both across time and between regions and within the same cemeteries (Brather 2014, p.579), making classification even more difficult with the result that e.g. Christlein (1968, pp.216) tried to match better equipped women to men from the same time on the same cemetery to find markers of different levels of wealth.

[9] Tests were performed using Stata's `swilk` and `ksmirnov` programmes.

The differences between the distribution of the simulation of selection based on height and the empirical observation suggest that the two groups of men differentiated by the presence of a *spatha* in their grave do not have to be regarded as being selected (purely) based on height from a single population without noticeable differences in living standards. However, exercises of this sort cannot rule out more subtle influences of height on attained social status.

On average the 96 men buried with a *spatha*, the proxy for a higher social status, have an estimated height of 170.9 centimetres, 3.1 centimetres taller than the 830 men found without such a long sword. A number of regressions, detailed in table 2.2, add nuance. Adding dummy variables for the cemeteries into an OLS model with robust standard errors reduces the coefficient for the *spatha* slightly to 2.7 centimetres and reduces the fit compared to an OLS model with only the *spatha* dummy as an independent variable and standard errors clustered on the cemetery level. A number of specifications of multilevel models with random intercepts and coefficients on the cemetery level reveal differences between the three grave-goods indicators described above.

While the fixed effects coefficient for the presence of a *spatha* is highly significant and large, the presence of a shorter sword, the *seax* is not as strongly associated with taller individuals. Men buried with this most common type of weapon were on average 0.9 centimetres taller than the unarmed, a finding of marginal statistical significance. The association of precious metals with estimated height is much stronger, though the model's fit is not as good as that of the *spatha*-model. Multilevel-model (4) includes all three indicators, revealing that only the association between the presence of a long sword and height remains large and statistically significant on conventional levels in the presence of the other measures. These results are compatible with the interpretation discussed above that the presence of a *spatha* in a grave is an indicator of a social position of the deceased that was to some extent hereditary, i.e. correlated over generations or related to the status of the household they grew up in.

However, the difference found here is small compared to the height differences between people from the opposite ends of the social spectrum recorded in recent centuries that are reported above. The reasoning of the simple model above implies that for the same observed height difference, the level of social mobility is larger if the underlying height difference resulting from childhood differences in living standards is larger. Since the share of men buried without a *spatha* approaches 90 percent of the sampled population, their average height will not be increased substantially even if social mobility were substantial.

So finally, and on a rather speculative note, given the variation of the height estimates in light of the finite sample size and the uncertainty about the processes governing the deposition of swords in graves as well as the latent parameters, the observed height levels and differences can be used in equations (3) and (4) to back out an implicit correlation coefficient.

$$f = \frac{\mu_{h_E} - \mu_h}{b} \xrightarrow{p} \phi + p - \phi p \quad \Rightarrow \quad \phi = \frac{f - p}{1 - p} \tag{2.5}$$

Applying the models to the data, suitable values for the latent variable b have to be taken from the literature, as discussed in the second section. The 'true' height of the disadvantaged is another latent variable, but given the relatively small size of the elite, the average height of the 'mixed' population of ordinary people, including those that may have grown up in elite households, is not substantially larger and can be used as an approximation.

For the sample, this simple model would imply between 58 and 97 percent of the men buried with a *spatha* had grown up enjoying a higher standard of living, using the 90 percent confident bounds of the mean of their height. As per equation (5), this corresponds to a correlation coefficient ϕ of 0.58 to 0.95 between privileged childhood circumstances and elite status at the time of death.

For larger assumed values of latent height difference b, the implied intergenerational correlation is smaller. A difference of $b = 5$ centimetres instead of $b = 4$ centimetres, for example, would imply a correlation coefficient ϕ between 0.41 and 0.74, all else being equal. Assuming smaller values for the latent height difference would imply very low grades of social mobility in the sampled early medieval population.

Conversely, of course, the latent height difference b can be calculated for given correlation coefficients ϕ and probabilities of success p.

$$f = \frac{\mu_{h_E} - \mu_h}{b} \xrightarrow{p} \phi + p - \phi p \quad \Rightarrow \quad b = \frac{\mu_{h_E} - \mu_h}{\phi + p - \phi p} \tag{2.6}$$

Using, as above, the 90 percent confidence intervals of the mean of estimated heights of those buried with a *spatha* and the average height of those buried without one, the transmission coefficients ϕ reported by Borgerhoff Mulder et al. (2009), 0.36 for "small-scale agricultural" and 0.43 for "small-scale pastoral" societies imply huge underlying differences between 5.5 and 8.9 centimetres, and between 4.8 and 7.8 centimetres, respectively. An intergenerational correlation coefficient ϕ of 0.75, along the lines of Clark (2014), implies a difference b in the interval from 3 to 4.9 centimetres.

2.7 Conclusion

Differences of characteristics determined during childhood and youth, such as average adult stature, cannot be reliably measured using averages of groups defined by features which their members may have acquired only later in live. Each of the groups is likely to have members for whom the measured variable was influenced in different ways if the traits defining the groups are not also strongly correlated with those influencing factors. The size of this bias of average estimated height differences is assessed with a simple illustrative model of a two-strata society and a newly assembled dataset of 926 men excavated from 26 mostly southwestern German cemeteries dated to the 5th to 8th centuries CE.

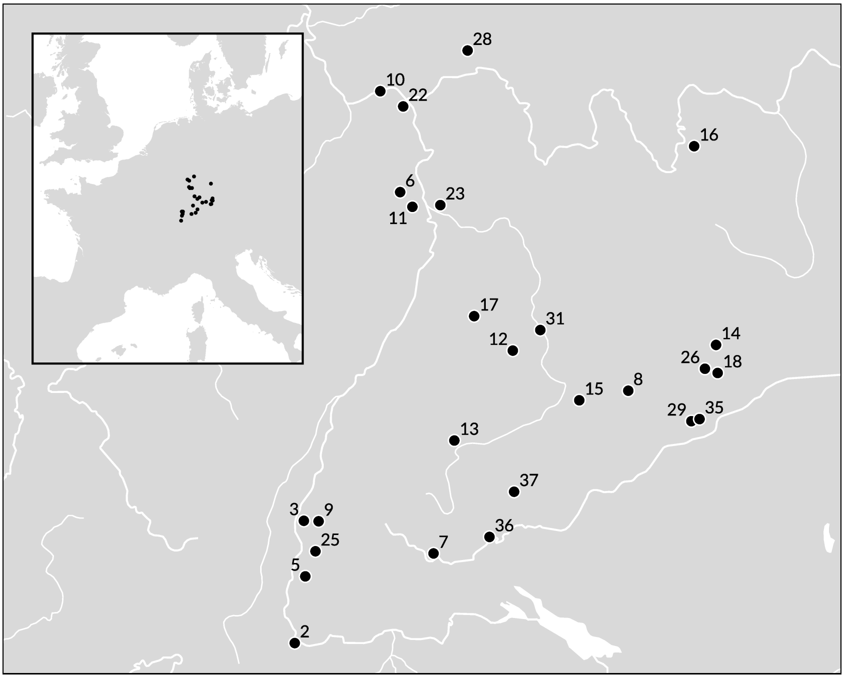
The biased average height advantage of men buried with a long sword over their contemporaries interred without one is almost 3 centimetres. This type of artefact, and other rare grave-goods, can be tentatively used to identify members of different strata of the early medieval society.

Using values from the literature on differences in biological living in stratified societies to approximate latent variables, the model can be used to back out rough estimates of intergenerational correlation and inequality of life chances from the difference of estimated heights measured between the two groups identified in the sample.

The reported intergenerational transmission coefficients for material wealth in small-scale agricultural or pastoral societies are within the 90 percent confidence interval or only slightly lower than the coefficients suggested by the simple model. Conversely, the degree of social mobility in the southwestern German early medieval societies, implied by the model and the parameters from the data and the literature, is consistent with observations from similar recent and historical societies.

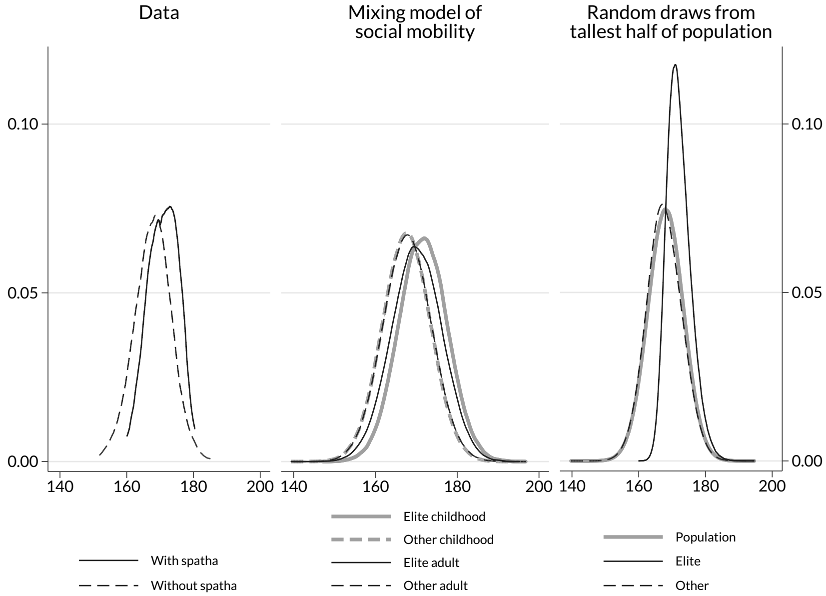
2.8 Figures and tables

FIGURE 2.1: Map of the sampled cemeteries



– The numbers correspond to the first column of table 2.1, which details the number of individuals from each of the cemeteries included in the database and summary statistics.

FIGURE 2.2: Comparison of height distributions



– Left panel: Height estimates of 926 adult males, Stata: `kdensity, kernel(epan2) bwidth(4)`.
– Central panel: Correlated Bernoulli, childhood difference: 4 cm, 10,000 repetitions, Stata: `ovbd, means(0.1037, 0.1037) corr(1, 0.58  0.58, 1)`
– Right panel: Samples of 10, 1,000,000 repetitions, Stata: `rnormal(168.1, 5.34)`.

Table 2.1: Summary statistics and sources

		Estimated height			buried with			
Cemetery		N	$\bar{x}$	s	*spatha*	*seax*	*Au/Ag*	Sources
1	Bernerring (Basel)	17	168.4	5.44	9	7	4	Martin (1976)
2	Bischoffingen	10	162.5	5.85	0	4	0	Hoff (1973), Bury (1974), Werner (1975), Fingerlin (1986)
3	Buggingen	17	170.0	6.94	1	2	1	Jansen (2003)
4	Dirmstein	21	164.9	6.19	0	3	3	Leithäuser (2006)
5	Donaueschingen	97	167.0	6.36	4	8	7	Röhrer-Ertl (1991), Buchte-Hohm (1996)
6	Donzdorf	9	169.1	4.19	2	4	4	Neuffer (1972)
7	Eichstetten a. K.	44	168.2	6.15	4	13	5	Sasse (2001)
8	Eltville am Rhein	80	168.3	4.10	1	12	5	Blaich (2006)
9	Eppstein	60	169.6	4.69	11	21	11	Engels (2012)
10	Hechtsheim (Mainz)	46	166.2	4.85	4	13	7	Queisser (1988), Koch (2011)
11	Hemmingen	10	170.7	2.81	1	0	2	Müller (1976), Obertová (2008)
12	Horb-Altheim	21	169.4	2.74	6	5	8	Obertová (2008), Beilharz (2011)
13	Kirchheim am Ries	67	167.9	5.54	10	19	6	Neuffer-Müller (1983)

Continued on next page

Table 2.1: Summary statistics and sources

		Estimated height			buried with			
Cemetery		N	$\bar{x}$	s	*spatha*	*seax*	*Au/Ag*	Sources
14	Kirchheim u. Teck	13	169.0	7.16	3	6	2	Becker (1985), Däcke (1998)
15	Kleinlangheim	28	168.1	4.99	2	5	2	Schultz (1978), Pescheck (1996)
16	Knittlingen	33	166.7	5.22	0	0	0	Damminger (2002)
17	Kösingen	14	168.0	5.95	3	4	2	Knaut (1933)
18	Munzingen	26	168.5	3.52	2	5	3	Burger-Heinrich (n.d.), Groove (2001)
19	Neresheim	22	171.5	4.68	3	2	2	Knaut (1993)
20	Nieder-Erlenbach	30	167.9	4.81	0	8	2	Dohrn-Ihmig (1999)
21	Niederstotzingen	9	170.0	5.61	9	6	6	Paulsen (1967), Wahl et al. (2014)
22	Pleidelsheim	44	168.8	5.75	7	16	7	Koch (2001)
23	Sontheim a.d. Brenz	26	171.2	4.88	5	12	9	Neuffer-Müller (1966)
24	Stetten a.d. Donau	44	169.7	4.86	4	8	7	Weis (1999)
25	Truchtelfingen	12	168.9	5.75	4	8	1	Schmitt (2007)
26	Vogelstang	126	167.3	4.77	1	6	–	Rösing (1975), Koch (2007)
	Total	926	168.1	5.34	96	197	106	

- N is the total number of (male or probably male) adult individuals, excavated from a cemetery, with sufficient long-bone measurements, $\bar{x}$ is the arithmetical average of their estimated (Pearson 1899) heights, and s the standard deviation.
- The numbers in the "buried with" columns indicate how many of the individuals had a double-edged long sword (*spatha*), short sword (*seax*), or any item made from gold or silver (*Au/Ag*) buried with them. These categories are not mutually exclusive.

TABLE 2.2: Regression results

Estimated height	OLS		Multilevel mixed effects			
	clustered	robust	1	2	3	4
Spatha	3.08	2.71	2.92			2.24
	(5.59)	(4.99)	(4.74)			(3.46)
Seax				0.88		0.33
				(1.87)		(0.66)
Precious metals					1.67	0.84
					(2.42)	(1.20)
Cemetery dummies	No	Yes	RE	RE	RE	RE
Intercept	167.81	167.30	167.94	168.11	168.11	167.83
	(633.19)	(392.03)	(484.10)	(557.38)	(516.32)	(506.61)
N	926	926	926	926	800	800
F/Wald χ^2	31.20	4.00	22.44	3.50	5.84	20.15

- The OLS models are estimated using Stata's `regress […], vce(robust)` and `regress […], vce(cluster […])`, respectively; t-statistics in brackets.
- The multilevel mixed effects models are estimated using Stata's `mixed` command with random intercepts and coefficients (not reported) by cemetery; t-statistics in brackets.
- The variable indicating grave-goods made of or with gold or silver is not available for the *Vogelstang (Mannheim)* cemetery, reducing the number of observations in models 3 and 4.
- Long swords (*spatha*) were found in 96, short swords (*seax*) in 197, and precious metals (gold/silver) in 106 of the burials.

Living Standards and Inequality in the Early Middle Ages

3

Abstract

How does the transformation from tribal structures to more centralised governance influence inequality of living conditions in a society? Analyses of the distribution of estimated body heights of about 2,200 individuals excavated from 40 cemeteries in Central Europe provide some evidence of increasing inequality of estimated stature among men during the 5th–8th centuries. For women, inequality shows an increasing tendency as well, while there is no apparent trend in average height levels of both sexes. This is consistent with local elites being able to capture larger shares of agricultural production when state-like institutions of a Frankish dukedom replaced the structures of Alamanni tribes during the Merovingian era. Declining rates of grave-goods deposition observed in the dataset are also consistent with less intensive status competition in an increasingly rigidly ranked society.

This chapter has been revised after receiving comments from two anonymous referees.

English-language quotations from German texts are my own translations, except where the terms are well-established in the literature.

3.1 Introduction

As new evidence on increasing economic inequality in various European regions emerges (cf. Lindert and J. G. Williamson 2016), it appears that income and wealth inequality mostly increased right from the beginning of the analysed time series in the late medieval or early modern periods. For earlier times and the very long run, however, evidence is still more scarce. Where written sources such as the tax registers or censuses on which the recent studies are based are not available, other measures of (economic) well-being can be useful. Van Zanden, Baten, Foldvari, et al. (2014) and van Zanden, Baten, d'Ercole, et al. (2014), for example, present trends for levels and distributions of various indicators of living standards, including average body heights which are closely related to consumption, going back to the 1820s. Blum (2013, 2014) assesses height inequality and the effects of inequality on the level of living standards using panels of anthropometric data from up to 124 countries beginning as early as the 1840s.

This paper estimates inequality of biological living standards in Central Europe during the Merovingian era (5–8th centuries) based on mortuary evidence from 40 excavated cemeteries (see map, figure 3.1). As historical sources suggest that governance became more centralised and social stratification more rigid during that time, the sample is split in two, separating those living before and after about 600 CE. The separation of this time period during which people in the study area buried their dead adorned with grave-goods into two broad phases also finds support in archaeological analyses of the finds. Inequality of estimated heights is slightly higher in the later period, when the elite probably had larger extractive capabilities, as the framework of Boix and Rosenbluth (2014) would suggest. They discuss height inequality and its connections with the political and cultural institutions of societies and their production possibilities, referring to a number of case studies ranging from Ancient Egypt over native American societies to a diachronic study of Japanese populations. They argue, in line with Milanovic et al. (2011), that the ambition and ability of elites to capture some of the output produced by the people in their societies depend on cultural and political institutions, as well as on productivity and economic arrangements. Similarly, the "formation of a stronger and more centralized fiscal-military state" is put forward as a likely cause of the long-term rise of economic inequality in the Low Countries and in Italian states that has been traced back to the early modern sources in archival sources (Alfani and Ryckbosch 2016, p. 152).

Inequality of biological living standards is often assessed based on status-gradients of average heights, i.e. average height advantages of people belonging to elite social groups over other groups or the rest of the population. Although patterns of social stratification known from other sources (such as ethnographic descriptions for recent times) can often be recognised in the archaeological evidence (e.g. O'Shea 1981), absence of corroborating textual sources may leave the archaeological record more open to interpretation. Even if the social hierarchy of a society can be identified from the mortuary evidence, height differences between groups of people are likely a biased measure of inequality. If the social or economic status reflected in a persons burial was attained during life and differed from the status they had during childhood and youth, indicators of adult status and skeletal markers of childhood well-being may be at odds (cf. Meinzer 2017). While this 'diluting' effect of social mobility, which has long been known from other contexts, precludes accurate assessment of inequality of living conditions affecting growth except for extremely rigidly stratified societies, it may still be helpful to think about social mobility (Meinzer 2017). This paper focuses on the distribution of estimated heights as an alternative approach to measuring inequality of well-being that is not affected by difficulties of identification of status groups or social mobility. Baten (2000) expected that populations where some people are struggling to provide for their children while others can shield their children's health from insults have more pronounced inequality of adult stature and proposed the coefficient of variation of heights as an indicator of inequality of biological living standards.

In contrast to conscription statistics or other sources that detail actual measurements of stature, the mortuary evidence is typically restricted to measurements of long-bone length. Even the best-preserved skeletons are often incomplete after centuries of exposition to the soil or were deposited in a way that does not allow measuring the length of the dead body. Evaluations of the numerous regression formulae that have been proposed in the literature to estimate heights from long-bone lengths based on a variety of samples naturally focus more on mean estimated heights than on differences of standard deviations (e.g. Siegmund 2010, 2012). This paper assesses the implications of a number of popular height estimation formulae for the coefficient of variation of estimated heights to provide necessary background information for the analyses of inequality of estimated heights in the early medieval dataset.

Apart from the human remains, grave-goods deposited alongside the deceased, presumably as part of a burial rite, have been excavated from many graves on the early medieval cemeteries. They have the potential to provide another perspective on inequality, although they are more difficult to interpret. Individual height is – within the bounds of heritability – largely an outcome of consumption during childhood, i.e. of nutrition and attrition due to illness and strain (Tanner 1990; Bogin 2001). Inequality of adult heights, therefore, corresponds to inequality of the previous generation which allotted the resources to their children. Decisions over details of the burials and eventual grave-goods could not be influenced directly by the people whose remains are excavated by archaeologists. To put it in a nutshell, the consumption of an individual's parents and family influenced their height, while the grave-goods were deposited by the individual's children.

The number of artefact types deposited in graves can be used to construct a Gini coefficient of grave-goods inequality, assuming that more diverse deposits are indicative of higher wealth or status of the grieving community and in extension of their deceased member. Counting only types of artefacts instead of individual things allows the integration of many individual finds, that are described in catalogues of the material, into broader categories such as riding equipment, bronze vessels, and brooches. In the later part of the study period, people received fewer grave-goods in general. Inequality of the number of artefact types found in graves rose as the share of people buried without any grave-goods increased. This cannot, however, be interpreted directly as an increase in material inequality, since intricate details of grave-goods and more general patterns of their deposition are at the core of archaeological dating of the burials which is used to define analysed time periods in the first place.

Additionally, the size of the burial-pits themselves can be informative, if the burying community expended more energy on the inhumation of people who had been more important to them. Operationalising the concept and constructing a suitable variable from the published documentations of excavations proves to be challenging due to heterogeneous reporting practices and uncertainty about potential changes of the surface of the cemetery between burial and excavation. However, inequality of burial-pit base area remained constant throughout the study period.

Since political and social change were likely not uniform across the study area and average heights have been found to be influenced by dietary patterns arising from agricultural specialisation and agro-environmental endowments, the spatial distribution of the sites should not be overlooked. As the coefficient of variation of estimated heights is a population-level variable, regional differences are assessed on the level of 'natural regions' defined for environmental and administrative purposes, since continuous covariates, such as indicators of suitability for certain crops, would have to be transformed into categorical variables for the analyses as well. The overall pattern of higher inequality in the 6th and 7th centuries typical for the regional developments, though the estimated intervals of the coefficient of variation grow substantially as the size of the sub-samples decreases in the more detailed analyses.

The next section puts this paper into the context of long-term anthropometric studies of biological living standards and inequality thereof and discusses the approximation of confidence intervals around coefficients of variation to augment point estimates in light of the study's usage of estimated heights. It then goes on to outline the historical context of the establishment of the Frankish empire under the Merovingians and how that might have influenced inequality in the region and discussing the archaeological basis for splitting the study period into two phases at about 600 CE before finally providing background information on the interpretation of grave-goods. The third section describes the newly compiled dataset and the preparation of the data, focusing on the comparison of different regression formulae used in the literature to estimate stature from long-bone measurements and their implications for the estimation of height inequality. Then, the results of analyses of inequality measures derived from the dimensions of burial-pits as proxies for energy expenditure and the number of distinct types of artefacts deposited in graves are presented and discussed, finding that no clear trend for the former and increasing inequality for the latter. The main analyses find that inequality of estimated heights was lower in an earlier period prior to about 600 CE than in a later phase thereafter. This result tends to hold for a further split into three time periods and a division of the sample based on the location of cemeteries in different 'natural landscapes.'

3.2 Background and brief literature review

Most measures of inequality are based on individual-level income or wealth data which have not been documented in sufficient detail for most of human history. The few relevant written sources surviving from the Early Middle Ages are often concerned with diets and consumption habits of rulers and people in their attendance (e.g. Anthimus 1996) and remain mostly silent on the topics of living standards enjoyed by people of different fortunes. Shifting attention from income or wealth inequality to consumption and inequality of living standards and well-being opens up a number of opportunities. Individual-level data on consumption of goods and services can be literally unearthed with relative ease, as long bones excavated from cemeteries allow estimation of individual heights, which can be aggregated to assess the level and inequality of the biological standard of living of larger populations. Following the assessments of various indicators of health and living standards in the Americas collected in Steckel, Sciulli, et al. (2002), Steckel (2004) and

Koepke and Baten (2005, 2008) assessed trends of biological living standards in Europe over many centuries using measurements of excavated human remains. More recently, Koepke (2014) extended her studies even further into the past, reaching as far back as the 8th century BCE. Boix and Rosenbluth (2014) actually use the coefficient of variation of estimated heights based on mortuary evidence to analyse long-term developments of inequality in the Americas, Europe, and Japan.

Mortuary evidence is often used to assess inequality through differences in the endowment of burials with grave-goods. Based on the presence or absence of various types of artefacts, or other characteristics of the graves, individuals are sorted into different groups often interpreted as socio-economic strata. As between-group differences are only biased reflections of the underlying unequal circumstances which shaped the proxy measurements if group membership can change over the life cycle of the individuals, these would have to be adjusted for the level of social mobility (Meinzer 2017, cf.). If, for example, some of the adult people buried in a way that is associated with higher socio-economic status did not grow up in high-status households, their stature will still reflect the dire circumstances of their childhood. Conversely, some individuals whose privileged childhood is reflected in their taller stature may not have been able to retain their status and would be counted among the ranks of the people not distinguished by a lavish burial. Drawing connections between average heights and consumption inequality on the household level is still more complicated since family size may have been related to wealth or status, as reported for more recent times (e.g. Clark 2007). If the disadvantaged had not only less-well nourished children who ended up as shorter adults, but also fewer of them, the average difference would underestimate the degree of inequality.

Baten (2000) proposed the coefficient of variation, the ratio of the standard deviation and the mean of a populations' heights, as an indicator for inequality in a study of 19It-century Bavarian military conscripts. Using modern data on various populations from Africa, Moradi and Baten (2005) demonstrated that measures of inequality based on coefficients of variation of height correlate with other measures such as Gini-coefficients of the income distribution. More recently, this approach has been used to describe inequality of living standards and augment long-term observations of income inequality for time periods and regions where conventional data is not available (van Zanden, Baten, Foldvari, et al. 2014; van Zanden, Baten, d'Ercole, et al. 2014), and also applied to skeletal data (Boix and Rosenbluth 2014).

Deaton (2008), however, cautions that the functional form of the relationship between income and heights matters for the relationship between income inequality and height inequality. Conceptually, height inequality could be expected to reach higher levels in societies where many people are left with only the means of most basic subsistence, i.e. less than necessary to adequately feed their children and prevent growth-stifling undernutrition and starvation. In the framework of Milanovic et al. (2011), this would be societies with a high "inequality extraction ratio", where the elite capture almost everything produced by the people. Of course, the advantage of the elite is not only limited by their extractive capacity, but also by the output produced by the people they exploit. As long as production is barely above subsistence level, even realising the highest "inequality extraction ratio" would not ensure that members of the elite were substantially better off. As a population-level indicator, height inequality as such cannot shed light on differentiation of the society into socio-economic strata or the relative well-being of their members.

3.2.1 Coefficients of variation of height

The empirical coefficient of variation $\widehat{CV}$, calculated simply as the ratio of the empirical standard deviation and the mean is biased downward, although it converges even faster with a growing sample size than the standard deviation itself. Sokal and Braumann (1980) nevertheless recommend using a correction factor such that

$$CV^* = \left(1 + \frac{1}{4n}\right)\widehat{CV}.$$

In light of the limited size of the sample analysed in this paper, and the variation introduced by the different height estimation formulae, it seem reasonable to augment the point estimates of the coefficient of variation with confidence intervals to assess the magnitude of any potential differences between sub-samples of interest.[1] Gulhar et al. (2012) compare several interval estimators for the population coefficient of variation, demonstrating the satisfactory performance of their proposed user-friendly estimator based on a χ^2-distribution and the uncorrected empirical coefficient of variation,

$$\frac{\sqrt{n-1}\widehat{CV}}{\sqrt{\chi^2_{\nu,1-\alpha/2}}} < \widehat{CV} < \frac{\sqrt{n-1}\widehat{CV}}{\sqrt{\chi^2_{\nu,\alpha/2}}},$$

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[1] Most of the literature using coefficients of variation of height as indicators of inequality reports them multiplied with a factor of 100 to only report significant figures. However, as the analytical assessment of differences between the inflated values would be misleading, as would be reporting actual test statistics alongside inflated values, I do not inflate the coefficients of variation.

where $\chi^2_{\nu,p}$ is the p^{th}-percentile of the distribution with $\nu = n - 1$ degrees of freedom, and α is the complement of the confidence level.

For a statistical test of any differences between the coefficients of variation of height of various groups of individuals from the dataset, the distribution of the estimator has to be taken into account. As the exact standard error of the coefficient of variation is a rather complicated expression, Sokal and Braumann (1980) recommend an approximation,

$$s_{CV^*} = \sqrt{\frac{CV^{*2}}{2n}\left(\frac{n}{n-1} + 2CV^{*2}\right)\left(1 + \frac{1}{4n}\right)^2}.$$

Using this, the standard error of the difference between the *CVs* of two population samples,

$$s_{CV_1^*-CV_2^*} = \sqrt{s^2_{CV_1^*} + s^2_{CV_2^*}}$$

is all that is needed to calculate the usual t-test,

$$t = \frac{CV_1^* - CV_2^*}{s_{CV_1^*-CV_2^*}}.$$

Empirical significance levels should be computed using pooled degrees of freedom.

Alternatively, the magnitude of any differences of the coefficients of variation between two time periods can be assessed with Monte Carlo simulations. Here, two samples of random numbers are drawn from a normal distribution with the parameters of the height distribution observed in data of the earlier phase. Both samples have the same size as the corresponding samples in the actual dataset. Then, the difference between the coefficients of variation of the two simulated samples random numbers is compared with the difference observed in the early medieval dataset. To obtain numerically calculated *p*-values, the simulation is repeated many times, tallying the share of repetitions of the trials where the difference was more extreme than in the data, i.e. with the same sign but a larger absolute value.

3.2.2 Societal change in the Merovingian era and the meaning of grave-goods

The study period was a time of profound social and political change in Central Europe. This section argues that living conditions in the region were likely becoming less equitable beginning in the 6th century. Then, the next subsection reports that, at the most abstract level, archaeological chronologies based on the excavated material tend to distinguish an earlier from a later phase with a breaking point around the year 600 CE. This could plausibly be connected to the political turmoil, since many of the adults who died at the turn of the centuries grew up and reached their terminal height many years or even decades earlier. Another sub-section proceeds to outline interpretations of the grave-goods of the study period and discusses strategies to operationalise grave-goods data for the analysis of inequality.

During the late imperial period, a number of the tribes living within *Germania Superior* or close to its eastern border were called Alamanni,[2] a name first mentioned in the early 3rd century. They, as well as other tribes, were frequently engaged in violent conflict both among themselves and with the empire and its *foederati*. A coalition of Alamanni tribes was defeated by the Franks under king Clovis at the end of the 5th century. After some decades of turmoil involving the Ostrogoths who controlled the areas to the east, the Alamannia was integrated into the Frankish dominions and organised as a dukedom. What remained of the ambitions of the local elite were curtailed in 746 CE, when a number of local leaders was arrested and executed at a meeting, and the region placed under more direct Frankish rule.

These substantial political changes have likely influenced many aspects of the lives of local people, such as the frequency of engagement in violent conflict with other communities in neighbouring regions, the amount of time they could invest in agricultural production, and integration of local markets into long-distance trade networks. Details, however, are scarce in the historical record but as e.g. Steuer (2004, p.217) remarks, the turmoil of this period of “fundamental transition from chiefdoms into a state” is likely reflected in the changing burial customs of the time. Noting the remark that “military cooperation is th[e] primary kind of cooperation which prepares the way for other kinds” (Spencer 1900, p.280), Blankertz (2016, pp.91) describes the kind of process that may have happened here, where military elites in segmented small-scale societies secured their positions as feudal lords, as “internal conquest.”

People in Central Europe had begun to favour inhumation over cremation in the 4th century, at a time when the control of the Roman Empire over the region weakened, and other groups sought to take control. Lavish burials with weapons and other objects reminiscent of the regalia of leaders of the Roman military and civil administration are interpreted in the archaeological literature as attempts of local elites to establish and strengthen claims to authority in their communities (cf. Halsall 2010). In the case of the “conquest society” of the Anglo-Saxons in the 5th and 6th centuries, Härke (2011)

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[2] For a primer on the history of the Alamanni, see Geuenich (2005).

interprets the weapon burial rite as a means to display and maintain cultural distinctiveness as well as dominance. The custom was taken up throughout the region, and by the middle of the 5th century, the first so called *Reihengräberfelder* where individuals were buried adorned with grave-goods were established in the study area. While the earliest cemeteries were only used to bury a few dozen people from two or three generations, later ones are used for two centuries and longer and amass up to several hundred burials (cf. Theune 2004). Later in the 7th century, people deposited fewer grave-goods, especially weapons, with their deceased and buried a growing share of people without any objects. Some people, however, received more elaborate graves with ring ditches around them and probably mounds of earth on top of them while others where seemingly buried around those central graves (Steuer 2004). In the 8th century, grave yards in the vicinity of church buildings came into fashion and burials on the *Reihengräberfelder* came to an end around the same time that people generally stopped depositing artefacts (Fingerlin 2004). This development can be seen as another instance of the general pattern that deposition of grave-goods typically decreases as institutions become more stable (Childe 1945).

3.2.2.1 Two periods

The time period during which the people in the sample were buried on the cemeteries, i.e. the 5–8th centuries, are tentatively divided into an earlier and a later phase with the dividing line somewhere toward the end of the 6th and the beginning of the 7th century. Around that time, the composition of grave-goods assemblages and the style of particular objects changed in many European regions, including the Alamannia. Dating schemes that divide the material into broader phases, such as Ament (1977), typically draw the line between an earlier and a later phase at around 600 CE. While the anthropometric data would have been generated decades before the dated burials, when the people who are measured after their death as adults grew up and reached their terminal height, the phases can be generally understood as before and after 600 CE.

Regarding archaeological dating, Steuer (1998) stresses that the goods deposited in graves had to be produced at first, were acquired later on either by the people in whose graves they were later deposited or by others and were finally put into the earth. Accepting the premise that the types of details used for typological dating are indeed roughly normally distributed over time, starting off as rare novelties, becoming popular and more common before tapering out in the end, does not indicate whether the derived dates refer to the production period or the time when something was deposited in a grave. All of this implies, that artefacts are likely to have been made earlier than suggested by commonly used typological phases (Steuer 1998, p. 140). Although it is by no means clear that the changes in style of the various artefacts used for archaeological dating have a causal relation to political and societal changes in the first half of the 6th century, those challenges show that the separation of the sample to asses differences between people born before and after the political and societal turmoil of the first half of the 6th century should be done with a later cut-off date.

Recently, Döhrer (2011) analysed grave-goods from 23 cemeteries, many of which are also studied in this work, dividing the inventories using four broad relative-chronological categories, of which the earliest and latest were too sparsely populated for serious statistical analysis. The latest burials of the second group and the earliest of the third are dated to 570–600 CE. Her study relied on a number of previously established relative chronologies developed by other archaeologists which are mostly not specific about their ties to absolute dates.

The vagueness of the distinction between those phases in archaeological dating and the social and political change in early medieval Alamannia imply that every attempt to simply split the sample in two parts may be problematic and has the potential to water down differences in living standards and inequality between an earlier and a later phase.

As a robustness check, individuals from graves dated within a few decades of the year 600 are separated for some analyses to improve the distinctiveness of the period of consolidating Frankish rule from the time before. This corresponds to the recent effort of Friedrich (2016), who puts forward a three-phase chronological model for Merovingian era southern Germany, with a transition period between the 520/30s and the 610/20s, i.e. from the second quarter of the 6th century to the time around 600 CE and a decade or so into the 7th century.

3.2.2.2 The meaning of grave-goods

At first sight, the diversity of the excavated grave-goods regarding not only the types of artefacts but also the materials they were made of and details of manufacture seems to make them ideal proxies of material wealth or socio-economic status. However, since "[b]urials are not 'mirrors of life'" and can only "provid[e] distorted reflections of the past" because the grave-goods were deposited intentionally and are, therefore, not simply mechanically linked to characteristics of the deceased but connected through "thinking, religion and social ideology" of the bereaved, straight-forward approaches are potentially problematic (Härke 1997). This sub-section reviews some of the interpretations of the early medieval grave-goods.

Textual historical sources, unfortunately, tend not to dwell on the issue of burial ceremonies of ordinary people and even the local elites in the countryside. Interpretations of the mortuary evidence can, therefore, be rooted only in the evidence itself and in comparisons with ethnographic data describing burial practises of other people at different times and in different places. Härke (2014) enumerates a number of possible explanations for the practise of inhumation with grave-goods, concluding that there is probably no simple underlying scheme to be discovered since burial ceremonies almost certainly had multiple layers of meaning for everyone involved.

Until well into the 20th century, there was a straightforward and commonly accepted interpretation of grave-goods assemblages from Merovingian era burials in the archaeological literature. Assuming legal texts from the 8th century, such as the *leges* and *pactus Alamannorum* which stipulate *wergeld* for killing and maiming others graduated by their legal standing (with free people being literally worth more than unfree people or those from middling categories), to reflect customs of Germanic tribes from earlier periods, weapons were perceived as tokens of legal status (e.g. Veeck 1926; Redlich 1948).

Differences in the relative abundance of certain weapons between cemeteries are harder to square with this interpretive framework if no substantial differences in the social structure of the local communities are to be assumed. The next approach becoming popular suggested that the 'quality' of grave-goods reflected wealth rather than legal or social status based on the observation that silver plated belt buckles, for example, and other seemingly precious artefact were commonly associated with larger weapons and overall higher numbers of different types of artefacts (Christlein 1968). Wealth, it was argued, was not necessarily related to legal status, as people in subordinate positions could have also been successful farmers, artisans or merchants, while not every free man should be expected to be able to afford accessories made of precious metals (Christlein 1973).

This framework of *Qualitätsgruppen* was later extended in order to better account for differences between cemeteries without resorting to postulate cultural differences on small regional scales. The proximity to the royal court supposedly mediated the overall level of grave-goods deposition. The closer someone was to the king, both physically and socially, the more exquisite grave-goods should be expected (Steuer 1982). A wealthy person of high social status living in the periphery of the realm would basically be expected to receive a burial similar to that deemed fit for someone of lower status and wealth but closer to the king.

This seems at odds with observations that lavishly furnished burials are surprisingly scarce in the vicinity of centres of power such as the Merovingian royal city of Metz (cf. Halsall 2010). Staging impressive ceremonial burials involving regalia of leadership and power, it has been argued, may have been a sensible way for elite families to cope with the loss of an important family member posing a threat to their claim to power and pre-eminence. Elaborate and expensive burials, especially those involving armaments, then, could be interpreted as a symptom of political turmoil and contestable social stratification.

Age-at-death and the stage in the life cycle imagined for the deceased by the bereaved, has long been recognised as a major influence on the burial rite, especially the selection of grave-goods (Sasse 2001). However, the tendencies discussed in archaeological analyses of the excavated material are mostly of a very general nature. Brather (2009, pp.368) concludes that, for example, the age groups in which women were most likely to be interred with brooches are *juvenile*, *adult*, and *mature*, as well as older women or adult women in general, depending on the cemetery. In light of the sample sizes, which are rarely larger than 40 or so for any sex and age-group combination, heterogeneous reported findings are not surprising.

3.3 Data and data preparation

The dataset assembles information about more than 7,600 individuals buried on 40 cemeteries in the southwestern German state of Baden-Württemberg and adjacent regions, as shown on the map (figure 3.1). It is an extension of the dataset presented and used by Meinzer (2017) to argue that social mobility may complicate the interpretation of height differences associated with certain grave-goods. Since the analyses in this paper are concerned with adult long-bone measurements, individuals who had no sufficiently well preserved bones, or were not old enough when they died have to be excluded. Deducting these leaves almost 2,200 individuals who were at least anthropologically adult, i.e. whose height had peaked before the time of their death and of whom at least one long bone was well-enough preserved to have its length measured and entered into the dataset. Summary statistics of the cemeteries are reported in table 3.1, including references to the publications or unpublished reports from which the data are compiled.

Although, unfortunately, the bodies of many individuals who were buried on the sampled cemeteries decomposed so far that not even the strongest of their bones remained, this should not seriously bias the results. The taphonomic processes involved in skeletonisation and finally the dissolution of the skeleton are unlikely to be influenced by the socio-economic status of the deceased or their families, or even by the stature of the deceased. Once the soft tissue has decomposed and the skeleton has direct contact with the soil, preservation depends mainly on soil chemistry and groundwater (cf. Dent et al. 2004). Where these environmental factors have allowed bones to be preserved at all over many centuries, the size of bones of the same kind is unlikely to be a limiting factor for preservation. From humidity, acidity, and other chemical properties of the soil to land usage of the cemetery area during the intervening centuries, a host of variables would have had to coincidentally strike the right balance in order for e.g. a smaller femur to perish where a slightly larger one would have persisted. At least in the cases included in the database, the archaeologists' decision to include burials and human remains in the documentation of a cemetery was not influenced by characteristics of the burials. Every single burial that was found in the excavated areas was documented, typically even those that turned out not to have been graves after all. However, previously erected buildings limited the area of an excavation in some cases, so that a few cemeteries were only partially examined. In other cases, a number of burials had already been destroyed before construction workers or bystanders noticed them.

Apart from anthropometric data, i.e. long-bone measurements or height estimates derived from them, the database contains anthropologically determined age and sex of the individuals, as well as archaeological data on the burial itself, such as the dimensions of the pit and the general condition of human remains and other finds, and some details of eventual grave-goods. Not every archaeologically excavated and documented cemetery has also had the skeletal material analysed anthropologically. While data on some skeletal series without documentation of the archaeological finds has been collected into the database – this study is, after all, concerned with anthropometric measures of living standard and inequality – cemeteries without any individual-level anthropometric data are not included.

The grave-goods data is reported rather heterogeneously in the archaeological literature surveyed to compile the dataset. Apart from very general classifications, there does not seem to be an established typology of the material that is used by most archaeologists to describe the grave-goods. Therefore, different names often point to objects are likely instances of basically the same type of artefact. This does not pose major difficulties for some of the larger objects, such as the double-edged long sword which is named *spatha* in most catalogues but simply 'sword' in a few exceptional cases, or the shorter single-edged blade typically named *seax* which is often classified in more detail as according to its size and shape. For smaller objects, this is more of a problem, especially in advanced stages of corrosion. 'Awl,' 'iron pen,' or even 'piece of iron' can all be descriptions of the same thing, seemingly dependent on the confidence of the archaeologist.

It has to be kept in mind that the objects have been interred for several centuries, generally under conditions not suitable for the preservation of organic materials. Therefore, most excavated grave-goods are the more or less corroded metal parts of the artefacts that have originally been deposited.

The database contains information about more than 23,000 objects retrieved from almost 4,500 burials. As raw information, the objects are described with the same name used to describe them in the respective catalogue, as well as the main materials they are composed of, and their number, for more than one piece was often deposited of some kinds of brooches or dress plates. For artefacts that were initially only one part of a larger object, such as multiple clasps of shoes or leg-bindings, the name of this functional unit of individually reported objects is recorded as well. From this database of individual items and their properties, a number of indicator variables are prepared to be used as attributes of the individuals who had been buried with the artefacts. Artefacts and functional units, referred to by more than 1,000 different names in the archaeological documentations, are consolidated into 34 categories.

Most dates affixed to the early medieval burials are determined using typologies of the grave-goods. As classifying and ordering the material is one of the core competencies of archaeologists and many of the documentations of cemeteries evaluated to compile the database are published doctoral theses, it is no surprise that no common dating scheme has been used. Knaut (1993, p.189), for example, shows a synopsis of a number of ways in which the material has been sorted into chronological phases. Although each of these systems of phases takes into account local particularities of the abundance and distribution of grave-goods, the material is similar enough throughout the region and during the time in question that the dating schemes are in broad agreement.

Given that not everyone was buried with grave-goods and that some of the graves of those who were, have been looted not too long after burial, the number of dated individuals is again smaller than the number of people excavated from cemeteries for which archaeological information is available. Grave-robbery may have been systematically related to the content of the graves if looters were able to identify the burials with more abundant and valuable grave-goods before they started digging and were searching for treasure. However, the motives of early medieval grave-robbery and the extent to which it was targeting materially promising burials is a subject of active debate in the archaeological literature (Klevnäs 2015, e.g.). Reporting of evidence for looting or disturbance of the burials in general varies between the authors of the documentations. Few mention explicitly that burials have not been disturbed when they do not find evidence to the contrary but most only remark on the topic to report that human remains and grave-goods were found in certain states of disarray or that the excavators saw discolourations marking the filled-in hole dug by the grave-robbers in the soil.

3.3.1 Estimating height inequality

Unfortunately, the actual stature of the people buried on the *Reihengräberfelder* cannot be ascertained, since their bodies were laid down in various positions even before decomposition destroyed the anatomical composition. Directly measuring skeletal length as the remains are unearthed is, therefore, unlikely to yield results comparable across individuals, especially where only the most robust bones have not decayed completely.

A solution to this conundrum has been found in the regularities of adult body proportions. The dimensions of individual bones correlate strongly with each other and with height. A number of regression formulae have been proposed in the literature, based on different skeletal samples, which yield substantially different results (cf. Siegmund 2010, 2012), as table 3.2 shows. Estimating of the coefficient of variation of heights, requires not only the mean but also the standard deviation of estimated heights, which has not received similar attention in comparisons of approaches to height estimation. This section demonstrates the magnitude of the differences implied by methods commonly used in the literature, finding that the estimation formulae proposed by *Ruff.2012* yield better results than the others in smaller samples with known height or accurately measured skeletal length.

As the regression lines of estimated heights for given *femur* lengths show, the estimation formulae of Trotter and Gleser (1952, 1977) for "American whites", which are often used in the English-language literature, emphasise the differences between shorter and taller people while the formulae of Breitinger (1937) and especially Bach (1965), which are more commonly used in the German literature, yield a rather small range of estimated heights for the same measurements. Both formulae from Pearson (1899) estimate similarly short people as the Trotter/Gleser formulae at the lower end of the relevant range of *femur* lengths, but much shorter tall people at the other end. For men, the estimated Pearson heights at the longer end of the range of bone measurements are just slightly shorter than Breitinger heights. For women, however, Bach heights are shorter than Trotter/Gleser heights only for very long *femora* but much taller than both other estimates toward the lower end of the relevant range. The other set of Trotter and Gleser (1952, 1977) formulae, for "American Negroes", yield results similar to the Pearson (1899) formulae, differing mainly for longer female *femora*, where the estimated heights end up half way between Pearson's and Trotter/Gleser's "whites."

Recently, Ruff et al. (2012) presented a new set of estimation formulae, based on a larger sample of skeletal data from a heterogeneous European sample. The heights used in their computations, however, are not measurements but have been estimated using an "anatomical stature technique," i.e. by adding up the articulated lengths of the various parts of the skeleton contributing to height. As the graphical comparison of the estimation formulae using only *femur* lengths in figure 3.2 shows, the Ruff et al. regressions have a steeper slope than all of the methods commonly used in the literature.

The regression formulae are meant to be used with measurements of long bones of anthropologically *adult* individuals, i.e. those who had stopped growing before they had died. Notably, shrinking with age, as it has been observed in historical populations when heights of standing or sitting individuals was measured (cf. Meinzer 2015, pp.173), and seems to be reflected in the measurements of skeletal length, is of no concern here, since the effect is caused by changes in the soft tissue of the spinal column whereas the length of the long limb bones does not decrease again. Estimated heights should not be compared directly to heights of living populations of varying ages or including elderly people.

Siegmund (2012) argues that the formulae of Pearson (1899) and Trotter and Gleser (1952, 1977) "American Negroes" yield the best results of any single estimation formulae for the Central European pre-historical material, while the newer formulae of Ruff et al. (2012) yield similar results for men but taller heights for women. He compares average estimated heights of a number of series to the actual average stature measured before the individuals skeletonised, carefully measured *in situ* skeletal lengths, or "living heights" calculated by adding the lengths of various parts of the skeletons of individuals with extraordinarily well-preserved skeletons. To assess height inequality, however, the dispersion of the various measures and estimates are as important as the mean which has received most of the attention in comparisons of height estimation formulae.

The different slopes of the regression lines imply that the coefficient of variation of estimated heights will be different for different estimates based on the same dataset. For both sexes, the "American white" formulae from Trotter and Gleser (1952)Trotter.1977 yield higher measures of inequality than the formulae from Pearson (1899). The estimates of Breitinger (1937) and Bach (1965), widely used in the German literature (Koepke and Baten 2005, p.70), imply the lowest levels of height inequality. The Trotter and Gleser (1952) "Negro" formulae result in slightly higher inequality than Pearson (1899), but still far from their "white" counterparts. The highest levels of inequality are implied by the formulae of Ruff et al. (2012), for both men and women.

Applied to the same underlying data, the formulae for female heights, with the exception of Bach (1965), imply larger coefficients of variation of height than their counterparts for male heights. Figure 3.3 illustrates this, with kernel densities of simulated data, drawn from normal distributions with the parameters observed in the early medieval data.

The difference between the coefficient of variation of Breitinger-heights and that of Trotter/Gleser-heights is, for example, about as large as the approximated 95 percent confidence interval around the coefficient of variation of Pearson-heights for a sample of only 70 or so observations, using the parameters of the observed distribution of femur lengths. For women, the range of coefficients of variation is substantially larger still.

However, it is not obvious that the single formulae preferred by Siegmund (2012) for estimating relatively accurate average heights also yield the most accurate estimates of the variance of heights.[3] Figures 3.4 and 3.5 compare densities of height distributions, estimated with the formulae discussed above, with the empirical densities of measured heights or adjusted *in situ* skeletal length from two of the series used by Siegmund (2012) for his comparison of means. The first is a 19th century French anatomical series published by Rollet (1888), which was later used by Pearson (1899) as the basis for his estimation formulae, and the second is a series of skeletal lengths, measured during the excavation of the *Eichstetten* cemetery (Sasse 2001). As it turns out, all but the Ruff et al. (2012) estimation formulae yield empirical distribution functions with excess kurtosis over the distribution of the measured stature or length.

Since the formulae proposed by Ruff et al. (2012) yield variations of heights close to those of the height measures in the smaller validation samples and are mostly spot-on as well on means, they are used preferentially throughout this paper.

Due to differences in body proportions, the regression coefficients of the same bones are different in the estimation of male and female stature.

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[3] Although Siegmund (2012) generally prefers using averages of heights estimated with several formulae, he still expresses preferences for individual ones for those who want to keep it simple.

Sexual dimorphism in the early medieval populations, differences in inequality between the sexes, or sex-specific influences of factors associated with living standards, therefore, cannot be analysed using estimated heights.

In the cases where only height estimates and no actual long-bone measurements were provided, those are used to calculate the implied lengths of *femur*, *humerus*, *radius*, and *tibia* which are in turn used to compute estimates according to the Ruff et al. (2012) formulae.

3.3.2 Construction of graves

Slightly more abstract than classifications of types of grave-goods are analyses of the relative costs of burial. According to the "energy expenditure principle" (Tainter 1975), the death and subsequent burial of high-ranking people interrupted the daily life of local communities more profoundly than the demise of yet another commoner, which may have been reflected in more elaborate "interment facilities."

While the dataset contains information on the dimensions of the burial pits and eventual remains of wooden constructions or stones found in the graves, there are a number of caveats to consider. Though a seemingly simple concept, the measures of the grave-pits may not be comparable across cemeteries, possibly not even across different areas of the same cemetery. The catalogues are not always clear on where the width and length of a pit were measured, which is problematic if the walls are not parallel. Using only the base area may underestimate the efforts expended on grave-pits with larger openings. The depth is even more contentious, since the ground surface level at the time of the burial is generally unknown. Depths have either been measured from the surface level at the time of the excavation or from ground level after mechanised removal of sod or topsoil.

However, as depth measurements seem to be more problematic than the other dimensions, and most grave-pits had rather vertical walls, the base area seems to be a more reliable proxy for the expended energy than the excavated volume. It has to be kept in mind, though, that local soil conditions as well as the type of tools used to dig grave-pits likely affected the amount of energy that actually was expended.

3.3.3 Making use of grave-goods data

Consolidating similar objects among the thousands of grave-goods documented in the database into indicator variables for a smaller number of artefact types, as described above, does not address the challenges of interpretation of grave-goods assemblages. On the contrary, if particular items had specific symbolic meanings, some of the nuance might get lost as a consequence of aggregating the data. The indicators are, however, helpful to compare grave-goods across individual burials on a more abstract level. Archaeologists have used the number of different types of artefacts as a proxy for the exclusiveness of grave-goods assemblages (Hedeager 1980), either as such or weighted with the inverse of the relative frequency at which the kinds of objects were found in the sampled burials (Jørgensen 1987; Siegmund 1998). While analyses of numbers of artefact types will be somewhat sensitive to changes in the definitions of artefact types, the latter method is even less robust, since the weights attached to rarer items can change dramatically on the inclusion or exclusion of individual burials. Excluding less-common artefact types to address this problem would diminish the main perceived advantage of the method, namely its potential ability to take into account the relative rarity of certain grave-goods.

3.3.4 Regional disparities

Well-defined boundaries, such as the *Limes* fortifications established to control the border region between the Roman empire and the *Germania magna* in late antiquity are rather exceptional before the concept of the territorial state was developed later in the Middle Ages. The ecclesiastical provinces of the Roman church, which was a major political force in the power vacuum left after the end of the Roman Empire in the west (Dam 2005, pp.214) for example, were understood as the area inhabited by the parishes of their dioceses, not as exactly charted territories. Borders, then, were mostly physical boundaries or features of the landscape which likely persist until today. Therefore, the cemeteries in the study area are assigned to groups defined by the extent of so called "natural regions," geographical divisions useful for environmental planning and similar purposes (cf. Otremba and Meynen 1948), instead of political or administrative boundaries.

Using this scheme takes into account various environmental and climatic factors attempting to define regions that can be experienced as distinct from one another by an attentive observer in the field. Using these to sort the sites into a number of groups circumvents the potentially problematic need to construct categorical variables from indicators of suitability for certain crops or other agro-environmental data that are typically defined on interval or ratio scales and available at finer spatial resolution.

Here, 'second-order landscape regions' (Bundesamt für Naturschutz 2014) are used to sort the cemeteries into four groups, as shown on the map (figure 3.1). One group of cemeteries is located in the southeast and away from the heartlands of the Merovingian kingdoms in the low mountain ranges of the Swabian and Franconian Jura. Two cemeteries located in the adjacent Keuper Uplands are added to this group. Another rather dispersed set of cemeteries was found in the rolling hills of the Gäu Plateaus stretching from between the Swabian Jura and the Black Forest to the Central Uplands. A cluster of well-documented cemeteries included in this dataset were excavated in the Northern Upper Rhine Plain. They are combined with a smaller number of cemeteries from the Scarp-lands on either side of the Rhine since the other cemeteries in the Upper Rhine Plain are concentrated in its southern part and are designated as a distinct group because of their relative separation from the other places.

Patterns of settlement names were long seen to imply that the inhabited area in the region and the number of settlements increased substantially during the Merovingian era (e.g. Jänichen 1972). However, much of the land was probably used extensively before it was settled, so the Early Middle Ages in southern Germany saw "the intensification of land use practices, changing the landscapes from marginal outlands to agrarian inlands." (Schreg 2014, p. 92) Nevertheless, population density likely remained very low, with estimates of just 0.9 to 1.3 people per square kilometre for the Merovingian Rhinelands (Zimmermann et al. 2009, p. 377).

3.4 Results and Discussion

The average heights of all the male and female individuals in the sample, estimated with the Ruff et al. (2012) formulae, are 169.4 and 160.5 centimetres, respectively. Height averages reported for the study period based on different samples are typically not readily comparable because they are not based on other methods of height estimation. Nevertheless, as table 3.2 shows, the average Breitinger-heights of males in the sample, 172.2 centimetres for the earlier, and 171.8 centimetres for the later phase, are not far from the average male Breitinger-height of slightly more than 172 centimetres that Koepke and Baten (2005, 76, Figure 2) report for European males living in the 6th century.[4] The average male Trotter/Gleser-heights[5] of the sample from the 7–8th centuries, 173.5 centimetres, is similar to the simple average

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[4] They report, however, an average of less than 171 centimetres for the 5th century and a larger decline for the 7th and 8th centuries, to about 171 and about 170 centimetres, respectively (Koepke and Baten 2005, 76, Figure 2).

[5] Not shown in table 3.2

of Trotter/Gleser-heights of 173.4 centimetres reported by Steckel (2004) for Northern European males from the 9–11th centuries and conforms to the decline from earlier times that he expected.

Although the early medieval people are rather short compared to the heights of today's 20–25 year old Germans who average 181 and 168 centimetres, they were somewhat taller than the sample of French people whose measurement used in the above discussion of height estimation formulae. The men in this sample of people born in the late 18th and early 19th century averaged 166.3 centimetres and the women 154 centimetres (Rollet 1888). Bavarian prisoners born during the 19th century were measured to be 167 and 156 centimetres tall, on average (Baten 2000), i.e. substantially shorter than the sample of the early medieval population, assuming that the height estimations are close to the stature people would have had as young adults. This also fits to descriptions of long-term trends of average heights suggesting that people tended to be shorter in Roman-ruled areas during Antiquity and later, during the Middle Ages and the early modern period, before reaching the level of the Early Middle Ages again in the 19th century when the secular growth in heights began (Steckel 2004; Koepke and Baten 2005).

As table 3.2 shows, fewer people can be assigned to the earlier period, the time before 600 CE, than to the later period, while a substantial number of people cannot be sorted into either of the group with sufficient confidence. The average estimated heights of both sexes are slightly shorter for the people deemed to have been buried in the later phase, while the un-dated female individuals size up to an average height between the values of both periods whereas the males that have not been dated turn out to be shorter on average than even those assigned to the later period. At best, the differences are of only marginal significance if cemetery characteristics and other possible imbalances are not taken into account. In the three-phase chronological model, the average estimated heights of people dated into the middle period are between those of the earlier and later phases.

Regarding the four natural regions, differences of average estimated heights are similarly fragile. If anything, the people who were buried in the Swabian and Franconian Jura or the Scarplands on both sides of the Rhine were slightly taller than the others, but in general, most regional sub-divisions of the population sample enjoyed about the same biological standard of living.

3.4.1 Grave goods – burial inequality

As both the actual grave-goods and the modes of burial seem to have varied significantly over time, differences in the distribution of traits between the earlier and the later phase cannot simply be interpreted as changes in inequality. Furthermore, data quality issues are probably a greater concern for indicators derived from grave-goods and details of tomb-construction.

However, while some types of burial were more popular at different times, the base area of the burial pit is not typically interpreted as having significance for purposes of archaeological dating. Since the mortuary evidence is available for some individuals whose skeletons were not sufficiently well-preserved to allow their height to be estimated, analyses of these variables can at least compare individuals in the main sample with the others along those dimensions.

Table 3.3 presents summary statistics and Gini-coefficients of the base area of burial pits for people buried during both periods, separated by sex of the buried because the size of the grave and the height of the dead person are positively correlated. Unfortunately, the sample sizes are getting very small because the subset of burials of individuals with an archaeological date has to be further restricted to grave-pits that had been used to bury only one person at a time and for which the necessary measurements are documented. However, there are very few burials where the skeleton was well-enough preserved to allow it to be sexed but not well-enough preserved to have long-bone measurements taken. The burial pits of the lesser preserved men may have been slightly smaller than those of the others. Interestingly, the median grave in the later time period appears slightly larger, though Kolmogorov-Smirnov-tests do not allow rejection of the null hypothesis of equality of distributions for male burials. The inequality of the base-area distributions does not seem to exhibit any consistent trends over time. In light of the theory of grave-goods and burial furnishings as remnants of ceremony staged to impress the local community and emphasise claims to power of the family or group who had lost one of their members, it is no surprise that aggregated data does not reveal substantial differences. Local conditions likely varied more within the almost two-century long time slices than between them. Unfortunately, a more fine-grained analyses is not possible with the available data.

A more serious conceptual challenge facing the analysis of inequality trends in grave-goods assemblages is that the dating itself is based on the same evidence. Apparent changes in the distribution and frequency of occurrence of certain types of artefacts are at the core of the archaeological dating schemes. Describing the same observations again, now interpreting them as inequality trends, would not further the exploration of the dataset. Table 3.4 shows that there are indeed differences in the distribution of grave-goods between the earlier and the later phases. Both men and women were buried with more different types of artefacts that were distributed more equitably before 600

CE. Since the custom of furnishing burials with grave-goods was gradually given up in the late 7th and 8th century, lower numbers of artefact types in that time period are no surprise. Subtracting the difference between the median number of artefacts in early-phase burials and later-phase burials from the number of artefact types of the burials dated to the time before 600 CE, counting negative results as zeroes, reduces the difference of distributions and inequality to insignificant levels.

3.4.2 Height inequality

The coefficients of variation of estimated Ruff et al. (2012) heights in the full early medieval sample are 0.0437 for men and 0.0424 for women. To put these numbers into perspective, the coefficients of variation of the adjusted skeletal lengths of the *Eichstetten*-people are 0.0497 and 0.0498, respectively, and those of Rollet's French people are substantially lower, with 0.0334 and 0.0357 for men and women. Height inequality was slightly higher again in a sample of Bavarian prisoners born throughout the 19th century (Baten 2000), with coefficients of variation of 0.0378 for men and 0.037 for women. Height inequality in more recent samples of German men born between 1939 and 1979 who were physically examined for military conscription was on a similar level, with coefficients of variation between 0.037 (birth-cohort of 1960) and 0.0385 (birth-cohorts of 1973 and 1978) (Jaeger et al. 2001).

Historically, inequality first seems to have been markedly lower than this in "agrarian societies with simple war technologies," as Boix and Rosenbluth (2014) report coefficients of variation of height below 0.03 for *Zuni Pueblo* from northwestern New Mexico, based on actual height measurements from the late 19th century and skeletal data for earlier periods. However, since coefficients of variations from measured heights are often lower than 0.04 (Moradi and Baten 2005; Blum 2014), the possibility remains that the remarkably high inequality of Ruff et al. (2012) estimated heights is due to the property of those estimators to generate relatively dispersed heights compared with other estimation formulae, as discussed above. In light of the detailed comparison of height estimation formulae, it seems more prudent to refrain from direct comparisons of coefficients of variation based on height measurements with those based on estimated heights, especially if those have been computed with different formulae. To demonstrate this, table 3.5 shows the results discussed below not only for Ruff et al. (2012) heights but also based on the other estimation formulae compared above.

As noted above, the sample is smaller if it only includes individuals that have been dated individually based on details of their burial or grave-goods or that have been excavated from cemeteries which were used exclusively in either of the periods. The coefficient of variation of Ruff et al. (2012) height estimates is larger after 600 CE for both sexes. Male height inequality increases from 0.0406 to 0.0440. The latter value is the same as the value calculated for the unrestricted sample, so the heights of individuals dated to the earlier phase are even more similar than those of people who have not been dated at all. For female heights, inequality levels vary less between the time periods, with coefficients of variation of 0.0415 for the earlier, and 0.0443 for the later period. Here, the values are on both sides of the one computed for the unrestricted sample, though the first-period value is only ever so slightly smaller.

Figure 3.6 shows point estimates of the coefficients of variation together with approximated 90 percent confidence intervals which overlap to a large extent due to the moderate number of dated individuals of both sexes from each of the time periods. Nevertheless, the difference between the time periods is more pronounced for men, whose heights were more equal than those of women in the earlier phase and became similarly unequal in the later phase. If there was indeed an increase of inequality of living standards over time, a more rigorous separation of the two phases should yield more pronounced results. Dropping individuals dated to the decades before and around 600 CE from the sample yields slightly smaller coefficients of variation in the earlier period for both men and women. However, since the sub-samples dated to that phase were smaller to begin with, the increase of the confidence intervals drowns out the change of the point estimates.

Analytically, approximations of the standard errors of the estimated coefficients of correlation proposed by Sokal and Braumann (1980) can be used to perform significance tests. Table 3.5 shows that the empirical significance levels of tests of the null hypothesis of identical coefficients of variation of male heights in both time periods are slightly larger than conventional levels for some of the height estimates. Using Monte-Carlo methods to augment the conservative approximations yields similar results. Repeatedly drawing samples of the same size as the observed dataset from a normal distribution with the parameters of the early-phase estimated heights shows that about 7.2 percent of 100,000 simulated repetitions with Ruff et al. (2012) heights yield larger-than-observed differences between coefficients of variation of simulated data drawn from the same distribution for both periods. With Pearson (1899) estimates, the share of simulated cases with larger differences is reduced to 4.4 percent. Using the sample sized reduced by dropping individuals dated to around 600 CE for the simulation yields 13.6 and 10.4 percent of repetitions with larger differences, respectively.

The nature of the available evidence, 40 samples of individuals mostly in the small double-digit numbers, does not encourage a more detailed exploration of potential relationships between the coefficient of variation of heights and geographical and climatic factors with site-level variability. Even without differentiating between the time periods, dividing the data by anthropologically determined sex and providence from one of the four 'natural regions' substantially inflates the confidence intervals around the coefficients of variation. Nevertheless, going by the point estimates, the post-600 samples had less equally distributed estimated heights in all regions except the Southern and Middle Upper Rhine Plain in the southwest of the study area (figure 3.7). However, even there, the 90 percent confidence interval around the coefficient of variation of sample from the earlier phase contains the point estimate of the sample from the later phase for both males and females.

3.5 Conclusion

Analysing inequality of living conditions in the past is difficult because household budgets and similar data often employed for these purposes are not available for most of human history. With the concept of the biological standard of living, mortuary evidence from excavated burial grounds can be used to assess average estimated stature of individuals as a proxy for the level of living standards and the coefficient of variation of estimated heights as an indicator of inequality of living conditions.

A comparison of various methods of estimating human height from long-bone measurements shows that several of the methods commonly used in the literature yield surprisingly different results for the same input. In two small samples of people for which both long-bone measurements and heights or skeletal lengths are documented, the method of Ruff et al. (2012) provides the best fit between the distributions of both kinds of measures. In any case, these explorations show that comparisons between coefficients of variation of height based on different height estimates or on measured stature might be misleading.

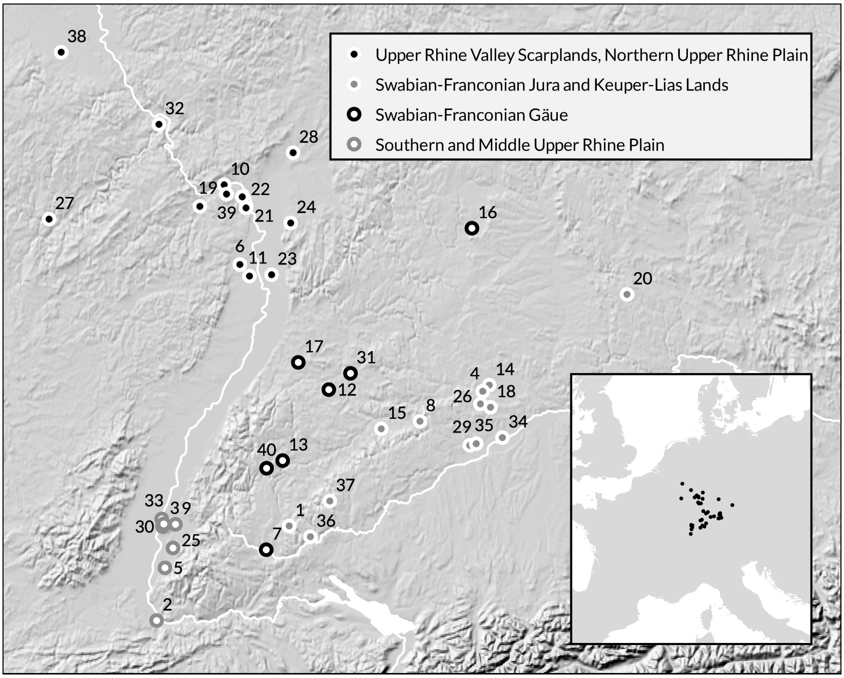
Anthropometrical data of about 2,200 individuals from 40 excavated cemeteries suggests that inequality of estimated heights increased during the Merovingian era in southwestern Germany, at least for parts of the population. As the level of estimated heights stagnated or even slightly decreased during the time, living conditions may have worsened considerably for the least advantaged people. The absence of suitable data related to consumption or income from other sources, however, precludes analyses of the relationship between the level and distribution of inputs and the observed anthropometric outcomes. The basic pattern is similar for slightly more fine-grained analyses that differentiate between three time periods, separating a intermediate phase of a few decades before and after 600 CE from the two main phases, as well as for an analyses that splits the sample into four groups based on 'natural regions.'

While energy expenditure for the burials, crudely proxied with the base area of the burial-pits, shows no clear differences between the earlier and later times, fewer types of artefacts were typically deposited in graves after about 600 CE. Since grave-goods are used to establish archaeological chronologies of the burials, these results mainly show that the two phases actually seem to be distinct even when the grave-goods data is analysed on a more abstract level. This is consistent with interpretations that people were not as eager to endow their deceased with grave-goods later in the Merovingian era either because their social position was rather more secure and they did not have to publicly assert their position or because they knew that their chances of winning over the community to accept their leadership were slim.

Seeing the presumed low population density in the region at the end of the Merovingian era and the substantial share of the land that remained unsettled and untilled, there may be more to increasing inequality than pure Malthusian pressures. A more rigidly structured social order could have also facilitated arrangements where some families in a small-scale agricultural society were able to secure access to some of the output of other families. As a result, more people may have had difficulties providing for their children at a level that prevented stunting or other adverse outcomes. Rising inequality of biological living standards, as reflected in larger coefficients of variation of estimated height, could have been a side effect of increasing stability and capability of the state. The progressing relative enrichment of the elites that has been documented for other European regions may have begun in the Early Middle Ages.

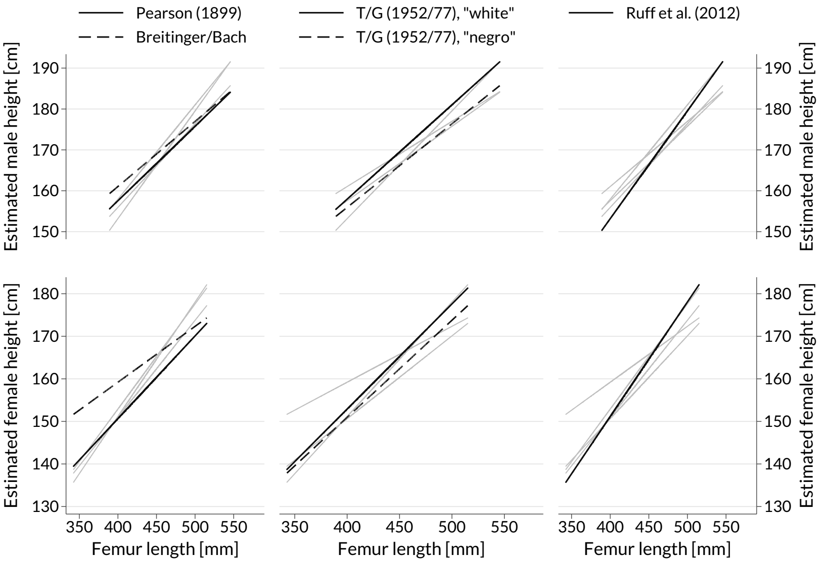
3.6 Figures and Tables

FIGURE 3.1: Map of the cemeteries



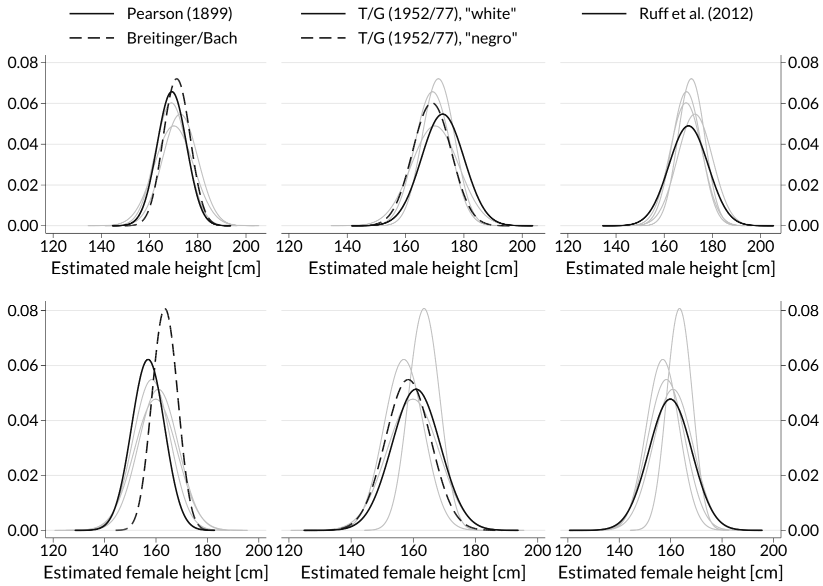
– The numbers correspond to the first column in table 3.1.
– The relief is based on the *GTOPO30* global digital elevation model by the U. S. Geological Survey (USGS).
– Streams and Lakes are drawn using *WISE Large rivers and large lakes* data from the European Environment Agency (EEA).
– The cemeteries were sorted into groups using a shapefile of the *Naturräumliche Gliederung* that was kindly provided by the Bundesamt für Naturschutz (2014).
– This map is similar to figure 4.1.

Figure 3.2: Regression lines, height on femur length



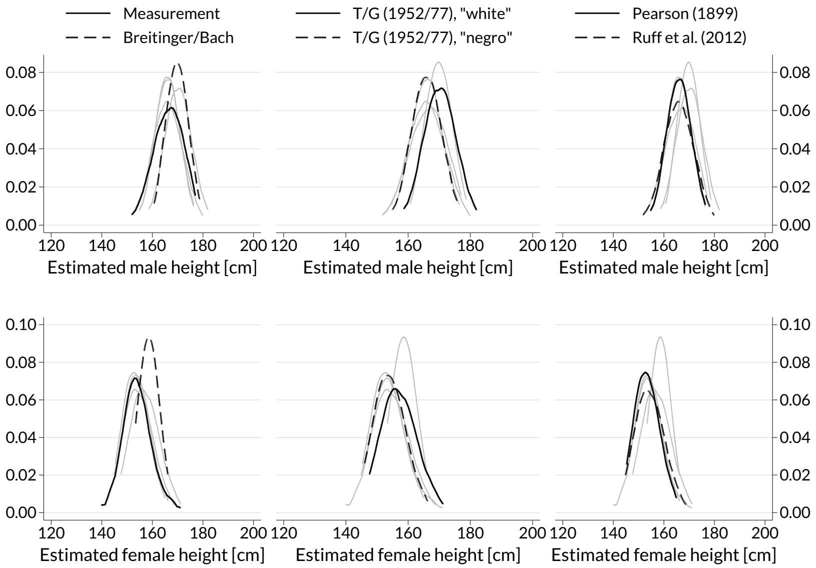
– The graphs depict the regression lines for for femora over the range of values observed in the early medieval dataset. *T/G* refers to Trotter and Gleser (1952, 1977), *Breitinger/Bach* to Breitinger (1937) for males and Bach (1965) for females.

Figure 3.3: Comparison of height estimates using simulated data



– Kernel density estimates drawn with Stata: `kdensity height_estimate, kernel(epan) bwidth(3)`.
– The underlying data are 1,000,000 random draws from normal distributions with the means and standard deviations of the observed distributions of male and female femora in the early medieval database.
– *T/G* refers to Trotter and Gleser (1952, 1977), *Breitinger/Bach* to Breitinger (1937) for males and Bach (1965) for females.

FIGURE 3.4: Comparison of height estimates with Rollet's (1888) Lyon sample

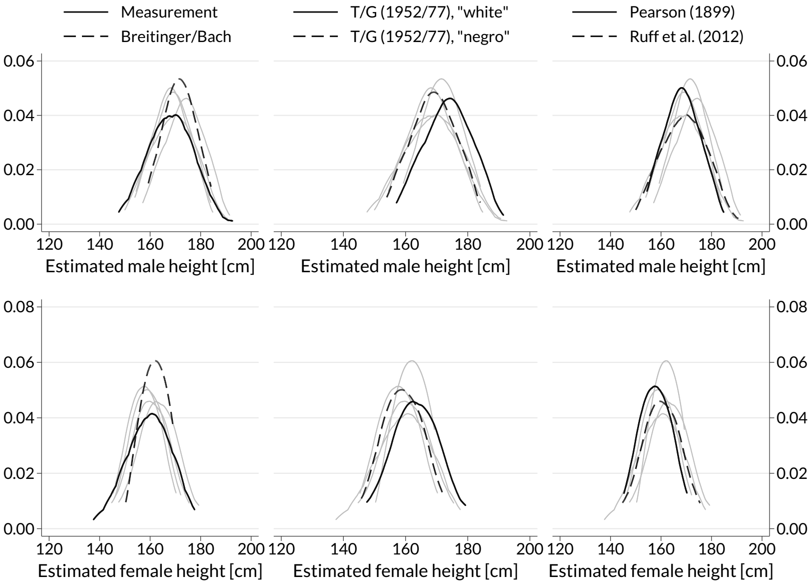


– Kernel density estimates drawn with Stata: `kdensity height_estimate, kernel(epan) bwidth(3)`.

– Rollet (1888) sampled 50 men and 50 women aged 24 to 99.

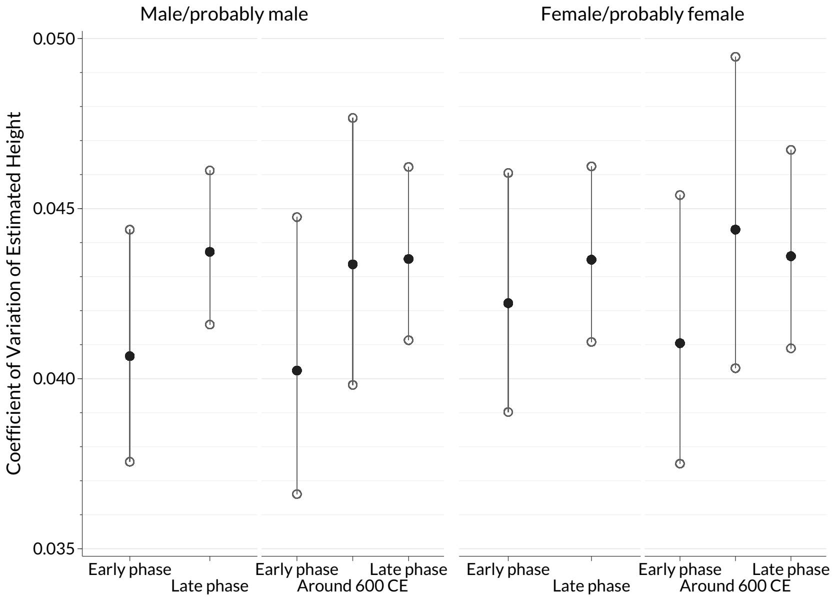
– *T/G* refers to Trotter and Gleser (1952, 1977), *Breitinger/Bach* to Breitinger (1937) for males and Bach (1965) for females.

FIGURE 3.5: Comparison of height estimates with *in situ* skeletal lengths from Eichstetten



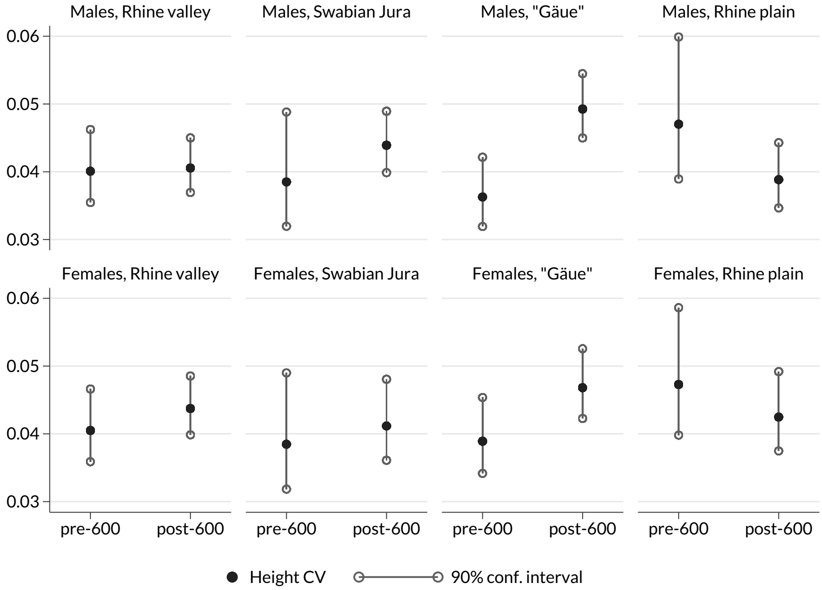
– Kernel density estimates drawn with Stata: `kdensity height_estimate, kernel(epan) bwidth(3)`.
– *T/G* refers to Trotter and Gleser (1952, 1977), *Breitinger/Bach* to Breitinger (1937) for males and Bach (1965) for females..

Figure 3.6: Inequality of estimated heights



– Coefficients of variation of estimated (Ruff et al. 2012) heights of the adult individuals archaeologically dated into the respective phases, based on chronologies developed in the respective publications (see table 3.1).
– Hollow circles indicate 90% confidence intervals, approximated as described in section 3.2.1. See table 3.2 for the underlying sample sizes and height estimates.

FIGURE 3.7: Inequality of estimated heights, by region



– Coefficients of variation of estimated (Ruff et al. 2012) heights of the adult individuals archaeologically dated into the respective phases, based on chronologies developed in the respective publications (see table 3.1).

– Confidence intervals, approximated as described in section 3.2.1. See table 3.2 for the underlying sample sizes and height estimates.

– *Rhine valley* refers to the scarplands of the Upper Rhine Valley and Northern Upper Rhine Plain, *Swabian Jura* to the Swabian-Franconian Jura and Keuper-Lias Lands, *"Gäue"* to the Swabian-Franconian Gäue, and *Rhine Plain* to the Southern and Middle Upper Rhine Plain.

Table 3.1: Summary statistics and sources

		♂		♀		
Cemetery		n	$\bar{x}$	n	$\bar{x}$	Sources
1	Aldingen	5	170.9	6	170.5	Schach-Dörges (2004)
2	Basel (Bernerring)	18	170.2	15	156.6	Martin (1976)
3	Bischoffingen	10	161.6	8	162.1	Hoff (1973); Bury (1974); Werner (1975)
4	Bopfingen	4	180.1	7	161.1	Desideri; Henke; Rosenstock
5	Buggingen	17	164.7	11	156.0	Jansen (2003)
6	Dirmstein	21	164.5	14	159.7	Leithäuser (2006)
7	Donaueschingen	97	168.1	75	159.6	Buchta-Hohm (1996); Röhrer-Ertl (1991)
8	Donzdorf	9	170.1	12	161.1	Neuffer (1972)
9	Eichstetten a.K.	45	169.1	42	160.4	Sasse (2001)
10	Eltville am Rhein	81	169.2	79	158.6	Blaich (2006)
11	Eppstein	60	171.0	59	165.2	Engels (2012)
12	Hemmingen	10	172.6	19	163.1	Müller (1976); Obertová (2008)
13	Horb-Altheim	21	170.3	20	163.2	Beilharz (2011); Obertová (2008)
14	Kirchheim am Ries	67	169.4	50	162.9	Neuffer-Müller (1983)
15	Kirchheim unter Teck	13	169.8	15	156.7	Däcke (1998); Becker (1985)
16	Kleinlangheim	29	169.4	38	159.0	Pescheck (1996); Schultz (1978)
17	Knittlingen	36	167.8	18	159.3	Damminger (2002)
18	Kösingen	14	169.4	9	166.6	Knaut (1993)
19	Langenlonsheim	39	168.1	30	160.0	Desideri; Henke; Rosenstock
20	Lauterhofen	19	169.7	13	154.5	Desideri; Henke; Rosenstock
21	Lörzweiler	3	166.5	5	162.1	Desideri; Henke; Rosenstock
22	Mainz-Hechtsheim	47	167.0	55	163.7	Koch (2011); Queisser (1988)
23	Mannheim-Vogelstang	127	167.8	128	159.9	Rösing (1975); Koch (2007)

Continued on next page

TABLE 3.1: Summary statistics and sources

		♂		♀		
Cemetery		n	$\bar{x}$	n	$\bar{x}$	Sources
24	Mühltal	9	174.2	9	162.5	Desideri; Henke; Rosenstock
25	Munzingen	26	169.5	25	158.0	Groove (2001); Burger-Heinrich
26	Neresheim	24	173.3	42	161.6	Knaut (1993); Speith (2012)
27	Newel	6	170.8	3	159.8	Desideri; Henke; Rosenstock
28	Nieder-Erlenbach	32	168.6	29	157.8	Dohrn-Ihmig (1999)
29	Niederstotzingen	9	171.5			Paulsen (1967); Wahl et al. (2014)
30	Oberrotweil	21	170.6	21	156.1	Desideri; Henke; Rosenstock
31	Pleidelsheim	47	170.6	58	159.6	Koch (2001); Speith (2012)
32	Rübenach	11	166.1	4	159.6	Desideri; Henke; Rosenstock
33	Sasbach a.K.	15	167.3	7	160.3	Schoof-Hosemann (1975); Herrmann (1976), Kirchberg (1976)
34	Schretzheim	29	173.1	14	165.1	Koch (1977); Donié (1999)
35	Sontheim a.d. Brenz	26	173.5	19	157.8	Neuffer-Müller (1966)
36	Stetten a.d. Donau	44	171.5	29	158.4	Weis (1999)
37	Truchtelfingen	12	170.7	1	165.1	Schmitt (2007)
38	Vettweiß-Mersheim	17	170.3	17	160.7	Desideri; Henke; Rosenstock
39	Wackernheim	10	167.4	3	158.4	Desideri; Henke; Rosenstock
40	Wittendorf	12	169.4	11	158.4	Lehmann (2003)
	Total	1142	169.4	1027	160.5	

- The numbers correspond to the numbers on the map, figure 1.
- Heights are estimated using the Ruff et al. (2012) formulae.

Table 3.2: Sample sizes and average heights, earlier and later periods

	5–6$^{\text{th}}$ c	$\sim$ 600 CE	7–8$^{\text{th}}$ c	no date
	Male/probably male			
Number of individuals	214		514	414
Ruff et al. (2012) heights	170.0		169.5	169.0
	(6.89)		(7.46)	(7.57)
Pearson (1899) heights	168.7		168.3	168.1
	(5.05)		(5.53)	(5.61)
Breitinger (1937) heights	172.2		171.8	171.4
	(4.45)		(4.77)	(4.88)
Number of individuals	152	178	398	
Ruff et al. (2012) heights	170.3	169.9	169.3	
	(6.87)	(7.54)	(7.34)	
Pearson (1899) heights	169.0	168.6	168.1	
	(5.04)	(5.55)	(5.45)	
Breitinger (1937) heights	172.4	172.0	171.7	
	(4.46)	(4.81)	(4.70)	
	Female/probably female			
Number of individuals	219		400	408
Ruff et al. (2012) heights	161.8		160.0	160.2
	(6.71)		(7.08)	(6.83)
Pearson (1899) heights	158.7		157.3	157.5
	(5.30)		(5.56)	(5.10)
Bach (1965) heights	162.6		161.6	161.8
	(3.73)		(3.94)	(3.87)
Number of individuals	167	141	311	
Ruff et al. (2012) heights	161.9	160.8	159.9	
	(6.55)	(7.22)	(7.05)	
Pearson (1899) heights	158.9	158.0	157.2	
	(5.17)	(5.69)	(5.52)	
Bach (1965) heights	162.7	161.8	161.5	
	(3.58)	(4.16)	(3.89)	

- Standard deviations of estimated heights in brackets.
- In the second blocks of height estimates, people dated to the decades around 600 CE are excluded from the 5–6$^{\text{th}}$- and 7–8$^{\text{th}}$-century groups. The undated individuals are the same as those documented in the first blocks.

TABLE 3.3: Inequality of base areas of burial pits

	♂		♀	
	no heights	heights	no heights	heights
5–6th centuries				
Number of individuals	105	94	109	90
Median base area $[m^2]$	1.92	2.10	1.72	1.71
Gini coefficient	0.25	0.24	0.25	0.21
7–8th centuries				
Number of individuals	142	125	118	113
Median base area $[m^2]$	1.89	2.22	2.1	2.1
Gini coefficient	0.23	0.25	0.24	0.27
`ksmirnov` (distributions)	0.498	0.859	0.044	0.005
t-test (Ginis)	0.64	−0.29	0.145	−1.25

- *[N]o heights* are the burials of anthropologically sexed and archaeologically dated individuals without height estimates, *heights* are those with long bones well-enough preserved for measurement.
- Results of a simple t-test for equality of early- and late-period Ginis using bootstrapped standard errors calculated with the Stata programm `ineqerr` by Jolliffe and Krushelnytskyy (1999).
- Kolmogorov-Smirnov equality-of-distribution tests were performed on the respective samples from the early and late time periods using Stata's `ksmirnov`; the table provides the exact combined p-values.
- Burial pits used to interr more than one person at a time are excluded.

TABLE 3.4: Inequality of number of artefact types in grave-goods assemblage

	♂		♀	
	no heights	heights	no heights	heights
$5–6^{\text{th}}$ centuries				
Number of individuals	111	69	90	58
Median artefact types	6	6	5	4
Gini coefficient	0.32	0.27	0.34	0.30
$7–8^{\text{th}}$ centuries				
Number of individuals	172	54	123	58
Median artefact types	2	4	3	3
Gini coefficient	0.51	0.38	0.47	0.38
`ksmirnov` (distributions)	0.000	0.010	0.000	0.068
t-test (Ginis)	−3.06	−2.13	−1.79	−1.30

- *[N]o heights* are the burials of anthropologically sexed and archaeologically dated individuals without height estimates, *heights* are those with long bones well-enough preserved for measurement.
- Gini-coefficients are computed for all individuals matching the criteria, including those without any grave-goods.
- Results of a simple t-test for equality of early- and late-period Ginis using bootstrapped standard errors calculated with the Stata programm `ineqerr` by Jolliffe and Krushelnytskyy (1999); since the programme discards null-values, all numbers of artefact types have been increased by 0.0001.
- Kolmogorov-Smirnov equality-of-distribution tests were performed on the respective samples from both time periods using Stata's `ksmirnov`; the table provides the exact combined p-values.
- Burial pits used to interr more than one person at a time or marked in the catalogue to have been robbed or otherwise disturbed are excluded.

TABLE 3.5: Analytical assessment of differences in inequality levels

	$\text{CV}_{5^{th}/6^{th}\ c}$	$\text{CV}_{7^{th}/8^{th}\ c}$	t-stat	%
Male/probably male				
Ruff et al.(2012)	0.0406	0.0440	−1.43	0.07
...with gap around 600 CE	0.0404	0.0434	−1.08	0.14
Pearson (1899)	0.0300	0.0329	−1.65	0.04
...with gap around 600 CE	0.0299	0.0324	−1.24	0.10
Trotter/Gleser (1952/77) “white”	0.0334	0.0364	−1.54	0.06
Trotter/Gleser (1952/77) “negro”	0.0311	0.0333	−1.20	0.11
Breitinger/Bach (1937/65)	0.0259	0.0278	−1.24	0.10
Female/probably female				
Ruff et al.(2012)	0.0415	0.0443	−1.09	0.13
...with gap around 600 CE	0.0405	0.0441	−1.27	0.09
Pearson (1899)	0.0334	0.0353	−0.96	0.16
...with gap around 600 CE	0.0326	0.0352	−1.11	0.12
Trotter/Gleser (1952/77) “white”	0.0411	0.0443	−1.27	0.10
Trotter/Gleser (1952/77) “negro”	0.0355	0.0381	−1.18	0.11
Breitinger/Bach (1937/65)	0.0230	0.0244	−1.04	0.14

- The CV columns show adjusted coefficients of variation for the two time periods.
- The t-statistics are calculated using approximated standard errors and adjusted coefficients of variation as recommended by Sokal and Braumann (1980).
- ‘%’ is the share of 100,000 repetitions of simulated draws from a normal distribution with the parameters observed in the early-period data used for both samples, where the difference between the coefficients of variation is larger (in absolute values) than in the early medieval data.

Persisting Patterns of Human Height? Regional Living Standards in the Early Middle Ages

4

Abstract

‘Proximity to protein production’ has recently been identified as an important determinant of regional variation of biological standards of living, as evidenced by average heights. The number of cows per person turned out to be a useful proxy where milk consumption had not been documented. Re-analyses of agricultural production and average male heights in early 19th-century Central Europe show that indicators of agricultural suitability constructed from modern agro-ecological data are strongly correlated with historical agricultural specialisation. This paper uses a dataset of estimated heights and evidence on circumstances of the burial from about 2,200 individuals who had lived in southwestern Germany during the 5th–8th centuries to assess the usefulness of modern proxy variables for explanations of regional differences in living standards in the distant past. Assuming some continuity in the relative suitability of smaller areas, the results suggest similar responses to environmental and climatic constraints, even though population density, agricultural technology, market integration, and consumption patterns of subsistence farming were very different from 19th-century conditions.

This chapter has been submitted to an academic journal.

English-language quotations from German texts are my own translations, except where the terms are well-established in the literature.

4.1 Introduction

The biological standard of living, proxied with average heights, tends to be correlated with agricultural specialisation. Analysing data from the early years of military conscription in 19th-century southern Germany and France, e.g. Baten (1999, 2000, 2009) demonstrated that young men in districts with higher per-capita milk production grew taller than those growing up in regions specialising in cereals or potatoes. The same basic pattern, that "proximity to protein production" has significant influence on average heights (cf. Meinzer and Baten 2016, for a brief review) has been found in other world regions (e.g. Moradi and Baten 2005; Baten and Blum 2014).

Can these historical regional patterns of average heights, of the biological living standard people enjoyed, be traced further back in time? Did children grow up into (on average) taller adults in the same regions of Central Europe during the Early Middle Ages as they did in the 19th century? The agricultural output that has been identified as driving the results for the 19th century was determined to some degree by environmental differences. For these, the "first nature" (cf. Krugman 1993) of a place, i.e. the climate and geographical features, is likely to be more important than the "second nature" of man-made improvements upon the first, such as roads and canals, than it is for the location of trading hubs and centres of manufacturing. While the latter gained importance with the development of rail roads and industrialisation in general in the 19th century, it has probably also been influential in the Roman economy with its substantial scale of long-distance trade. Regarding the Early Middle Ages, however, archaeological finds suggest that food and many necessities were locally sourced in Merovingian southwestern Germany (Steuer 1997).

While the conscription data and the agricultural statistics from the 19th century cover most of the study region with administrative-district aggregates that can be linked to regional environmental characteristics, the early medieval data is more dispersed with no obviously best way of mapping it onto the administrative districts.[1] Assessing the relationship between height outcomes and environmental characteristics of the districts for the conscript data or of small regions around the cemeteries for the early medieval data is a way to avoid further reducing the number of observations. Since the statistics of agricultural production from the early 19th century are among the first that were compiled for the study region and there are no comparable sources for the Early Middle Ages, the diachronic comparison is based on a number

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[1] The map of the historical administrative districts (figure 4.2) shows that a surprisingly large share of the cemeteries are located very close to district borders.

of proxy variables for agricultural suitability constructed from modern data. This allows using similar methods to construct the covariates for both time periods instead of somehow assigning values from the historical agricultural statistics to cemeteries or aggregating data from different cemeteries to conform to administrative district boundaries. Since it is not obvious, which of the proxies for the relative suitability for dairy farming that could be constructed in many ways from modern agro-environmental data are conceptually the best suited for analyses of biological living standards in this study, regressing height data from both time periods on very similarly constructed proxy variables and comparing the results may also help finding suitable candidates, assuming that the relationship between environment and biological outcomes did not change too much.[2] Preliminary steps involve the historical agricultural statistics, replicating the results of (e.g. Baten 1999) and others using the sample as constructed and prepared for the main analyses and assessing the relationship between the historical and the modern covariates.

The link between dairy farming and taller average heights in 19th-century Germany is robust to changes in estimation strategies and slightly different approaches to data preparation. Following a brief section providing background information from the literature and another one discussing the various datasets, the main results regarding the share of young men rejected from military service for failing to meet the minimum height requirement and the number of cows per person on the level of administrative districts are replicated using multilevel mixed-effects models. In a next step, the historical relative population densities of cattle and pigs are regressed on a battery of indicators of suitability for various agricultural specialisation constructed using modern data. Following this 'training case,' the modern indicators are correlated with a sample of estimated heights of almost 2,200 individuals whose skeletal remains were excavated from 40 cemeteries from southwestern Germany dating to the early medieval Merovingian era (5th–8th centuries). This two-step approach yields at least qualitatively similar patterns for both the Early Middle Ages and the 19th century.

4.2 Background and literature review

"The Long Economic and Political Shadow of History" (the title of three volumes edited by Michalopoulos and Papaioannou 2017), i.e. the persistence of historical patterns influenced by characteristics of nature or decisive events

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[2] The underlying potential problem of "researcher degrees of freedom" has been highlighted by e.g. Simmons et al. (2011) and Gelman and Loken (2014).

in the distant past, is increasingly receiving attention in economics. Relative sizes of cities and regional patterns of population density seem to be fairly stable over time. Davis and Weinstein (2002), for example, found the population density of Japanese regions to be remarkably persistent, with rank correlation coefficients above 0.5 between any period since the beginning of agriculture and 1998. Even large external shocks, such as the bombing campaigns of the United States in World War II (which included the nuclear bombing of Hiroshima and Nagasaki) apparently resulted only in temporary deviations from cities' long-term growth paths. A similar account of the resilience of city growth and regional differences in economic activity is reported by Brakman et al. (2004) for the German case, where allied air raids and soviet occupation were the exogenous shocks to city size and regional integration.

Are regional differences of (biological) well-being similarly stable over time as settlement patterns? Grasgruber, Cacek, et al. (2014) and Grasgruber, Sebera, et al. (2016) emphasise that differences in diets, which to some extent reflect local agricultural specialisation, account for a large part of the variation of heights, averaged at the national level. They report a 10-centimetre height advantage of peoples eating substantial amounts of animal protein over those subsisting on plant-based diets that provide the required daily intake of protein and overall calories (Grasgruber, Sebera, et al. 2016, p.194). Regional dominance of specific crops or agricultural techniques is often rooted in environmental characteristics or resource endowments due to the requirements of different crops, that where even more important in the past. Within the parts of Central Europe that were settled in the Early Middle Ages, the environmental differences are of course less pronounced than e.g. between regions especially suited for paddy-field farming of rice or sheep husbandry. At the margin, however, even smaller differences e.g. in the duration of the growing season likely influenced the decision between cereal cultivation, pasture, or other land uses.

4.2.1 'Proximity to protein production'

Many perishable foodstuffs, such as dairy products, were difficult to transport before refrigeration, pasteurisation, and motorised transportation were invented and widely adopted. Regional differences in the biological standard of living that arise from agricultural specialisation should, therefore, be larger in regions with less well-integrated markets for foodstuffs, and should typically have been larger in the past as well. Using agricultural statistics and data on human heights from examinations of young men for military conscription, Baten (1999, 2009) examined regional variation of agricultural production and average heights in the 19th century.

For earlier times, Koepke and Baten (2008) studied the link between average heights, estimated from archaeologically excavated human remains and the prevalence of bovine remains among bones of domesticated animals. They found estimated heights to be larger in parts of Europe where bones of cattle were especially common compared to those of pigs and sheep or goats.

Unfortunately, the mortuary evidence from the Early Middle Ages analysed in this paper does not allow using the approach of Koepke and Baten (2008) – inferring the relative importance of cattle/dairy farming from excavated animal bones – for the micro-regions around the cemeteries. Most of the excavated animal bones associated with the people in the sample are likely the remains of food offerings, though some belong to animals that were buried in their own graves. While many of the cemeteries in the sample have at least one burial of a horse, burials of dogs were less common, and only one of the cemeteries in the sample had a grave of a doe (Martin 1976). Looking at the minimum number of individual animals that can be inferred from the available bones, those that ended up as part of food offerings in the graves outnumber those interred whole. It seems probable that food offerings interred during a burial ritual are not representative of the diet of the early medieval populations. For many cemeteries, however, the archaeological documentations from which the dataset used here is compiled, do not contain archaeozoological analyses of the excavated animal bones.

4.2.2 Agricultural specialisation in the Early Middle Ages

Finds from archaeological contexts better suited to shed light on every-day life, such as refuse-pits or remains of settlements, are typically not available to augment the mortuary evidence from the Early Middle Ages. While thousands of cemeteries from that time have been excavated (and mostly remain in storage waiting to be analysed at some point in the future), fewer settlements from that time have been found. Still, knowledge about subsistence strategies of the Early Middle Ages in southwestern Germany is mostly inferred from archaeological finds. Written sources pre-dating the 8th century are rare. Works concerned about food and nutrition, such as Anthimus (1996), are not directly concerned with agricultural production and describe circumstances at the royal court that were probably different from the those of the rural communities that buried their dead on the sampled cemeteries.

As long as people in the past tended to accurately perceive local environmental conditions and tried to make the most of them, e.g. by concentrating on dairy farming in regions better suited for permanent pasture than for cereal cultivation, the suitability of soil and climate for certain crops may be a sensible proxy or instrument for agricultural production. While historical weather records such as annual summer temperature averages are available for long periods of time, the relatively high volatility of precipitation and temperature averages in Late Antiquity and the Early Middle Ages (cf. Büntgen et al. 2011) is an obstacle to attempts of matching them with the anthropometric information that is mostly dated using typological seriation of associated archaeological finds.[3] However, local growing conditions depend on more than regional temperature averages or early summer precipitation.

Land cover, soil quality, relief and other factors have likely changed to some extent between the early medieval period and today, but since no reliable data with sufficient spatial resolution to analyse local differences is available, present-day conditions are probably the best starting point for approximations of past conditions. When comparing the characteristics of smaller areas, implicit claims of continuity can be reduced to the basic assumption that their rank order with regard to the various indicators of suitability is somewhat stable over time through appropriate construction of the variables. The high plateau of the Swabian Jura, for example, that is colder and wetter today than its warmer and less rainy forelands, was probably so as well in historical times given the orography of the region and common wind directions, even when the levels of both variables have been different.

However, using potential yields calculated for modern varieties of crops cultivated using modern technologies may prove more useful for the recent past. Archaeo-botanical evidence from the Early Middle Ages does not show a dominant cereal crop, in contrast to the Roman era and the Middle Ages later on (e.g. Rösch et al. 1992). Cultivating a different cereals at the same time is interpreted as an "obvious [...] attribute of a rural society without food trade" (Rösch 2008, p.236). Prior to the invention and wide-spread use of the 'heavy plough' around 1000 CE, fertile clay soils could not be tilled and thus were of little use to the people, as examples such as the spread of settlements into areas with clay soils in Denmark in the wake of that particular innovation show (Andersen et al. 2016). In the study area, it has long been argued that the places with names deemed to indicate that they were founded early in the Merovingian era are concentrated on land with higher agricultural yield potential according to a classification scheme used by the German tax authorities (Wacker 1978; Hoeper 1997).

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[3] Assuming that depositions of specific types of artefacts over time follow unimodal distributions, archaeologists typically compute the first orthogonal dimension of a sparse matrix of assemblages (rows) and presence of artefact types (colums) using correspondence analysis to infer plausible rankings of the assemblages, i.e. a scheme of relative chronology (e.g. J. Müller and Zimmermann 1997).

4.2.3 Estimating heights from long-bone measurements

Heights of individuals who lived in the Early Middle Ages have to be reconstructed or estimated from measurements of their skeletal remains for the subsequent analyses. Various processes of decomposition can affect the position of individual bones (cf. Dent et al. 2004, on human decomposition) so that the length of the skeleton measured *in situ* would still be a somewhat biased measure of the persons height before they died. Furthermore, most of the excavated skeletons are not as well-preserved as they would have to be to allow for accurate measurements. And where the grave has been robbed at a time when the body had already disintegrated, the remains are often in disarray, or even piled up in a corner of the burial-pit. The lengths of the long limb bones, especially those of the legs which contribute directly to it, are strongly correlated with body height. Assuming some similarity of body proportions between the study population and samples of individuals for whom both long bone measurements and stature or body length are known, the heights of the study population can be estimated using regression results from the reference group.

A number of regression formulae have been proposed, based on different skeletal samples, which can yield strikingly different results (cf. Siegmund 2010, 2012). The estimation formulae of Trotter and Gleser (1952, 1977) for "American whites", which were often used in English-language literature (Steckel 2004, p. 213), emphasize the differences between shorter and taller people while the formulae of Breitinger (1937) and especially Bach (1965), which are more commonly used in the German literature (cf. Koepke 2014), yield a rather small range of estimated heights for the same measurements. Both formulae from Pearson (1899) estimate similarly short people as the Trotter/Gleser formualae at the lower end of the relevant range of *femur* lengths, but much shorter tall people at the other end. For men, the estimated Pearson heights at the longer end of the range of bone measurements are just slightly shorter than Breitinger heights. For women, however, Bach heights are shorter than Trotter/Gleser heights only for very long *femora* but much taller than both other estimates toward the lower end of the relevant range. The formulae proposed by Ruff et al. (2012) not only yield averages very close to the Pearson (1899) estimations and have been recommended for skeletal material from Central European populations of the Early Middle Ages (Siegmund 2012) but seem to perform well with regard to the standard deviation of estimated heights as well (cf. Meinzer 2017).

The following analyses use Ruff et al. (2012) estimated heights, calculated directly from long-bone measurements, or from implied long-bone lengths where no raw data but only height estimates based on other formulae are available. The implied measurements are calculated using the respective estimation formulae for *femora*, *tibiae*, *humeri*, and *radii* and the given height estimate.

4.3 Data

This paper uses data generated in three time periods. The first sub-section discusses the early medieval mortuary evidence, the second one describes the anthropometric data from 19th century conscription statistics and the summary data from agricultural censuses that has been used before to assess the relationship between average heights and dairy production (e.g. Baten 1999, 2000, 2009). The third sub-section discusses contemporary data that is used to construct proxies for the suitability for crops or the relative suitability for dairy farming.

4.3.1 Early medieval mortuary evidence

The early medieval dataset combines anthropometric measurements of about 2,200 adult individuals excavated from 40 cemeteries in Central Europe with archaeological details of grave-goods and burials.[4] Figure 4.1 indicates the location of these cemeteries on a map showing a shaded relief and larger rivers and lakes for orientation. The numbers on the map are used as identifiers in table 4.1 which provides numbers of individuals, summary statistics, and references to the sources from which the dataset is compiled.

While a large number of early medieval cemeteries have been excavated in the region, most of the material remains to be analysed archaeologically or anthropologically, or comes from incompletely excavated or unsatisfactorily preserved cemeteries (cf. Gauß 2013; Dauber 1972). The database covers the sites and samples that are well documented, augmented with anthropometric data for a number of places for which no archaeological documentation was available. This pre-selection of cemeteries for analyses may have favoured places close to cities with universities, where the finds were analysed, from the overall sample of excavated cemeteries. Those, in turn, are more likely to have been discovered in places where construction activity picked up after

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[4] It is also used elsewhere to analyse inequality of biological living standards, as expressed in the coefficient of variation of estimated heights, finding a higher level of inequality among the people buried after around 600 CE. Meinzer (2017) uses a previous version of the dataset to assess differences in estimated male heights associated with conspicuous grave-goods and caution that these may not accurately reflect inequality of living standards.

during the 20th century, when heritage and conservation laws ensured that accidental discoveries triggered archaeological surveying. Together, this may skew the sample towards locations that turned out to be better suited for human settlement in the long run. But it does not seem likely that the communities in those places should have had systematically different subsistence strategies from those who were not yet excavated or analysed, or who have been destroyed in the past.

4.3.2 German statistics from the 19th century

4.3.2.1 Conscription statistics

During and after the Napoleonic wars, many of the German states introduced national conscription to increase the size of their standing armies and generate military reserve forces. A useful by-product of these efforts are conscription lists, containing personal information, including height measurements, of complete birth cohorts of young men, at least in the best cases.

For the Grand Duchy of Baden, Ammon (1894) compiled and published average heights and percentages of short and tall conscripts measured between 1840 and 1864. In addition to average heights in metres, with a state average of just 1.64 metres, he reported the percentages of young men who were shorter than 1.62 and 1.57 metres, and taller than 1.70 and 1.75 metres, respectively. The numbers are aggregated over the time period of 25 years and reported on the level of municipalities, of which Baden had about 1,600. Interestingly, conscripts were measured in the principal town of the municipality where they were born, not where they lived when they reached the age for their military duties (cf. Ammon 1894, p.3). Eleven of the districts for which he further aggregates the data contain two or more of the districts of the reference year 1862, however, since the data are also given on the municipality level, the numbers can be constructed for the 23 older administrative units. The rest of the 64 districts and cities were more or less the same in 1894 as they were 30 years earlier.

For the Kingdom of Bavaria, two volumes of the *Contributions to the Statistics of the Kingdom of Bavaria* (Hermann 1853, 1859), a statistical yearbook, report the number of young men who were called up for compulsory military service as well as the number of men rejected for lack of height, and because of other illnesses for the birth years between 1808 and 1815, and between 1830 and 1835. The Bavarian minimum height requirement was 5 feet 4 inches, i.e. 157.6 centimetres, remarkably similar to that of Württemberg. The more than 280 judicial districts for which the data are given were consolidated into 184 districts and cities in 1862, drawing on Volkert and Bauer (1983). Aggregating the data from the yearbooks according to the administrative reforms will only be inaccurate in the few cases where municipalities of the same judicial district became parts of different administrative districts. Here, the numbers were assigned to the administrative district that inherited the largest area of the former judicial district. the Bavarian sources, unfortunately, do not report average heights.

The statistical yearbook for the Kingdom of Württemberg (Riedle 1834) reports average heights of conscripts measured in 1833, when the total average was 58.25 Württemberg decimal inch, or 166.9 centimetres, as well as percentage shares of young men taller than 6 Württemberg 'shoes', or 171.9 centimetres, or shorter than 55 decimal inches, or 157.6 centimetres, respectively. Later, aggregate total numbers of conscripts, and numbers of measured and examined conscripts rejected for lack of height or because of other illnesses or disabilities were reported for the years between 1834 and 1857 (Sick 1858). Both sources report the data only aggregated on the level of 64 districts.

The Prussian Rhinelands are mainly included to broaden then basis for comparisons between modern-day agro-climatical data and historical data on agricultural production, since data on the share of conscripts rejected for lack of height only seems to be available for the larger administrative regions. The 58 Rhineland districts were organised into five administrative units for which Prussian statistics are available. The key variable is the percentage of eligible men aged 20 to 24 years who were temporarily unfit due to lack of height, as reported by Dieterici (1855). As young men who were rejected for being too short were re-measured annually until they were 24 years old, the share of men with terminal heights below the cut-off point of 5 Prussian feet and 5 feet 2 inches, i.e. 162.2 centimetres. The statistics of the Prussian Rhinelands report the share men in the relevant age-bracket that actually served in the military on the district level, but since rejection does not imply any causes and the military's demand for personnel also played a role, the Rhinelands are excluded from the replication efforts.

Table 4.2 also shows summary statistics for the aggregated indicators of the percentage of young men who were notably tall, i.e. taller than 170 centimetres in Baden or about 172 centimetres in Württemberg, or too short for military service.

4.3.2.2 Agricultural production

Statistical yearbooks published by the authorities of the various German states contain information on numbers of different animals, harvested crops, land use, and many other agricultural inputs and outcomes, often disaggregated to the level of local administrative units. Some of the reported measurements, such as the number of dairy cows per inhabitant, are readily comparable across states and times,[5] but others are more challenging. These were the early days of economic statistics, and reporting practices were very far from being standardised internationally.

The number of dairy cows per person is expected to have the strongest effect on the share of young men too short for military service. In cattle-districts, even the poorest people were likely to have had access to high-quality protein, if only from skimmed milk, left over after the cream had been diverted for other purposes, butter milk, or whey, a by-product from cheese production. The (shadow) prices of these products were likely rather low because they could not be sold elsewhere, since refrigerated transportation was not yet an option. Discussing the historical statistics used as a source by Baten (2009), Viebahn (1868) cites research that fresh milk was profitably transported only for up to three miles by road and 30 miles by rail road at that time in America, likely because he did not have numbers for the local conditions in Prussia. Including other cattle, such as young animals raised for meat production, or oxen and other animals primarily used to provide traction for various purposes, should reduce the strength of the relationship, since these animals do not directly provide protein in a similarly equitable fashion. Nevertheless, the overall number of cattle per inhabitant is still expected to be strongly negatively correlated with the share of short men.

Pigs do not provide a similarly steady stream of protein to rich and poor alike, so their number per inhabitant is not expected to have had a strong impact on the average height of the men called up for military service. Other animals are probably even less directly related to protein production or have more volatile numbers and are therefore harder to compare across countries. Horses, which were not typically raised for meat production are an example for the former category, smaller animals such as chicken have rather short generation times and fall into the latter category.

The share of arable land planted with certain crops belongs to the more challenging variables due to reporting differences. Not all of the sources go into as much detail regarding the area used for specific crops as the Bavarian land use statistics for 1853, so the share of non-forested land used to cultivate

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[5] Morgenstern (1965, pp.46) recounts a cautionary anecdote, where the number of pigs in Bulgaria seemingly increased dramatically from one year to another, because the transition from the Julian to the Gregorian calendar shifted the census date around the time where most of the pigs were slaughtered every year, to make the point that there are many sources of measurement error and other factors that can be important for the interpretation of economic statistics.

any crops is constructed as a blunt indicator of the importance of agriculture in the administrative districts since it is either reported directly or can be computed from its components for all four states considered here.

The Bavarian numbers are from two other volumes of the *Contributions* (Hermann 1855, 1857), the same statistical yearbook from which the aggregated numbers of conscripts with various physical properties are taken. The first volume of the *Statistical Yearbook for the Grand Duchy of Baden* (1868) provides a variety of key figures on agriculture and farming. Essays in different volumes of the statistical yearbooks for the Kingdom of Württemberg (18231850) cover the results of agricultural censuses. Finally, the *Contributions to the Statistics of the Prussian Rhinelands* (1829) provide district-level agricultural data from the early 19th century.

In contrast to the outcome variables, i.e. the shares of short and tall young men, which are typically reported as aggregated data, the historical agricultural variables are constructed using numbers from agricultural censuses of individual years, typically in the timespan covered by the military data. Since these may not be representative of typical conditions during the formative years of the men in the sample, simple averages from several years are used where the data is readily available. It is, however, not obvious that aggregates computed from several years are necessarily superior measures, given that administrative boundaries and reporting practices changed over time. Table 4.3 summarises the agricultural production variables described above. The administrative districts of the four states, in the boundaries of 1862, are shown together with the sample cemeteries in figure 4.2.

4.3.3 Climate and environment – modern data

4.3.3.1 Composite indicators – potential yield

With the *Global Agro-Ecological Zones* system, the *Food and Agricultrure Organization of the United Nations* (FAO) provides data on a range of factors relevant to agricultural production. Using a complex model, they estimate yield potentials for common crops with a spatial resolution of 5’ by 5’ using soil quality, climate constraints, and other factors. For cattle farming, the relevant crops are pasture legumes and pasture grasses, both assuming low input level rain-fed agriculture. For the alternative, agricultural production of foodstuffs for human consumption, there are a number of different cereals and other plants. Galor and Özak (2015, 2016) propose the “caloric suitability index” to solve the potential problem arising from lack of knowledge about the crops people actually cultivated and the differences in suitability between plants. They weigh the “agro-climatically attainable yield” of 48 relevant plants with the caloric density of the produce and determine the maximum number of calories that could be produced per hectare per year, and other similar measures. For their purposes, they also construct the same set of indices limiting the crop plants to those available before the Columbian exchange, restricting e.g. potatoes and maize to their respective regions of origin in the Americas.

Since the "caloric suitability index" only takes into account crops that are fit for human consumption, it is not directly useful to assess the suitability for dairy farming or other specialisations. Baten, Szołtysek, et al. (2016) use the quotient of *Food Insecurity, Poverty and Environment Global GIS Database* (FGGD) suitability scores for pasture and cereals as an instrument for the number of cattle per person, i.e. 'proximity to protein production.' Since potential yields for "pasture grasses" or "pasture legumes," that are also provided in the *GAEZ* system from which the "caloric suitability index" is derived, indices of relative suitability for pasturing are constructed by dividing the potential yield calculated for each raster point by the respective "caloric suitability" for the subsequent analyses. Transforming the former into calories per area per year based on assumptions about the optimal rate of conversion of feed into milk or meat would allow for a dimensionless index number. However, since those assumptions would have to be based on the characteristics of modern races of animals and modern methods of animal husbandry, which are very different from early medieval conditions, this could instil a false sense of accuracy. Regression analyses on the outcome variables in both the 19th-century 'training' case and the early medieval are done using the "caloric suitability indices" for the optimal caloric yield, and the potential yield of pasture grasses and legumes, as well as the indices of relative suitability for production of animal fodder compared to human fare.

4.3.3.2 Phenological indicators

Another kind of data is obtained without measuring instruments. Phenological records detail the occurrence of life cycle events of plants in different years. Trained observers of *Deutscher Wetterdienst* monitor regions stretching between 1.5 and 5 kilometres around their homes, noting on which day of the year specific plants reach certain developmental stages. The duration of the growing season, for example, can be defined in various ways such as the number of consecutive days with a minimum air temperature above a certain threshold (typically 5°C) when plants can experience most growth, or as the number of days between growth of new foliage and leaf drop in deciduous plants (Chmielewski 2007, p. 31).

Here, the average day of the year on which the first leaves appeared on various species of trees[6] is subtracted from the average day on which they have shed about half of them in autumn to calculate the duration of the growing season in days (cf. Chmielewski 2007). As observations are localised, values for the area around the cemeteries (i.e. the settlements using the cemeteries) have to be interpolated. For each of the cemetery and for the centroids of the administrative regions, the average of the nearest ten observations is computed using the inverse of distance to the third power as weights.

To appraise the suitability of micro-regions for cereal farming and pastures, the time between the beginning of stem elongation and the grains reaching hard dough state, averaged over three kinds of cereal grains[7] each for winter and spring varieties, and the duration of the life-cycle of grass on permanent grasslands from greening in early spring to the first harvesting of hay are constructed as indicators mimicking the approach used for the growing season.

4.3.3.3 Soil quality

The yield potential of German crop land has been assessed according to the *Muencheberg Soil Quality Rating* (Mueller et al. 2007) taking into account features of the soil as well as climatic risk factors. The results, available as raster data, have been prepared similar to the other spatial data. However, since only actual crop land, used for farming in the 2010s is assessed, the soils of some regions such as the Black Forest have not been rated. Fortunately, this is a minor problem for the analysis of early medieval living standards, since no cemetery has been excavated in the Black Forest and it is suspected to have remained largely devoid of settlements until later in the medieval period.

The assumption would be that better farmland made it easier to provide for a larger population, relying mainly on grain production to produce as many calories as possible on the available land. While cereals are sufficient to provide enough energy, they are not as rich in protein of high biological value as animal-based foods. With very low population density, as in the Early Middle Ages, people may not have had to cut back on land-intensive animal husbandry to ensure their subsistence on grains.

Soil characteristics are also the basis of the "Ertragsmesszahl," an indicator of yield potential that is used to calculate the property tax imposed on

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[6] *Aesculus hippocastanum*, *Betula pendula*, *Fagus sylvatica*, *Sorbus aucuparia* and *Quercus robur*.

[7] Winter and spring wheat (*Triticum*), Winter rye (*Secale*), winter and spring barley (*Hordeum*) and oats (*Avena sativa*).

agricultural land in Germany (cf. Wacker 1956).[8] The measure is based on classifications of the soil on a 50 metre grid, taking into account additional factors such as slope, hydrology, and climate.

Summary statistics of the indicators derived from modern data for the administrative regions, as well as circular areas around the locations of the cemeteries, are presented in table 4.4. It is augmented by table 4.7 in the appendix, where the statistics are reported separately for each of the states.

4.4 Results and discussion

As a benchmark test, the share of young men shorter than the minimum height requirements of the various German states, constructed from historical statistics as described above, is regressed on the number of cattle per person, and the other agricultural variables constructed from 19th-century statistics, replicating the analyses of Baten (1999, 2009), and others. The structure of the dataset suggests using multilevel models for regression analyses to explicitly take into account for possible country-specific differences between the sources.

Figure 4.3 shows standardised regression coefficients with one-standard error bounds, based on the results reported in table 4.5. Table 4.9 in the appendix additionally reports the effects of including or excluding a dummy variable for major cities, and results for the share of short people excluding the Bavarian districts so that the sample is the same as for the regressions on the share of tall people. Not surprisingly, the results for the shares of tall and short people have different signs but somewhat similar absolute values. Administrative areas with fewer cattle per person reported significantly lower shares of young men who were shorter than the minimum height requirement of the military, but not a statistically significantly larger share of tall young men. For (dairy) cows and pigs, the effects are both stronger in absolute terms and statistically significant at least on the ten percent level, with opposite signs. Regions with more cows per person had more tall and fewer short young men, while districts with more pigs per person had fewer tall and more short young men. Districts where a larger share of the land was used to cultivate crops also tended to have fewer tall young men.

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[8] Data were provided on request by the *Statistisches Landesamt Baden Württemberg*, the *Bayerisches Landesamt für Steuern*, the *Oberfinanzdirektion Koblenz* in Rhineland Palatinate, and the *Landesamt für Vermessung, Geoinformation und Landentwicklung* of the Saarland. For Hesse, the data are available at `http://www.hlnug.de/static/medien/boden/fisbo/bs/kompVO/table_kompvo.html`.

4.4.1 Re-assessing the 19th century

For the 19th century, in contrast to the Early Middle Ages, the proxy variables for agricultural specialisation and output can be assessed against actual agricultural output data. A two-stage regression approach, using numbers of animals per person implied by these regressions to explain the regional variability of biological living standards in the early medieval, would assume that the relationship between agro-climatical fundamentals and agricultural specialisation were very similar in both time periods. Figure 4.4 shows the relationships between the numbers of cows, cattle in general, and pigs per person and a variety of the proxy variables derived from modern data.[9]

Moving onto the 'training case' of proxy variables constructed from modern data, the results are summarised as standardised coefficients and depicted in figure 4.5. As described above, the various covariates have widely different scales and units, some of which, as those of the indices of relative suitability for various pasture grasses or legumes based on FAO/GAEZ data, are hard to interpret by themselves, so standardising is a useful approach. It has to be noted, however, that the outcome variables are somewhat different between the 19th-century German states (see table 4.2), namely that the share of short men was substantially lower in Bavaria than in the two other states. To have the variation inside the states reflected in the pooled data assessed with the multilevel model instead of focusing on the country averages, the shares of tall or short men are first standardised separately for each of them. The covariates, being derived from the same sources for all of the countries, are standardised over the full sample of administrative districts used for the respective analyses.

Districts with better suitability for pasture grasses or legumes relative to the "caloric suitability index" of Galor and Özak (2015, 2016) seem to have had lower shares of short young men, as would be expected if agricultural specialisation depended to some extent on environmental conditions. Interestingly, though, not only the standardised coefficients of the potential yield of pasture grasses and legumes by themselves, but also the potential yield of cereals in general show only slightly weaker relationships. The phenological indicators of the suitability for cereal cropping are somewhat inconsistent, but it has to be kept in mind that they are constructed from the number of days it takes the plants from an early growth stage to ripening of the grains. As described above, higher values of these variables could be expected to indicate lower suitability for grain agriculture, so the correlation has the expected sign.

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[9] More details shown in table 4.10 in the appendix.

4.4.2 Agricultural suitability and early medieval heights

Next, the early medieval estimated heights can be regressed on the host of indicators used in the analyses of the 19th-century data. While the underlying modern datasets used to construct those variables remain the same, the method to assign values to the units of analyses is somewhat different in this case, since the are no known administrative units to which the cemeteries (or better: the settlements using them) belong. As a straight-forward alternative, circular areas with a radius of 2.5 kilometres around the (approximate) location of the cemeteries are used to sample raster data using GIS software.[10]

Figure 4.6 shows standardised coefficients with one-standard error bounds from two-level models assuming the individuals to be grouped on the cemetery level.[11] The dependent variable in the right-hand panel is the average estimated height of adult males, so the coefficients should have the opposite sign from those presented in the left-hand panel of figure 4.5, showing the percentage share of young men shorter than the minimum height requirement in the 19th-century data. A higher share of short people implies a smaller average height, and vice-versa. The right-hand panel of figure 4.5 shows the share of tall men among the conscripts of Baden and Württemberg, for which the coefficients would be expected to have the same sign as those for average estimated heights.

Furthermore, the analyses are repeated using circular areas with a radius of 5 kilometres around the cemeteries, sampling again the median values of the raster data. The results, summarised in the left-hand side panel of figure 4.7, juxtaposed with the results shown in the right-hand side panel of figure 4.6, and detailed in table 4.8, both in the appendix, are virtually the same those for the smaller areas shown in the figure's other panel.

At first glance, the right-hand side panels of figures 4.5 and 4.6 look remarkably similar. Taking into account the left-hand side panel of figure 4.5, showing the results for regression of the share of short young men, however, does not simply reinforce that impression but emphasises the differences between the agricultural techniques and living conditions that mediate the influence of production on the biological well-being of the early medieval populations and the young men of the 19th century. While some of the relationships between the historical outcomes and the modern covariates go in the same direction, others are ambiguous or even have opposing signs. The

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[10] Spatial analyses of data available as georeferenced raster images were performed using the zonal statistics tools of the free and open source *QGIS Geographic Information System*, of the Open Source Geospatial Foundation Project.

[11] More details shown in table 4.11 in the appendix.

relative suitability for "pasture legumes" compared to the "caloric suitability index," for example, seems to go into the same direction, with higher values in districts or areas with fewer short young men or taller average heights. However, the most similar indicator, based on "pasture grasses" instead of "pasture legumes," does not have a similar relationship with the early medieval data. The 'raw' "caloric suitability index" of pre-Columbian-exchange crops has the same direction of effects for both periods, though the effect is small and rather ambiguous in the case of the 19th-century share of short men. The other potential yield indicators sampled from GAEZ/FAO data yield conflicting results, not matching expectations in the early medieval case and yielding conflicting results for the shares of short and tall people, respectively. As a group, the phenological indicators fare somewhat better, having at least the same sign for the point estimates, though the one-standard error boundaries show that the relationships between some of the indicators and the outcome variables are ambiguous. Districts and areas where observers reported a larger number of days between the grass on permanent pasture resuming to grow in spring and the first cut of hay tend to have had shorter adult males or a higher percentage of too-short potential conscripts. Interestingly though, there is no similar relationship between these outcomes and the potential yield of "pasture grasses" consistent over time.

It has to be noted that the settlements to which the early medieval cemeteries belonged are not evenly distributed throughout the region covered by the 19th-century data. The region was sparsely populated during that time, so the marginal land used for agriculture in the Early Middle Ages was likely much better than some of the land that was used in the agricultural production documented in the historical statistics. However, since there are fewer cemeteries than administrative districts, and the latter have a larger area than the circular regions around the former, the variability of the covariates constructed from modern data turns out to be somewhat higher for the cemetery regions, as shown in table 4.4. Therefore, the standardised effect sizes shown in the graphs for the two time periods are not necessarily directly comparable.

Comparing average height differences between populations from cemeteries in regions scoring the highest for the an environmental covariate with those from regions with low scores is an intuitive approach to assess potential associations. Table 4.6 compares average heights of males and females excavated from cemeteries in the first tercile on each of the proxies with those from the third tercile, showing t-statistics and p values from basic tests of equality of means. As in the more rigorous analysis, the phenological indicators are, as a group, associated with the most substantial differences in means, as reflected in the highest absolute values of the t-statistic. Average estimated male heights are about a centimetre higher in the group of people from cemeteries in the upper tercile regarding the time it takes for cereals to grow and ripen, i.e. the regions less well-suited for the cultivation of those crops. Regions where pasture grasses are typically cut earlier were home to, on average, taller men. Interestingly, the same is true for regions where the growing season, i.e. the time between the first appearance of leaves on deciduous trees and their shedding in autumn, is shorter. Similarly, men buried on cemeteries in areas scoring in the upper tercile of “Caloric Suitability Index”-numbers were also on average about a centimetre shorter than those from areas in the lower tercile.

4.4.3 Female heights

While the military data from the 19th century does not contain height information for women, because only men had to serve in the military, the early medieval cemeteries became the last place of rest for men an women alike. The results, summarised in the left-hand side panel of figure 4.6, differ from those for their male counterparts described above, first and foremost by being more ambiguous.[12] Only one of the fifteen variables constructed from modern data, namely the phenological indicator constructed from the duration of growth of summer cereals, has the whole interval of two standard errors shown in the graph on one side of the null-line. Incidentally, the sign of the point estimate is the same as it is for male heights. For more than a third of the variables, even the sign of the point estimate differs between the regressions on male and female heights.

The juxtaposition of females from cemeteries in the lower and upper terciles of environmental covariate scores of the area around the cemeteries (table 4.6) does not differ substantially from the results of the more elaborate analyses shown in figure 4.6. The associations between estimated female height and the covariates are similar to those observed for males for the phenological indicators, and mostly differ for the relative suitability scores constructed from GAEZ suitability for pasture crops and the “caloric suitability index.” For two thirds of the tested covariates, the t-statistic from the equality-of-means test is smaller in absolute value than it is for the same test of estimated male height averages.

The differences between males and females need not be interpreted as ruling out the viability of the approach of using climate and environmental data as proxies for agricultural production, since the relationship between output

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[12] More detailed results for the regressions summarised in the two panels of this figure are shown in tables and 4.13 and 4.12.

and actual consumption (which influences heights) is mediated by cultural practices that may have been markedly gender-specific. Even in recent populations, anthropometric studies found gendered differences, for example in the relationships between income and height inequality (e.g. Moradi and Baten 2005).

4.5 Conclusion

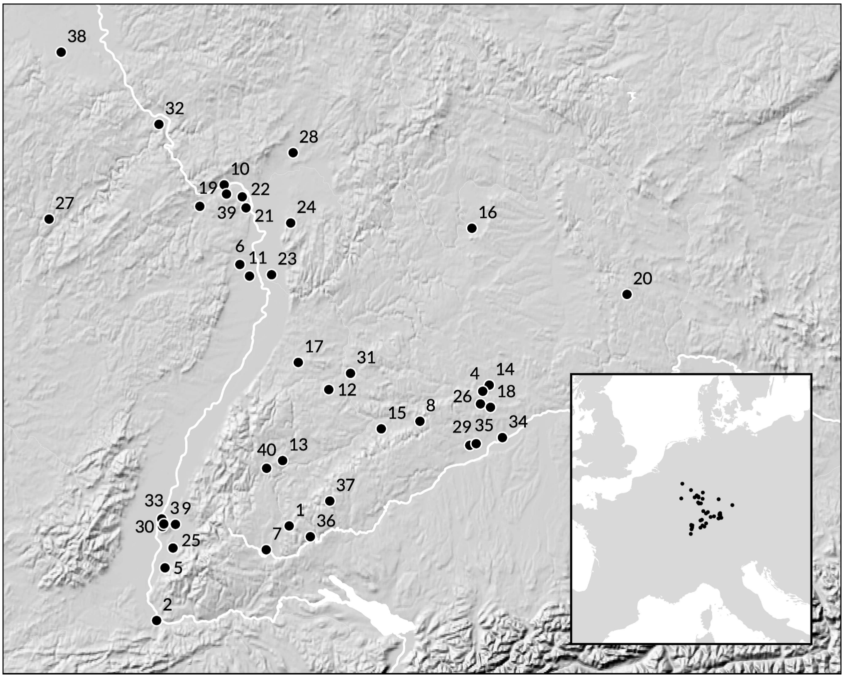
The general results of Baten (1999) and others are robust to variations of the specification of the model and can be replicated in multilevel models. 'Proximity to protein production,' operationalised as the number of cows per person, is strongly correlated with the biological well-being of the population, measured using the distribution of young men's heights, on an administrative district-aggregate level in three 19th-century German states. Proxy variables for the suitability of these districts for cattle farming or grain agriculture constructed from modern data correlate strongly with the variables derived from historical statistics that represent different agricultural specialisations.

The modern indicators of agricultural suitability themselves are, as their relationship with historical output and specialisation pattern suggests, themselves correlated with the historical proxy data for biological well-being. The indices of GAEZ/FAO "agro-climatically attainable yield" and the "Caloric Suitability Index" of Galor and Özak (2015, 2016) are arguably useful proxies for agricultural output, especially 'proximity to protein production,' as long as production technology and other circumstances can be assumed to be somewhat similar to those of early-industrial Central Europe.

For the Early Middle Ages, and presumably also for other eras in the distant path, the analyses suggest that proxies based on modern data should be used cautiously, taking into account technological and cultural differences. The very low population density of the region during the Early Middle Ages may have allowed people to deviate from maximising calorie production in favour of increased crop diversity or more land-intensive modes of production than cereal cultivation. The regional patterns of height averages associated with differences in the 'proximity to protein production' that are documented for the 19th century may have persisted since much earlier times.

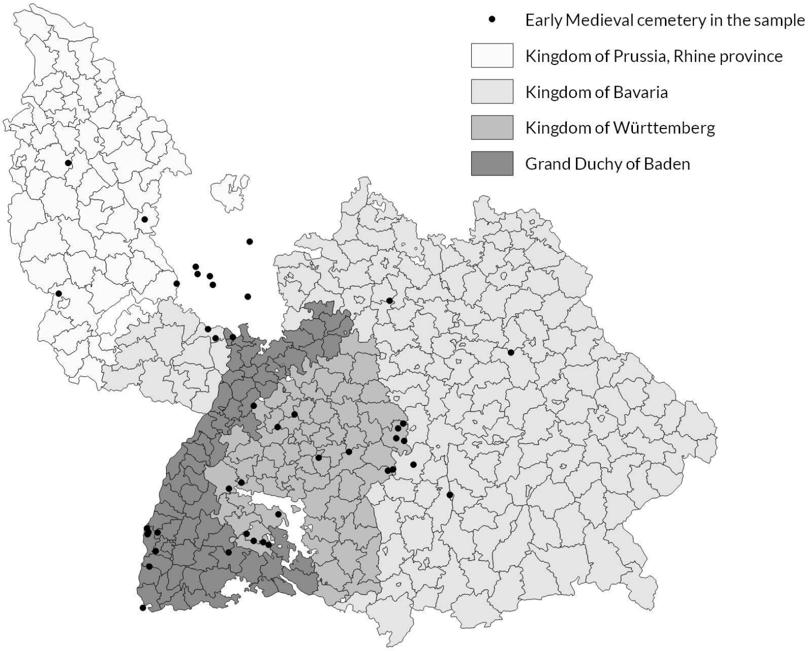
4.6 Figures and tables

Figure 4.1: Map of the cemeteries



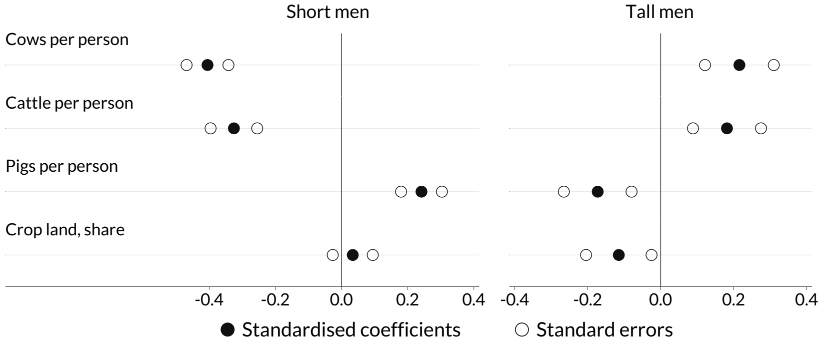
– The numbers on the map correspond to the numbers in table 4.1.
– The relief is based on the *GTOPO30* global digital elevation model by the U. S. Geological Survey (USGS).
– Streams and Lakes are drawn using *WISE Large rivers and large lakes* data from the European Environment Agency (EEA).
– This map is similar to figure 3.1.

FIGURE 4.2: Map of the administrative districts



– Administrative boundaries of 1862 from the *MPIDR Population History GIS collection*, which is based on Hubatsch and Klein 1975.

FIGURE 4.3: Agrarian statistics and share of tall or short men

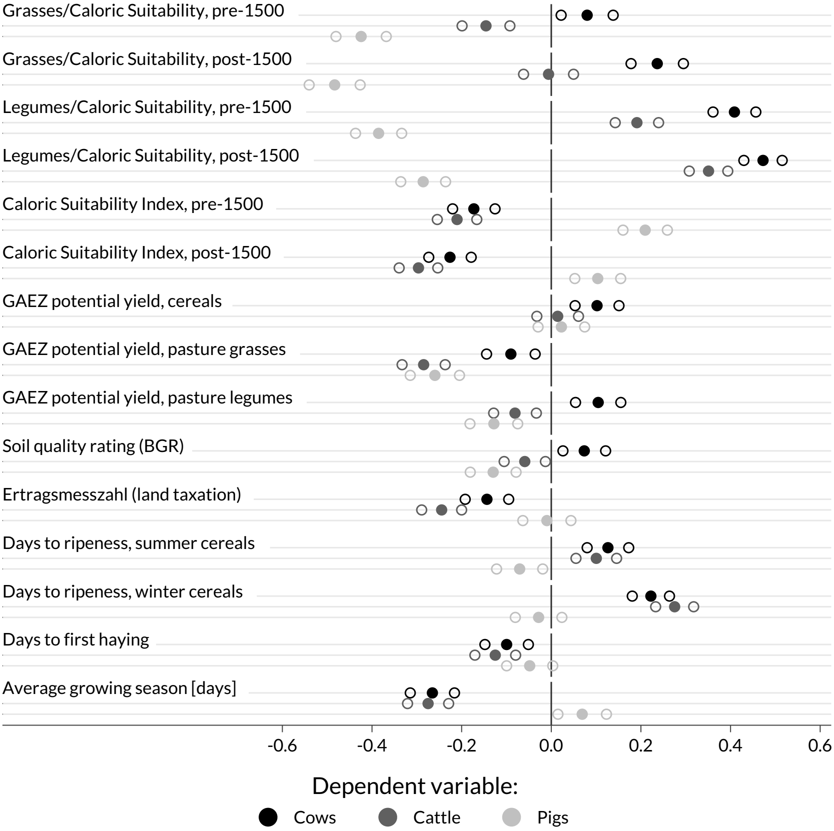


– Stata: `mixed short/tall `covariate' city || state: , covariance(unstructured).`

– The regressions of the share of young men rejected from military service for lack of height (short men) use a pooled sample of administrative districts of the Kingdoms of Bavaria and Württemberg, and the Grand Duchy of Baden.

– The share of young men who were taller than 172 or 170 centimetres (tall men) was only reported for Württemberg and Baden.

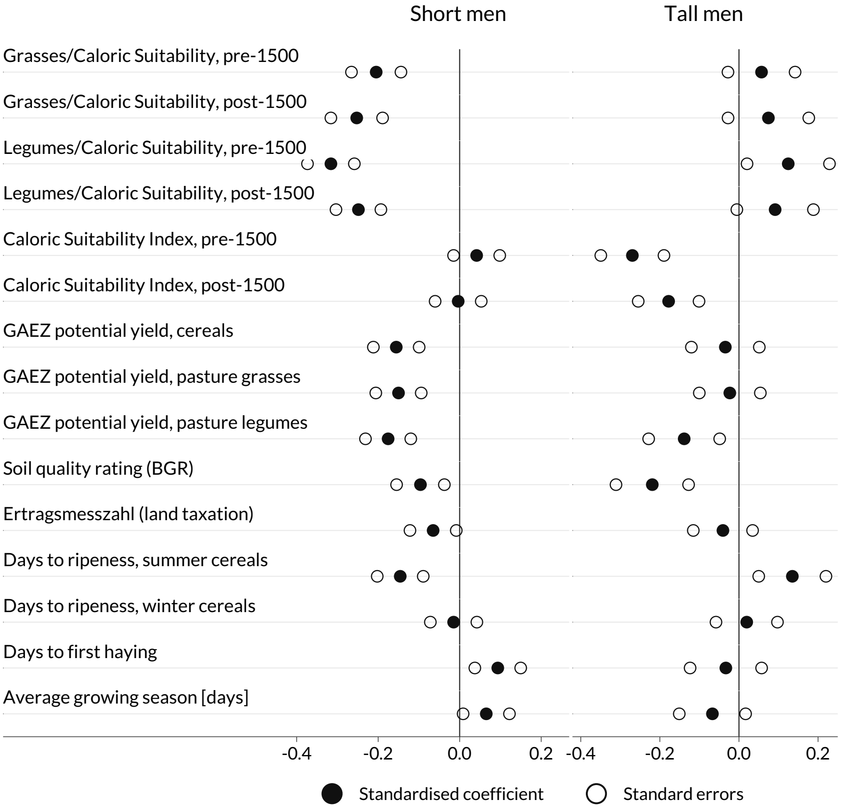
Figure 4.4: Animals per person and modern suitability for agriculture



–Standardised coefficients with standard-error bounds, Stata: `mixed `dependent variable' `suitability proxy' || state: city, covariance(exchangeable) reml`.

–The regressions use a pooled sample of administrative districts of the Kingdoms of Bavaria and Württemberg, the Prussian Kingdom's Rhine province, and the Grand Duchy of Baden.

Figure 4.5: Tall or short men and modern suitability for agriculture

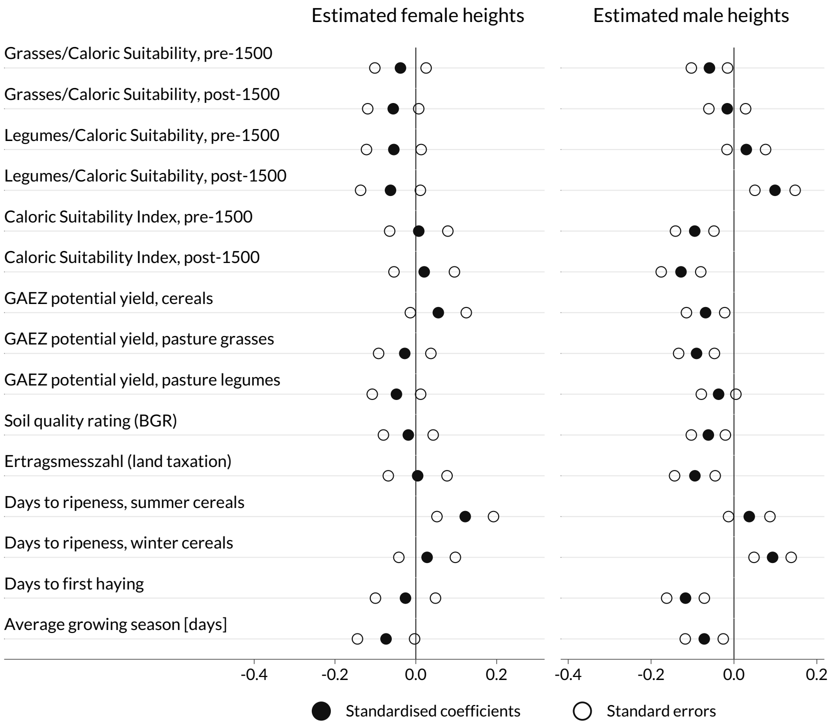


–Stata: `mixed short/tall `covariate' city || state: , covariance(unstructured).`

– The regressions of the share of young men rejected from military service for lack of height use a pooled sample of administrative districts of the Kingdoms of Bavaria and Württemberg, and the Grand Duchy of Baden.

– The share of young men who were taller than 170 or 172 centimetres was only reported for Württemberg and Baden.

FIGURE 4.6: Agricultural suitability and early medieval estimated heights



–Stata: `mixed HEIGHTruff_male/female `covariate' || cemetery: , covariance(unstructured)`.

– The covariates constructed from raster data are sampled from circular areas with a 2.5 kilometre radius around the (approximate) location of the cemetery.

Table 4.1: Summary statistics and sources, early medieval cemeteries

		♂		♀		
Cemetery		n	$\bar{x}$	n	$\bar{x}$	Sources
1	Aldingen	5	170.9	6	170.5	Schach-Dörges (2004)
2	Basel (Bernerring)	18	170.2	15	156.6	Martin (1976)
3	Bischoffingen	10	161.6	8	162.1	Hoff (1973); Bury (1974); Werner (1975)
4	Bopfingen	4	180.1	7	161.1	Desideri; Henke; Rosenstock
5	Buggingen	17	164.7	11	156.0	Jansen (2003)
6	Dirmstein	21	164.5	14	159.7	Leithäuser (2006)
7	Donaueschingen	97	168.1	75	159.6	Buchta-Hohm (1996); Röhrer-Ertl (1991)
8	Donzdorf	9	170.1	12	161.1	Neuffer (1972)
9	Eichstetten a. K.	45	169.1	42	160.4	Sasse (2001)
10	Eltville am Rhein	81	169.2	79	158.6	Blaich (2006)
11	Eppstein	60	171.0	59	165.2	Engels (2012)
12	Hemmingen	10	172.6	19	163.1	Müller (1976); Obertová (2008)
13	Horb-Altheim	21	170.3	20	163.2	Beilharz (2011); Obertová (2008)
14	Kirchheim am Ries	67	169.4	50	162.9	Neuffer-Müller (1983)
15	Kirchheim unter Teck	13	169.8	15	156.7	Däcke (1998); Becker (1985)
16	Kleinlangheim	29	169.4	38	159.0	Pescheck (1996); Schultz (1978)
17	Knittlingen	36	167.8	18	159.3	Damminger (2002)
18	Kösingen	14	169.4	9	166.6	Knaut (1993)
19	Langenlonsheim	39	168.1	30	160.0	Desideri; Henke; Rosenstock
20	Lauterhofen	19	169.7	13	154.5	Desideri; Henke; Rosenstock
21	Lörzweiler	3	166.5	5	162.1	Desideri; Henke; Rosenstock
22	Mainz-Hechtsheim	47	167.0	55	163.7	Koch (2011); Queisser (1988)
23	Mannheim-Vogelstang	127	167.8	128	159.9	Rösing (1975); Koch (2007)
24	Mühltal	9	174.2	9	162.5	Desideri; Henke; Rosenstock
25	Munzingen	26	169.5	25	158.0	Groove (2001); Burger-Heinrich

Continued on next page

TABLE 4.1: Summary statistics and sources, early medieval cemeteries

Cemetery		♂		♀		Sources
		n	$\bar{x}$	n	$\bar{x}$	
26	Neresheim	24	173.3	42	161.6	Knaut (1993); Speith (2012)
27	Newel	6	170.8	3	159.8	Desideri; Henke; Rosenstock
28	Nieder-Erlenbach	32	168.6	29	157.8	Dohrn-Ihmig (1999)
29	Niederstotzingen	9	171.5			Paulsen (1967); Wahl et al. (2014)
30	Oberrotweil	21	170.6	21	156.1	Desideri; Henke; Rosenstock
31	Pleidelsheim	47	170.6	58	159.6	Koch (2001); Speith (2012)
32	Rübenach	11	166.1	4	159.6	Desideri; Henke; Rosenstock
33	Sasbach a. K.	15	167.3	7	160.3	Schoof-Hosemann (1975); Herrmann (1976), Kirchberg (1976)
34	Schretzheim	29	173.1	14	165.1	Koch (1977); Donié (1999)
35	Sontheim a.d. Brenz	26	173.5	19	157.8	Neuffer-Müller (1966)
36	Stetten a.d. Donau	44	171.5	29	158.4	Weis (1999)
37	Truchtelfingen	12	170.7	1	165.1	Schmitt (2007)
38	Vettweiß-Mersheim	17	170.3	17	160.7	Desideri; Henke; Rosenstock
39	Wackernheim	10	167.4	3	158.4	Desideri; Henke; Rosenstock
40	Wittendorf	12	169.4	11	158.4	Lehmann (2003)
	Total	1142	169.4	1027	160.5	

- The numbers correspond to the numbers on the map, figure 1.
- Heights are estimated using the Ruff et al. (2012) formulae.

TABLE 4.2: Summary statistics, conscript heights data

	N	min	$\bar{x}$	max	IQR	St. dev.
Bavaria						
Percentage too short	179	0.55	2.32	6.40	1.41	1.07
Württemberg						
Percentage too short	64	4.47	10.6	19.8	7.13	3.96
Percentage tall	64	14.5	23.9	38.2	6.05	4.98
Baden						
Percentage too short	64	6.70	15.3	25.2	4	3.89
Percentage tall	64	10.9	18.9	28.9	4.30	3.85
Prussian Rhinelands						
Percentage too short	5	10.15	15.32	19.81	3.54	3.72

- *Sources:* The numbers come from volumes 3 and 8 of the *Beiträge zur Statistik des Königreichs Bayern*, the 1833 and 1857 volumes of the *Württembergische Jahrbücher für vaterländische Geschichte, Geographie, Statistik und Topographie*, volume 51 of the *Beiträge zur Statistik des Großherzogthums Baden*, and 21. issue of the *Mittheilungen des statistischen Bureau's in Berlin.*

TABLE 4.3: Summary statistics, historical agricultural data

	N	min	$\bar{x}$	max	IQR	St. dev.
Bavaria						
Cows per person	167	0.011	0.28	0.86	0.17	0.15
Cattle per person	167	0.013	0.57	1.16	0.30	0.26
Pigs per person	167	0.003	0.14	0.42	0.17	0.10
Württemberg						
Cows per person	64	0.019	0.26	1.03	0.05	0.13
Cattle per person	64	0.025	0.51	1.11	0.20	0.21
Pigs per person	64	0.023	0.13	0.30	0.09	0.06
Baden						
Cows per person	64	0.003	0.27	0.48	0.10	0.08
Cattle per person	64	0.003	0.48	1.16	0.20	0.18
Pigs per person	64	0.008	0.23	0.40	0.09	0.08
Prussian Rhinelands						
Cows per person	59	0.015	0.21	0.39	0.07	0.07
Cattle per person	59	0.020	0.36	0.76	0.22	0.16
Pigs per person	59	0.008	0.12	0.30	0.09	0.07

- *Sources:* The numbers come from volumes 6 and 7 of the *Beiträge zur Statistik des Königreichs Bayern*, the first volume of the *Statistisches Jahrbuch für das Großherzogthum Baden*, the 1823 and 1849 volumes of the *Württembergische Jahrbücher für vaterländische Geschichte, Geographie, Statistik und Topographie*, and the *Beiträge zur Statistik der Königl. Preussischen Rheinlande*.

Table 4.4: Summary statistics, modern indicators

	N	$\bar{x}$	St. dev.	IQR
Administrative regions				
Rel. suitability, grass, pre-1500	365	0.089	0.0085	0.011
Rel. suitability, grass, post-1500	365	0.088	0.0067	0.0095
Rel. suitability, legumes, pre-1500	365	0.067	0.0036	0.0047
Rel. suitability, legumes, post-1500	365	0.066	0.0034	0.0042
Caloric suitability index, pre-1500	365	8874.8	462.2	740
Caloric suitability index, post-1500	365	9026.6	639.2	864
GAEZ potential yield, cereals	365	147.0	57.7	76
GAEZ potential yield, pasture grasses	365	794.3	86.0	100
GAEZ potential yield, pasture legumes	365	591.7	37.7	50
Soil quality rating (BGR)	348	59.9	15.0	23
Ertragsmesszahl (land taxation)	337	43.7	11.0	14
Days to ripeness, summer cereals	357	111.0	6.43	7.72
Days to ripeness, winter cereals	353	319.3	13.1	18.4
Days to first haying	363	74.1	9.05	9.85
Duration of growing season	365	187.3	8.53	11.8

Continued on next page

Table 4.4: Summary statistics, modern indicators

	N	$\bar{x}$	St. dev.	IQR
Cemetery areas				
Rel. suitability, grass, pre-1500	40	0.092	0.011	0.012
Rel. suitability, grass, post-1500	40	0.089	0.0079	0.0095
Rel. suitability, legumes, pre-1500	40	0.066	0.0050	0.0057
Rel. suitability, legumes, post-1500	40	0.063	0.0051	0.0070
Caloric suitability index, pre-1500	40	9146.0	547.6	777.9
Caloric suitability index, post-1500	40	9519.1	877.6	1323.8
GAEZ potential yield, cereals	40	162.5	53.9	81.5
GAEZ potential yield, pasture grasses	40	843.2	108.0	158.8
GAEZ potential yield, pasture legumes	40	599.6	41.3	58.3
Soil quality rating (BGR)	37	64.1	16.7	28.9
Ertragsmesszahl (land taxation)	39	51.6	14.5	23
Days to ripeness, summer cereals	39	111.7	5.22	6.34
Days to ripeness, winter cereals	39	310.6	13.1	19.4
Days to first haying	39	75.7	7.35	10.6
Duration of growing season	39	192.6	8.99	14.6

- For the cemeteries, the values derived from raster data are median values for circular areas with a 2.5 kilometre radius around the location of the cemetery.

TABLE 4.5: Regression results, replication

	Too short	Too short, cities
Cows per person, various years	-3.77^{***}	-6.24^{***}
	(-3.26)	(-4.76)
N	295	295
χ^2	10.6	25.0
Cattle per person, various years	-1.60^{**}	-3.71^{***}
	(-2.36)	(-4.36)
N	295	295
χ^2	5.58	21.3
Pigs per person, various years	5.44^{***}	5.23^{***}
	(3.11)	(2.74)
N	295	295
χ^2	9.66	9.74
Arable land, various years	0.04	-0.02
	(0.23)	(-0.13)
N	301	301
χ^2	0.06	1.18

- Pooled sample of administrative districts of the Kingdoms of Bavaria and Württemberg, and the Grand Duchy of Baden.
- The second model includes a dummy variable for city districts, which typically had very low numbers of farm animals per person. The coefficients are not shown.
- Stata command: ``mixed short `covariate' (city) || state: , covariance(unstructured).``
- z-statistics in brackets. *, **, and *** denote significance on the 10, 5, and 1 percent significance levels, respectively.

TABLE 4.6: Difference between lower and upper tercile of modern covariates

Covariate	μ_{lower}	μ_{upper}	t stat	diff < 0	diff > 0	diff ≠ 0
Male/probably male						
Rel. suitability, grass, pre-1500	170.3	169.2	2.20	0.014	0.986	0.028
Rel. suitability, grass, post-1500	169.4	169.0	0.83	0.204	0.796	0.408
Rel. suitability, legumes, pre-1500	168.9	169.3	−0.73	0.767	0.233	0.467
Rel. suitability, legumes, post-1500	168.7	169.7	−1.89	0.970	0.030	0.060
Caloric suitability index, pre-1500	169.9	168.6	2.33	0.010	0.990	0.020
Caloric suitability index, post-1500	170.0	168.5	2.68	0.004	0.996	0.008
GAEZ potential yield, cereals	169.5	168.7	1.57	0.059	0.941	0.118
GAEZ pot. yield, pasture grasses	169.9	169.2	1.29	0.099	0.901	0.197
GAEZ pot. yield, pasture legumes	169.6	168.9	1.37	0.086	0.914	0.172
Soil quality rating (BGR)	169.8	168.8	1.84	0.033	0.967	0.066
Ertragsmesszahl (land taxation)	170.0	169.0	1.76	0.040	0.960	0.079
Days to ripeness, summer cereals	169.0	170.3	−2.34	0.990	0.010	0.020
Days to ripeness, winter cereals	168.7	170.3	−3.24	0.999	0.001	0.001
Days to first haying	170.9	169.1	3.40	0.000	1.000	0.001
Duration of growing season	169.9	168.6	2.49	0.006	0.994	0.013

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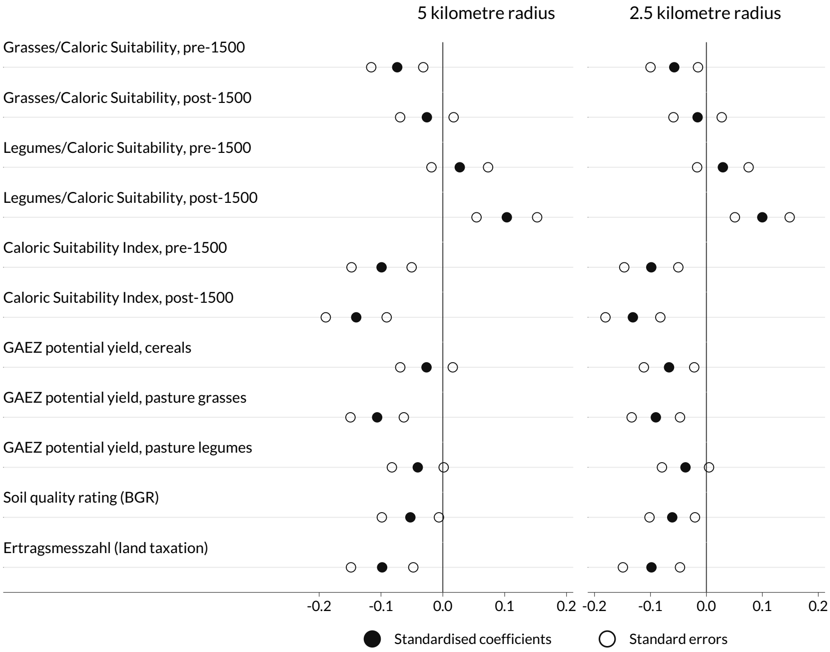
Table 4.6: Difference between lower and upper tercile of modern covariates

Covariate	μ_{lower}	μ_{upper}	t stat	diff < 0	diff > 0	diff $\neq$ 0
Female/probably female						
Rel. suitability, grass, pre-1500	160.1	160.5	−0.99	0.838	0.162	0.323
Rel. suitability, grass, post-1500	161.2	159.7	2.81	0.003	0.997	0.005
Rel. suitability, legumes, pre-1500	161.0	159.5	2.97	0.002	0.998	0.003
Rel. suitability, legumes, post-1500	160.7	159.6	2.19	0.014	0.986	0.029
Caloric suitability index, pre-1500	160.3	160.6	−0.58	0.719	0.281	0.563
Caloric suitability index, post-1500	160.8	160.5	0.60	0.274	0.726	0.548
GAEZ potential yield, cereals	160.3	161.5	−2.11	0.982	0.018	0.036
GAEZ pot. yield, pasture grasses	160.6	160.6	0.12	0.452	0.548	0.904
GAEZ pot. yield, pasture legumes	160.1	159.8	0.71	0.241	0.759	0.481
Soil quality rating (BGR)	160.5	160.3	0.33	0.371	0.629	0.741
Ertragsmesszahl (land taxation)	160.0	161.0	−1.67	0.953	0.047	0.095
Days to ripeness, summer cereals	158.6	161.1	−4.86	1.000	0.000	0.000
Days to ripeness, winter cereals	160.2	161.1	−1.89	0.970	0.030	0.060
Days to first haying	160.8	160.1	1.32	0.094	0.906	0.189
Duration of growing season	160.9	159.9	1.70	0.045	0.955	0.090

- The values derived from raster data are median values for circular areas with a 2.5 kilometre radius around the location of the cemetery.

Appendix 4.A

Figure 4.7: Covariates sampled from areas with 2.5 or 5 kilometre radius (estimated male heights)



– Estimated adult male heights, as in the right-hand side panel of figure 4.6.
– Stata: `mixed HEIGHTruff_male `covariate_20km2/80km2' || cemetery: , covariance(unstructured)`.

TABLE 4.7: Summary statistics (states)

	N	$\bar{x}$	St. dev.	IQR
Bavaria				
Rel. suitability, grass, pre-1500	179	0.085	0.0057	0.0057
Rel. suitability, grass, post-1500	179	0.084	0.0050	0.0053
Rel. suitability, legumes, pre-1500	179	0.065	0.0036	0.0044
Rel. suitability, legumes, post-1500	179	0.065	0.0037	0.0044
Caloric suitability index, pre-1500	179	8930.0	474.6	781
Caloric suitability index, post-1500	179	9019.9	595.3	866
GAEZ potential yield, cereals	179	142.5	58.1	81
GAEZ potential yield, pasture grasses	179	756.3	59.7	74
GAEZ potential yield, pasture legumes	179	583.0	37.1	50
Soil quality rating (BGR)	168	58.6	13.5	21
Ertragsmesszahl (land taxation)	178	42.6	9.38	13
Days to ripeness, summer cereals	176	110.8	6.29	8.79
Days to ripeness, winter cereals	171	320.8	12.1	15.9
Days to first haying	178	71.9	8.88	9.29
Duration of growing season	179	185.0	7.54	11.0
Württemberg				
Rel. suitability, grass, pre-1500	64	0.090	0.0043	0.0059
Rel. suitability, grass, post-1500	64	0.089	0.0031	0.0047
Rel. suitability, legumes, pre-1500	64	0.068	0.0022	0.0020
Rel. suitability, legumes, post-1500	64	0.067	0.0022	0.0022
Caloric suitability index, pre-1500	64	8844.9	373.3	656.5
Caloric suitability index, post-1500	64	8945.5	506.9	737.5
GAEZ potential yield, cereals	64	150.1	52.2	62.5
GAEZ potential yield, pasture grasses	64	798.0	62.5	73
GAEZ potential yield, pasture legumes	64	602.5	33.5	52
Soil quality rating (BGR)	62	58.3	13.5	19
Ertragsmesszahl (land taxation)	64	45.0	11.0	15.5
Days to ripeness, summer cereals	64	114.2	6.06	6.38
Days to ripeness, winter cereals	63	320.0	12.7	16.1
Days to first haying	64	75.5	9.59	10.2
Duration of growing season	64	186.2	7.44	10.7

Continued on next page

TABLE 4.7: Summary statistics (states)

	N	$\bar{x}$	St. dev.	IQR
Baden				
Rel. suitability, grass, pre-1500	64	0.098	0.010	0.014
Rel. suitability, grass, post-1500	64	0.093	0.0066	0.0085
Rel. suitability, legumes, pre-1500	64	0.069	0.0038	0.0051
Rel. suitability, legumes, post-1500	64	0.066	0.0041	0.0054
Caloric suitability index, pre-1500	64	8902.4	612.8	448.5
Caloric suitability index, post-1500	64	9349.3	932.6	1219.5
GAEZ potential yield, cereals	64	157.0	68.9	96.5
GAEZ potential yield, pasture grasses	64	879.4	115.2	202.5
GAEZ potential yield, pasture legumes	64	617.0	41.9	52.5
Soil quality rating (BGR)	63	64.1	11.3	17
Ertragsmesszahl (land taxation)	64	47.0	15.0	22
Days to ripeness, summer cereals	63	109.1	6.29	7.96
Days to ripeness, winter cereals	62	315.1	15.8	21.3
Days to first haying	64	76.9	7.81	9.14
Duration of growing season	64	193.2	8.85	12.1
Prussian Rhinelands				
Rel. suitability, grass, pre-1500	58	0.094	0.0077	0.014
Rel. suitability, grass, post-1500	58	0.093	0.0067	0.012
Rel. suitability, legumes, pre-1500	58	0.066	0.0022	0.0032
Rel. suitability, legumes, post-1500	58	0.066	0.0020	0.0023
Caloric suitability index, pre-1500	58	8706.9	226.6	408
Caloric suitability index, post-1500	58	8780.5	266.6	415
GAEZ potential yield, cereals	58	146.4	47.4	62
GAEZ potential yield, pasture grasses	58	813.3	63.5	95
GAEZ potential yield, pasture legumes	58	578.6	17.8	26
Soil quality rating (BGR)	55	60.6	22.3	35
Ertragsmesszahl (land taxation)	31	40.6	7.99	9
Days to ripeness, summer cereals	54	110.1	6.31	7.14
Days to ripeness, winter cereals	57	318.7	12.7	18.7
Days to first haying	57	76.4	8.79	9.40
Duration of growing season	58	189.5	8.77	12.8

- The aggregates from this table are shown in the top section of table 4.4.

Table 4.8: Summary statistics (areas with 5km radius)

	N	$\bar{x}$	St. dev.	IQR
Rel. suitability, grass, pre-1500, 5km	40	0.092	0.010	0.013
Rel. suitability, grass, post-1500, 5km	40	0.089	0.0079	0.0099
Rel. suitability, legumes, pre-1500, 5km	40	0.066	0.0049	0.0054
Rel. suitability, legumes, post-1500, 5km	40	0.063	0.0051	0.0066
Caloric suitability index, pre-1500, 5km	40	9137.7	544.6	681.1
Caloric suitability index, post-1500, 5km	40	9515.1	895.4	1322.9
GAEZ potential yield, cereals, 5km	40	159.8	49.1	68.5
GAEZ potential yield, pasture grasses, 5km	40	844.3	108.7	174.8
GAEZ potential yield, pasture legumes, 5km	40	598.9	41.5	61.5
Soil quality rating (BGR), 5km	40	62.7	16.0	26.9
Ertragsmesszahl (land taxation), 5km	39	51.8	14.3	22

- See table 4.4 for comparisons with the 2.5-kilometre-radius areas around the cemeteries.

Table 4.9: Regression results (states)

	Too short	Too short, cities	Tall	Tall, cities
Cows per person, various years				
Bavaria	-2.63^{***}	-4.03^{***}		
	(-5.00)	(-6.74)		
N	167	167		
χ^2	25.0	45.8		
Württemberg	-11.1^{***}	-12.8^{***}	6.34	7.53
	(-3.20)	(-3.67)	(1.36)	(1.59)
N	64	64	64	64
χ^2	10.2	14.9	1.86	3.07
Baden	4.97	-2.28	-2.00	12.2
	(0.86)	(-0.32)	(-0.35)	(1.84)
N	64	64	64	64
χ^2	0.74	3.57	0.12	12.6
Cattle per person, various years				
Bavaria	-0.63^{*}	-1.56^{***}		
	(-1.94)	(-3.42)		
N	167	167		
χ^2	3.75	12.1		
Württemberg	-5.66^{**}	-7.04^{***}	-0.07	0.63
	(-2.49)	(-3.05)	(-0.02)	(0.20)
N	64	64	64	64
χ^2	6.18	10.6	0.001	0.57
Baden	-1.26	-5.09^{*}	2.06	7.93^{***}
	(-0.48)	(-1.73)	(0.79)	(2.95)
N	64	64	64	64
χ^2	0.23	6.63	0.63	18.6

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Table 4.9: Regression results (states)

	Too short	Too short, cities	Tall	Tall, cities
Pigs per person, various years				
Bavaria	2.51^{***}	2.74^{***}		
	(3.07)	(3.08)		
N	167	167		
χ^2	9.43	9.87		
Württemberg	17.4^{**}	16.3^{**}	−11.6	−10.4
	(2.19)	(2.00)	(−1.13)	(−0.99)
N	64	64	64	64
χ^2	4.79	5.26	1.27	1.52
Baden	10.6	6.53	-16.6^{***}	−10.8
	(1.79)	(0.93)	(−2.96)	(−1.63)
N	64	64	64	64
χ^2	3.20	4.38	8.73	11.8
Arable land, various years				
Bavaria	0.095	0.10		
	(1.19)	(1.20)		
N	179	179		
χ^2	1.41	1.49		
Württemberg	0.51	0.31	−0.77	−0.74
	(1.03)	(0.54)	(−1.25)	(−1.02)
N	64	64	64	64
χ^2	1.07	1.48	1.56	1.57
Baden	−0.67	−0.49	−0.50	−0.72
	(−1.37)	(−1.01)	(−1.01)	(−1.48)
N	58	58	58	58
χ^2	1.88	6.27	1.02	6.85

- Administrative districts of the Kingdoms of Bavaria and Württemberg, and the Grand Duchy of Baden.
- The second and fourth models includes a dummy variable for city districts, which typically had very low numbers of farm animals per person. The coefficients are not shown.
- Stata command: `mixed short/tall `covariate' (city) || state: , covariance(unstructured)`.
- z-statistics in brackets. *, **, and *** denote significance on the 10, 5, and 1 percent significance levels, respectively.

TABLE 4.10: Regression results (historical output)

Dependent variable	β	z	χ^2	AIC	N
Rel. suitability, grass, pre-1500					
Cows per person	0.035	0.69	91.0	932.1	353
Cattle per person	-0.15^{***}	−3.41	159.1	879.9	353
Pigs per person	-0.38^{***}	−7.07	103.8	925.5	353
Rel. suitability, grass, post-1500					
Cows per person	0.20^{***}	3.65	109.3	921.8	353
Cattle per person	−0.052	−1.09	147.4	889.2	353
Pigs per person	-0.44^{***}	−8.02	120.2	913.9	353
Rel. suitability, legumes, pre-1500					
Cows per person	0.39^{***}	8.20	177.8	874.4	353
Cattle per person	0.18^{***}	3.81	171.8	876.5	353
Pigs per person	-0.34^{***}	−7.11	103.1	922.4	353
Rel. suitability, legumes, post-1500					
Cows per person	0.47^{***}	11.0	245.1	831.8	353
Cattle per person	0.34^{***}	8.03	244.0	832.3	353
Pigs per person	-0.28^{***}	−5.76	82.7	937.4	353
Caloric suitability index, pre-1500					
Cows per person	-0.16^{***}	−3.46	105.6	920.8	353
Cattle per person	-0.20^{***}	−4.59	180.1	869.7	353
Pigs per person	0.21^{***}	4.35	66.6	950.6	353
Caloric suitability index, post-1500					
Cows per person	-0.21^{***}	−4.51	116.2	912.8	353
Cattle per person	-0.28^{***}	−6.66	214.1	848.7	353
Pigs per person	0.097^{**}	1.96	49.6	965.2	353

Continued on next page

TABLE 4.10: Regression results (historical output)

Dependent variable	β	z	χ^2	AIC	N
GAEZ potential yield, cereals					
Cows per person	0.095^{*}	1.96	94.8	928.6	353
Cattle per person	0.0097	0.21	148.6	889.9	353
Pigs per person	0.015	0.28	45.3	969.0	353
GAEZ potential yield, pasture grasses					
Cows per person	-0.098^{**}	-2.11	93.3	928.2	353
Cattle per person	-0.26^{***}	-5.91	195.9	856.8	353
Pigs per person	-0.21^{***}	-4.36	66.7	950.5	353
GAEZ potential yield, pasture legumes					
Cows per person	0.092^{*}	1.91	95.2	929.0	353
Cattle per person	-0.078^{*}	-1.73	151.9	887.0	353
Pigs per person	-0.12^{**}	-2.38	51.6	963.4	353
Soil quality rating (BGR)					
Cows per person	0.071	1.51	79.4	862.2	336
Cattle per person	-0.062	-1.38	122.2	836.4	336
Pigs per person	-0.13^{***}	-2.62	46.4	911.2	336
Ertragsmesszahl (land taxation)					
Cows per person	-0.16^{***}	-3.36	108.4	826.0	325
Cattle per person	-0.26^{***}	-5.92	202.6	772.1	325
Pigs per person	-0.034	-0.64	46.5	896.4	325
Days to ripeness, summer cereals					
Cows per person	0.11^{**}	2.45	102.8	872.3	345
Cattle per person	0.091^{**}	2.06	157.4	853.4	345
Pigs per person	-0.076	-1.52	50.2	941.0	345
Days to ripeness, winter cereals					
Cows per person	0.22^{***}	5.36	141.2	781.3	341
Cattle per person	0.27^{***}	6.55	204.9	794.4	341
Pigs per person	-0.019	-0.37	46.8	933.5	341

Continued on next page

TABLE 4.10: Regression results (historical output)

Dependent variable	β	z	χ^2	AIC	N
Days to first haying					
Cows per person	-0.11^{**}	-2.44	95.5	921.7	351
Cattle per person	-0.14^{***}	-3.18	158.7	875.7	351
Pigs per person	-0.060	-1.20	47.0	963.1	351
Duration of growing season					
Cows per person	-0.25^{***}	-5.37	123.8	904.9	353
Cattle per person	-0.26^{***}	-6.11	197.1	855.2	353
Pigs per person	0.043	0.85	46.1	968.3	353

- Pooled administrative districts of the Kingdoms of Bavaria and Württemberg, the Grand Duchy of Baden, and the Rhineland province of the Kingdom of Prussia.
- The models include a dummy variable for city districts, which typically had very low numbers of farm animals per person. The coefficients are not shown.
- Stata command: `mixed cows/cattle/pigs `covariate' city || state: , covariance(unstructured)`.
- z-statistics in brackets. *, **, and *** denote significance on the 10, 5, and 1 percent significance levels, respectively.

Table 4.11: Regression results (historical heights)

Dependent variable	β	z	χ^2	AIC	N
Share of short men					
Grasses/Caloric suitability, pre-1500	-0.16^{***}	-3.08	10.5	1035.3	365
Grasses/Caloric suitability, post-1500	-0.19^{***}	-3.58	13.8	1032.4	365
Legumes/Caloric suitability, pre-1500	-0.25^{***}	-4.89	24.9	1021.5	365
Legumes/Caloric suitability, post-1500	-0.24^{***}	-4.62	22.3	1023.9	365
Caloric suitability index, pre-1500	0.065	1.23	2.49	1043.1	365
Caloric suitability index, post-1500	0.024	0.45	1.17	1044.4	365
GAEZ potential yield, cereals	-0.16^{***}	-3.13	10.8	1034.9	365
GAEZ potential yield, pasture grasses	-0.13^{***}	-2.62	7.83	1037.8	365
GAEZ potential yield, pasture legumes	-0.13^{***}	-2.61	7.79	1037.9	365
Soil quality rating (BGR)	-0.054	-1.01	1.74	995.0	348
Ertragsmesszahl (land taxation)	-0.051	-0.96	2.38	951.2	337
Days to ripeness, summer cereals	-0.14^{***}	-2.70	8.34	1013.4	357
Days to ripeness, winter cereals	-0.011	-0.20	1.15	1003.5	353
Days to first haying	0.061	1.18	2.41	1037.0	363
Duration of growing season	0.056	1.08	2.12	1043.5	365

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TABLE 4.11: Regression results (historical heights)

Dependent variable	β	z	χ^2	AIC	N
Share of tall men					
Grasses/Caloric suitability, pre-1500	0.035	0.42	8.20	364.3	128
Grasses/Caloric suitability, post-1500	0.071	0.68	8.50	364.0	128
Legumes/Caloric suitability, pre-1500	0.12	1.27	9.74	362.9	128
Legumes/Caloric suitability, post-1500	0.13	1.45	10.2	362.4	128
Caloric suitability index, pre-1500	-0.26^{***}	-3.52	21.2	352.7	128
Caloric suitability index, post-1500	-0.17^{**}	-2.41	14.2	358.8	128
GAEZ potential yield, cereals	-0.027	-0.33	8.13	364.4	128
GAEZ potential yield, pasture grasses	-0.065	-0.89	8.85	363.7	128
GAEZ potential yield, pasture legumes	-0.15^{*}	-1.84	11.6	361.1	128
Soil quality rating (BGR)	-0.24^{**}	-2.43	14.3	351.2	125
Ertragsmesszahl (land taxation)	-0.090	-1.24	9.63	363.0	128
Days to ripeness, summer cereals	0.13	1.60	10.7	360.1	127
Days to ripeness, winter cereals	0.065	0.85	10.1	343.6	125
Days to first haying	-0.055	-0.62	8.42	364.1	128
Duration of growing season	-0.12	-1.39	10.1	362.6	128

- Pooled administrative districts of the Kingdoms of Bavaria and Württemberg, the Grand Duchy of Baden, and the Rhineland province of the Kingdom of Prussia for the share of men rejected for lack of height. Definitions vary between states, values for the Prussian Rhinelands are for the next larger level of administrative units.
- Pooled administrative districts of the Kingdom of Württemberg and the Grand Duchy of Baden for the share of tall men.
- The models include a dummy variable for city districts, which typically had very low numbers of farm animals per person. The coefficients are not shown.
- Stata: `mixed short/tall `covariate' city || state: , covariance(unstructured)`.
- *, **, and *** denote significance on the 10, 5, and 1 percent significance levels, respectively.

Table 4.12: Regression results (early medieval men)

Covariate	β	z	χ^2	AIC
Grasses/Caloric suitability, pre-1500, 2.5km	-0.057	-1.31	1.72	3229.4
Grasses/Caloric suitability, pre-1500, 5km	-0.074^{*}	-1.74	3.02	3228.1
Grasses/Caloric suitability, post-1500, 2.5km	-0.013	-0.29	0.09	3231.0
Grasses/Caloric suitability, post-1500, 5km	-0.023	-0.53	0.28	3230.8
Legumes/Caloric suitability, pre-1500, 2.5km	0.034	0.72	0.52	3230.6
Legumes/Caloric suitability, pre-1500, 5km	0.030	0.65	0.43	3230.7
Legumes/Caloric suitability, post-1500, 2.5km	0.11^{**}	2.15	4.62	3226.7
Legumes/Caloric suitability, post-1500, 5km	0.11^{**}	2.21	4.90	3226.4
Caloric suitability index, pre-1500, 2.5km	-0.10^{**}	-2.11	4.46	3226.8
Caloric suitability index, pre-1500, 5km	-0.10^{**}	-2.11	4.44	3226.8
Caloric suitability index, post-1500, 2.5km	-0.14^{***}	-2.76	7.64	3223.7
Caloric suitability index, post-1500, 5km	-0.15^{***}	-2.95	8.73	3222.7
GAEZ potential yield, cereals, 2.5km	-0.069	-1.50	2.25	3228.9
GAEZ potential yield, cereals, 5km	-0.023	-0.54	0.29	3230.8
GAEZ potential yield, pasture grasses, 2.5km	-0.091^{**}	-2.08	4.33	3226.8
GAEZ potential yield, pasture grasses, 5km	-0.11^{**}	-2.48	6.16	3225.1
GAEZ potential yield, pasture legumes, 2.5km	-0.036	-0.85	0.72	3230.4
GAEZ potential yield, pasture legumes, 5km	-0.041	-0.95	0.91	3230.2
Soil quality rating (BGR), 2.5km	-0.062	-1.50	2.25	3095.5
Soil quality rating (BGR), 5km	-0.053	-1.14	1.29	3229.8
Ertragsmesszahl (land taxation), 2.5km	-0.10^{**}	-2.03	4.11	3176.2
Ertragsmesszahl (land taxation), 5km	-0.10^{**}	-2.04	4.15	3176.2
Days to ripeness, summer cereals	0.037	0.74	0.55	3197.8
Days to ripeness, winter cereals	0.10^{**}	2.10	4.42	3194.2
Days to first haying	-0.12^{**}	-2.50	6.26	3192.5
Duration of growing season	-0.072	-1.49	2.21	3196.2

- Stata: `mixed height `covariate' || cemetery: , covariance(unstructured)`.
- *, **, and *** denote significance on the 10, 5, and 1 percent significance levels, respectively.

TABLE 4.13: Regression results (early medieval women)

Covariate	β	z	χ^2	AIC
Grasses/Caloric suitability, pre-1500, 2.5km	-0.041	-0.68	0.46	2860.4
Grasses/Caloric suitability, pre-1500, 5km	-0.057	-0.95	0.90	2860.0
Grasses/Caloric suitability, post-1500, 2.5km	-0.056	-0.93	0.86	2860.0
Grasses/Caloric suitability, post-1500, 5km	-0.067	-1.11	1.23	2859.7
Legumes/Caloric suitability, pre-1500, 2.5km	-0.057	-0.87	0.75	2860.1
Legumes/Caloric suitability, pre-1500, 5km	-0.064	-0.98	0.96	2859.9
Legumes/Caloric suitability, post-1500, 2.5km	-0.062	-0.85	0.73	2860.2
Legumes/Caloric suitability, post-1500, 5km	-0.063	-0.86	0.74	2860.1
Caloric suitability index, pre-1500, 2.5km	0.009	0.12	0.01	2860.8
Caloric suitability index, pre-1500, 5km	-0.013	-0.18	0.03	2860.8
Caloric suitability index, post-1500, 2.5km	0.018	0.24	0.06	2860.8
Caloric suitability index, post-1500, 5km	-0.005	-0.06	0.00	2860.9
GAEZ potential yield, cereals, 2.5km	0.047	0.71	0.51	2860.4
GAEZ potential yield, cereals, 5km	0.021	0.35	0.12	2860.7
GAEZ potential yield, pasture grasses, 2.5km	-0.031	-0.49	0.24	2860.6
GAEZ potential yield, pasture grasses, 5km	-0.054	-0.85	0.72	2860.1
GAEZ potential yield, pasture legumes, 2.5km	-0.051	-0.86	0.74	2860.1
GAEZ potential yield, pasture legumes, 5km	-0.072	-1.25	1.55	2859.3
Soil quality rating (BGR), 2.5km	-0.018	-0.30	0.09	2740.5
Soil quality rating (BGR), 5km	-0.013	-0.19	0.04	2860.8
Ertragsmesszahl (land taxation), 2.5km	0.003	0.04	0.00	2821.3
Ertragsmesszahl (land taxation), 5km	-0.018	-0.25	0.06	2821.3
Days to ripeness, summer cereals	0.12^{*}	1.76	3.10	2829.2
Days to ripeness, winter cereals	0.025	0.35	0.12	2832.0
Days to first haying	-0.026	-0.34	0.12	2832.0
Duration of growing season	-0.076	-1.06	1.13	2831.0

- Stata: `mixed height `covariate' || cemetery: , covariance(unstructured)`.
- *, **, and *** denote significance on the 10, 5, and 1 percent significance levels, respectively.

History of Degenerative Joint Disease in Europe – Bioarchaeological Inferences about Lifestyle and Activity from Osteoarthritis and Vertebral Osteophytosis

5

Abstract

The *Global History of Health Project* seeks to understand variation in the human experience across Europe from Late Antiquity through the industrial/modern era. This period in European history encompasses an enormous diversity in subsistence strategies, social organization, health, and prosperity. This chapter addresses the lifestyle and physical activity of the people of Europe. The subsample of the *Global History of Health Project* database consists of 7,540 individuals from 101 sites across Europe. We use age-adjusted scores for presence/-absence of osteoarthritis (OA) of the axial and appendicular joints and vertebral bodies to explore degeneration of joint surfaces over time and according to socio-economic and geographic variation. This work elucidates fluctuating intensity in physical activity over time, sexual division of labor, physical activity of various socio-economic status groups, and geographic variation that relate to patterns of OA severity. Key findings include significantly more difficult and labor intensive lifestyle in the Early Middle Ages (6^{th}–10^{th} centuries CE) and a second peak in the Late Middle Ages (14^{th} and 15^{th} centuries) and Pre-industrial era (16^{th} century to about 1750). Our work supports other lines of evidence that suggest that increasing urbanization led to poor health and quality of life. This is shown by the documentation of high

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This is the manuscript of a chapter of the *Global History of Health Project*'s book *The Backbone of Europe* that will be published by *Cambridge University Press*.

Clark S. Larsen (The Ohio State University) and Kimberly D. Williams (Temple University) drafted the text based on analyses of a (now) out-dated version of the dataset. Nicholas J. Meinzer prepared the final dataset, reproduced and improved the analyses, visualised the results and revised the text together with Clark S. Larsen.

mean OA scores for males and females who were the drivers of this change from predominantly rural living to the large urban centers that characterize early modern Europe. Sexual division of labor is evident, and strongly supports very specific centuries-long occupational similarities for both sexes that speak to a level of continuity over the past two millennia of human occupation in Europe.

5.1 Introduction

Osteoarthritis (OA) and closely related osteophytosis (OP) – herein referred to as 'osteoarthritis' – are a group of conditions involving joint deterioration. Osteoarthritis pathogenesis involves focal, progressive loss of articular (hyaline) cartilage often accompanied by marginal (osteophyte) lipping and articular surface degeneration arising from direct bone-on-bone contact following loss of cartilage (Felson, Lawrence, et al. 2000; Pritzker 2003). It represents a pattern of responses to various predisposing factors, including genetic as well as environmental and behavioral causes (Corti and Rigon 2003; Felson, Lawrence, et al. 2000; Felson 2003; Valdes and Spector 2009; Zhang and Jordan 2008). There is considerable disagreement on the relative importance of these factors, but a mechanical loading environment due to activity figures most prominently among them (Block and Shakoor 2010; Felson, Lawrence, et al. 2000; Hough 2001; Moskowitz et al. 2004; Radin 1976; Radin et al. 1991). Like other degenerative pathology, osteoarthritis is cumulative with age, reflecting joint loading and associated damage over the course of a person's lifetime. Today, OA has significant societal and individual costs, and is the leading cause of chronic disability in older adults (Jordan et al. 2007). Owing to the aging of the population in developed countries especially, there has been an increase in prevalence (Zhang and Jordan 2008). For purposes of our discussion here, OA is an important record of past activity and lifestyle. In particular, because of the strong relationship with degree of joint loading, it is among the most informative variables available in which to evaluate lifestyle as it relates to workload and activity. While it is not possible to reconstruct specific activities from the study of OA in archaeological human remains, it is possible to address general features of lifestyle, working under the assumption when the data are controlled for age that individuals with more OA led more demanding lifestyles than individuals with less OA. Moreover, populations that have frequent daily repetitive activities that affect a specific joint will likely have more OA associated with the joint than populations having infrequent daily repetitive activities for the same joint.

This chapter examines OA of joint surfaces of the axial and appendicular skeleton across much of the continent of Europe from the pre-medieval era, or Late Antiquity, through industrial times. The leading focus of this chapter is addressing temporal changes. Over these millennia, human interaction with the environment and with each other, as well the way people made a living and provided sustenance for their families, changed dramatically. The unprecedented sample presented here ranges from farmers to craft or artisan workers to members of the military service. They lived in a variety of environments and circumstances including next to water bodies, on floodplains, and on hilly terrain. Over the temporal range of the sample as a whole, the role of men and women changed with regard to the technologies available that aided their movement across the landscape and the way food and other resources were produced and processed. Settlement patterns ranged from rural locales to large cities. All of these factors influence both intensity and type of activities. We seek to identify and interpret key lifestyle changes and patterns from this vast dataset. The sample used for these analyses documents an important cross-section of the people who lived, worked, and died across Europe over a large number of years. Regional variation in activity, access to resources, behavior, and landscape are all important factors for the local experience but the focus of this inquiry is on larger patterns of change over time in an extensive region and with regard to socio-cultural organization. The benefit of this perspective is that it reveals large-scale patterns of the human experience that transcend the local influences and provides a picture of how humans adapted to dramatically transformative political and social spaces across Europe from pre-medieval times through industrialization and the modern era.

Reverberations across Europe following the fall of Rome were experienced in a number of ways. For some people life did not change substantially, and this was a period of relative peace. For others, however, the breakdown of the existing economic and social systems led to dramatic day-to-day changes including the abandonment of some sites and a virtual rebuilding of lives in sometimes distant lands. While these experiences were varied across the continent, broad themes can be observed. Farming systems throughout much of Late Antiquity and the Early Middle Ages relied on the scratch plow or ard creating an arduous occupational landscape for much of Europe. The High Middle Ages saw technological advances such as the six horse gang plow and the spinning wheel which made farming and production of textiles a far easier way of life. White (1962) suggested that exploitation of iron mines in northern Europe revolutionized agriculture with less expensive and more readily available iron for implements such as the felling axe and field plow. “What this meant for increased productivity,” he stated, “cannot be demonstrated; it must be imagined” (White 1962, p. 41). As industrialization and urbanization advanced, settlement size grew dramatically, as did agricultural intensification, increased trade, and large-scale clearing of land and building endeavors. Woven into these broad strokes of human history in Europe are fundamental differences of experience between men and women, the poor and the rich, the farmer and the urban artisan or shopkeeper. This study explores the occupational history of these people and examines how technological advances, urbanization, and the environment predisposed to or mitigated the degeneration of the joints of the appendicular skeleton.

5.2 Materials and methods

5.2.1 Sample composition

The sample considered for the present chapter includes adults with an estimated age and sex. Adults were defined within the *Global History of Health Project* (GHHP) data collection protocol as those individuals for whom all long-bone epiphyseal fusion was complete. We included individuals who were scored as adults and who were aged 20 years and older. The primary variables used in the OA analyses were 1) summary OA score for each joint surface which necessitated the presence of both a right and a left joint surface for paired joints for calculation, and 2) vertebral body score by vertebrae class: cervical, thoracic, and lumbar. In the case of paired joints, individuals who did not have complementary right and left elements were not included in the analysis. There are two clear benefits to this approach. First, although it restricted the available sample size for analyses, it created a sample with key demographic variables which are important for most bioarcheological analyses, but especially so for studies of OA where the effects of age, sex-related activity, and sex-specific morphology may impact the results quite dramatically (Larsen, 2015). Second, the resulting sample available for OA analyses provides a record of variation by joint and side, including for the limb bones and the vertebral column for different contextual variables. Tables 5.1, 5.2, and 5.3 show the sites included in these analyses with numbers of male and female individuals with any OA scores, and the categories of the contextual variables.

5.2.2 Joint surface scoring procedure

Osteoarthritis was scored for all of the major joints (weight bearing and otherwise), including of the shoulder, elbow, wrist/hand, hip, knee, and foot/ankle as well as cervical, thoracic, and lumbar vertebrae. All joints were scored, including both right and left elements, but recording a single score for degeneration of the cervical, thoracic, and lumbar portions of the vertebral column where at least one vertebral body was present for observation.

The joint surfaces of shoulders, elbows, wrists and hands, hips, knees, and ankles and feet, and the vertebral bodies were scored using the following scheme, as given in the GHHP codebook (Steckel, Larsen, Sciulli, et al. 2011, pp. 31–33):

Score	Description
1	Joints show no evidence of pathological changes.
2	Slight marginal lipping (osteophytes < 3mm) and slight degenerative or productive changes are present. No eburnation is present but the surface may include some porosity.
3	Severe marginal lipping (osteophytes > 3mm) and severe degenerative or productive changes are present. Eburnation is common but not essential in this category if other degenerative aspects are severe. The surface may include substantial porosity.
4	Complete or near complete (more than 80%) destruction of articular surface (margin and face), including anklyosis.
5	Joint fusion (synostosis).
1	No degenerative changes on vertebral bodies.
2	Osteophyte formation on at least one vertebral body.
3	Extensive osteophyte formation on at least one vertebral body.

A summary OA score was produced for each joint surface using the highest score from the right and left elements. As described above, any individual that did not have a score for either the left or the right element was not considered in this analysis.

5.2.3 Statistical methods

Age-related degenerative changes to joints are often recorded to contribute to reconstructing physical activity in bioarcheologically-related OA research. Studies of OA progression in modern populations have demonstrated that progression of OA proceeds unabated once the degenerative process begins (e.g. Felson, Niu, et al. 2013). In order to account for the effect of age on this sample, we performed linear regression (OLS) analyses to correct for the age-influenced shape variation in the prevalence of OA. The mean of these resulting unstandardized residuals (summary OA scores minus the predicted OA scores) was plotted against each of the contextual variables considered rather than the actual summary OA score, thereby presenting the pattern of OA variation independent of age of the individual. Positive residuals indicate higher

OA scores than expected for age, while negative residuals indicate lower OA scores than expected for age. Males and females were considered separately in order to capture age-related changes due to sex-specific morphological differences. Degenerative changes to the bodies of the cervical, thoracic, and lumbar vertebrae were scored and the score for each vertebral class was also treated with linear regression in order to control for the effect of age on the changes of these bone surfaces. Mean vertebral scores for males and females were then generated and compared in the same way as mean OA scores and considered according to the socio-cultural, temporal, and geographic contextual variables. In addition to the mean residual OA scores, by sex and category of the context variable, figures 5.1–5.6 show 90% confidence intervals of the means. One-way Analysis of Variance (ANOVA) and subsequent post-hoc analyses were performed to augment the visualization of the OA residual scores using Tukey's honest significant difference test, the results are reported in tables 5.4–5.9 in appendix 5.A, detailing the difference between the residual scores of the compared groups.

5.2.4 Contextual variables

The GHHP analyses presented in this and the other contributions to the project are build on temporal, socio-cultural, and geographic variation, that has been observed for each of the sites. [1] The sample selected for analyses of OA is a subsample of the entire available database, limited by age, sex, and representation as described above.

5.3 Results

Results are divided here by temporal, socio-cultural, and geographic variation. Unless otherwise noted, all specifically mentioned results are statistically significant on the five percent significance level taking, however, only multiple comparisons among the levels of individual covariates into account.

5.3.1 Temporal variation

In general, males consistently had higher mean OA scores of the appendicular skeleton and vertebral bodies compared with females in the earliest time periods, and similar scores from the High Middle Ages onward. The mean

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[1] These will be described in detail in other chapters of *The Backbone of Europe*. A brief summary is given in section 1.2 of the introductory chapter.

scores are presented in figure 5.1 and specific details of this pattern, including where there are exceptions, are noted by time period below.

Nine Pre-medieval sites were in the sample examined here, including one military site, three sites of craft or artisan workers, and five sites of farming communities. During the pre-medieval era, mean OA scores of the shoulders, hips, feet and ankles, as well as the OA score for the thoracic and lumbar vertebrae were considerably greater for males than for females.

The Early Middle Ages were represented by 26 sites including craft or artisan workers, farmers, and one religious order. These sites were all from settlements categorized as rural sites, villages, or towns. The OA scores for all joints and vertebral bodies were substantially higher for males compared with females.

The sample for the High Middles Ages was comprised of 15 sites, mostly of craft or artisan workers and farmers. Here, the most substantial differences were registered for thoracic and lumbar vertebrae, with higher OA scores for males.

Fifteen Late Middle Ages sites were in this sample, including four religious order sites, one sample from a military context, but mostly craft or artisan workers and farmers. Across the board, the residual OA scores for males were higher than those for women, although the difference registered as significant only for the elbow joints.

The largest number of sites in this analysis was from the early modern era, with 29 sites, including farmers, craft or artisan workers, three samples from military contexts, a site related to a religious order, a hospital population, and five populations from other contexts that could not be subsumed into the other categories. None of the differences between males and females were statistically significant.

The seven industrial-era sites in the OA database included a military site, as well as farmers and craft or artisan workers, a category which includes factory workers in this time period. Again, there were no substantial differences in mean OA score between the sexes.

5.3.1.1 Intra-sex variation over time

For most of the time periods considered in this analysis, differences between the sexes most often indicated higher mean OA scores for males. Within-sex variation between time periods further reveals how lifestyle differed for each sex over time.

Between Late Antiquity, or the pre-medieval era in our parlance, and the subsequent Early Middle Ages there were some substantial intra-sex differences in OA. Both males and females experienced more OA of the hips and knees, while the increase in the score for the lumbar vertebrae registered as significant only for females. The universal drop in OA of all joints and vertebrae between the Early Middle Ages and the High Middle Ages was more dramatic, although few of the differences, namely the hips and lumbar vertebrae, were statistically significant for the females. For males, only the score for elbows was not significantly lower in the High Middle Ages than during the early medieval period.

Following the drop in OA scores during the High Middle Ages, the Late Middle Ages saw similar levels of OA for most joint surfaces. However, only the decrease for elbows of females was statistically significant. OA scores were generally substantially higher in the early modern era, with non-significant increases for the vertebrae, ankles and feet, and the wrists and hands of females. Finally, in the industrial-era, males and females alike experienced substantially less OA of almost every joint compared with the early modern era. Of the vertebrae, only the lumbar vertebrae of females registered with significantly lower OA scores.

In summary, we see a pattern of fluctuating OA scores over time and this pattern more often than not affected all joints and vertebral bodies in the same manner. It is clear from these data that the Early Middle Ages and the early modern era were the two periods where OA scores were the highest for both sexes overall and that the Late Middle Ages was a period of remarkably low OA scores in general. A peak high in the early modern era was followed by decline, nearly to its lowest point in the industrial era.

5.3.1.2 Farmers versus non-farmers over time

Because farming was ubiquitous over Europe for most of the time periods examined in this chapter, we also compared farmers versus non-farmers over time. These results demonstrate that farming had a specific and different impact on the joints compared with the non-farming occupations. Figures 5.2 and 5.3 illustrate these patterns.

There were no significant differences in mean OA score for any joint of the upper body for males from the pre-medieval through the early modern era with the exception of a higher prevalence of OA in the shoulders of non-farmers in the pre-medieval era, and higher scores for farmers' elbows, wrists and hands in the Late Middle Ages (figure 5.2). During the industrial period, when there was great disparity between urban non-farming and farming groups, the OA score for almost all joints was significantly different between these two groups of men, the wrists and hands being the sole exception, although the farmers' score was somewhat higher there as well.

Females exhibited similarly few differences in mean OA scores of the upper limb between these two groups in all time periods. Female non-farmers had a higher mean OA score for shoulders during the pre-medieval era and the early modern period, and higher mean OA scores for wrists and hands during the two earliest time periods.

Unlike the joints of the upper body, the joints of the lower limbs revealed more substantial differences between male farmers and non-farmers over time and fewer differences for females in these categories. During Late Antiquity, male non-farmers had higher mean OA scores for hips and ankles and feet. During the Late Middle Ages, however, male farmers had higher mean OA scores for knees and ankles and feet. Later, during the industrial period, farmers had significantly higher OA scores for all joints of the lower body and all vertebrae. There were no differences in lower limb OA scores between female farmers and non-farmers during any period except for the industrial era, when female farmers had higher OA scores for the hips compared with non-farmers and the pre-medieval period, where ankles and feet of female non-farmers had higher scores.

Finally, the OA scores of the vertebrae show a similar pattern of differences between farmers and non-farmers of both sexes. During the pre-medieval era, the thoracic vertebrae of male and female farmers and the lumbar vertebrae of male farmers demonstrated significantly lower OA scores compared with their non-farming counterparts. All of the statistically significant differences in subsequent time periods are to the disadvantage of farmers. Male farmers experienced more OA of all three classes of vertebrae in the early modern and industrial eras, of the thoracic during the Early Middle Ages, and of the lumbar vertebrae during the late medieval period. Female farmers experienced more OA of thoracic vertebrae during the industrial period and of the lumbar vertebrae during the early modern era. All types of vertebrae of female farmers were more strongly affected during the Early Middle Ages.

5.3.2 Socio-cultural variation

5.3.2.1 Socio-economic structure

Five categories for the socio-economic structure (SES) of the settlement or community that used the burial ground were represented in the sub-sample examined for OA: farmers, craft or artisan workers, military populations, religious orders and an umbrella category for ‘other’ groups represented by very few sites, such as a single hospital population (figure 5.4). In this discussion, as elsewhere, statistically significant differences (on the 5-percent level), taking into account only the number of multiple comparisons made between the various categories of socio-economic structures, are discussed unless otherwise noted.

5.3.2.2 Inter-sex variation within SES categories

The pattern of variation in OA scores between the sexes within each SES category (figure 5.4) is the same for both farmers and craft or artisan workers. Male farmers and craft or artisan workers had higher mean OA scores compared with their female counterparts for all joints and vertebral bodies. Additionally the mean residual score for males in both of these SES categories was consistently higher than expected for age (positive values), whereas the mean residual scores for the females were consistently lower than expected for age (negative values), with the sole exception of the lumbar vertebrae.

Females in religious orders had higher mean OA scores for all joints and all expect the cervical vertebrae, though the differences were only statistically significant for hips, knees, and wrists and hands. Males who were in the military category had a significantly higher mean residual score for OA of the wrists and hand than females, but lower scores for the lumbar vertebrae.

5.3.2.3 Intra-sex variation across Ses categories

In addition to the fact that male farmers and craft or artisan workers experienced more OA of nearly every joint surface and vertebral body compared with females, there were similar, though not statistically significant, intra-sex differences between farmers and craft or artisan workers (figure 5.4). Both male and female farmers had more degeneration of the vertebrae compared with craft or artisan workers, and less degeneration of the joints of the upper limbs.

Male members of a religious order had significantly less degenerative changes of the all joints and vertebrae than male farmers and craft or artisan workers, although some of the differences between males from religious orders and populations of mostly craft and artisan workers were not statistically significant. Females in religious orders only had significantly less OA of the elbow compared with female farmers and craft or artisan workers.

Males who died while in military service had significantly lower mean OA scores for all joints and vertebrae compared with male farmers and craft or artisan workers. The mean age at death for males in military service was 28.2 years (SD = 7.01 years) for this sample.

In summary, these data demonstrate that the populations with the largest mean OA scores for most joints included males, specifically farmers and craft or artisan workers. Categories of individuals who engaged in very specific activities such as members of the military, and those belonging to religious orders deviated from the pattern.

5.3.2.4 Settlement pattern

The results for the six settlement sizes (rural sites, villages, towns, small cities, major cities, and mega cities are presented in figure 5.5. A ‘mega city’ with more than 100,000 inhabitants was also available in this sample, but since it is the only one, it is folded into the major cities and not considered separately in the comparisons between settlement pattern categories. In this discussion, as elsewhere, differences that are statistically significant at the 5-percent level, taking into account only multiple comparisons between the different socio-economic structures, are discussed unless otherwise noted.

There were 34 rural sites in the OA sample analysis. These sites included two military populations, a religious order, three samples of craft or artisan workers, and an otherwise unspecified site; the remainder were farming communities. All elevation categories were represented in this sample, as well as all time periods except for the industrial era. Male and female mean OA scores differed significantly for all joints and vertebral bodies. In all cases, males had a higher mean OA score than females.

Thirteen village sites were considered. These included four sites of craft or artisan workers, two religious orders, six farming sites, and another unspecified site. All time periods except the industrial era were represented in this sample. Only the OA scores for shoulders and lumbar vertebrae differed significantly between the sexes. Again, these differences favored the females; the males had higher mean OA scores for each.

Twenty-nine towns were available for OA analyzes. The vast majority of them represented craft or artisan workers (n = 19) but there was also a hospital population, a military site, two religious orders, five farming communities and an otherwise unspecified site. All time periods were represented in this sample of towns. Except for the hip and knee joints, which were very similar between males and females, the mean OA scores for all joints and vertebral bodies were significantly higher for males compared with females.

Sixteen small cities were included in the OA sample analyzed here. These sites included a military site, a religious order, and two sites of the otherwise unspecified category. Craft or artisan workers (n = 8) and farmers (n = 4) make up the rest of the small city sites. No sites from the Early Middle Ages were in this sample. Mean OA scores for all joints and vertebral bodies except the elbow, hip, and thoracic vertebrae were significantly higher for males compared with females.

Nine major cities, including the sites from 'mega cities' were in this sample. Five sites represented craft or artisan workers, the others were two military sites, a site linked to a farming community and two otherwise unspecified samples. Mean OA scores for males and females only differed significantly for the knees, where females had higher OA scores.

5.3.2.5 Intra-sex variation across settlement patterns

The pattern of mean OA scores across settlement patterns was very similar for both males and females. Both sexes experienced the highest mean OA scores in rural locations, villages, or towns. Males in the largest cities had lower mean OA scores for all joint surfaces compared with males from other settlements, although not every pairwise difference was statistically significant. For females, many of the joint surfaces were equally worn out in settlements of different sizes, with the exception of the hips and lumbar vertebrae, where the OA scores decreased with settlement size. The differences between neighboring categories of settlement size were, however, not statistically significant.

5.3.3 Geographic variation

5.3.3.1 Elevation

With some exceptions in the highest elevation category, males and females were significantly different in both the lowest and the highest elevation categories (figure 5.7). In every comparison between males and females, males had a higher mean OA score except for the shoulders, hips, and knees of individuals from the middling elevation category (100–300m). These inversions are, however, not statistically significant in Tukey's honest significant difference test.

5.3.3.2 Intra-sex variation across elevations

Overall, there was no consistent pattern of OA scores by elevation category, but there was a tendency for upper-limb joints to exhibit lower OA scores in the highest elevation category. The joints of the lower limbs showed mixed results, with significant decreases for male and female ankles and feet from the middling to the highest elevation category, a decrease for female knees, and an increase for male hips. Degenerative changes of cervical, thoracic, and lumbar vertebrae did not differ significantly with elevation, with the exception of thoracic vertebrae of male individuals, which had lower OA scores in the middling category. However, the sample size of the highest-elevation category was rather small for these vertebrae, so this may be a statistical artefact.

5.3.3.3 Topography

Five categories of topography were considered in these analyses: the coast, major river flood plains, major river valleys, plains, and rolling hills (Figure 5.6). In this discussion, as elsewhere, statistically significant differences at the 5 percent level, taking into account only multiple comparisons between the topographical categories in this instance, are discussed unless otherwise noted.

Nine coastal sites were considered in this analysis. They consisted mostly of farmers and craft or artisan workers from rural settlements, villages, towns, and small cities. These sites dated between the pre-medieval period and the early modern era. There were no statistically significant differences between the sexes for mean OA scores of any of the joints, although the values for females were lower across the board.

The sample included 14 sites on major river floodplains. Farmers, members of religious order and populations from military contexts, and craft or artisan workers from most categories of settlement sizes were included. All time periods except the industrial era were represented by these sites. Significant differences between the sexes were present for all joints of the upper limb as well as ankles and feet, and cervical vertebrae. Females had significantly lower OA scores than expected for age, i.e. on average negative residuals.

There were 28 sites located in valleys of major rivers, such as the Danube and the Rhine. All of the time periods as well as all of the categories of settlement size and socio-economic structure were represented in this topographical category, with most of the samples having been identified as craft or artisan workers. Males had significantly higher mean OA summary scores for most joints and vertebral bodies, the exceptions being knee joints, shoulders, elbows, and the cervical vertebrae bodies, where were no significant differences existed between the sexes.

The 34 plains sites in the database mostly belonged to farming communities and craft or artisan workers. Although a majority of 15 sites in this category were classified as rural settlements, all other settlement sizes were represented as well. Males and females differed significantly with regard to mean OA scores for wrists and hands, ankles and feet, and thoracic vertebrae.

The topographic category of rolling hills consisted of 16 sites, including farming communities, craft or artisan workers, and a single site from a military context. Males had significantly higher mean OA summary scores for all joints except the ankles and feet and cervical and lumbar vertebrae.

5.3.3.4 Intra-sex variation between topographic categories

With a few exceptions (male ankles and feet, and female knees), OA scores were not significantly lower than those from sites located in the floodplains of major river in any other topographical category. These lower scores were significantly different for both males and females compared with the higher scores seen in sites in valleys of major rivers and on plains for all joints and vertebral bodies, with few exceptions, where the difference still had the same sign.

OA scores for both males and females from sites located on plains were most similar to the scores seen in the valleys of major rivers; indeed, the only statistically significant differences found in the within-sex comparisons between these two topographic categories were a lower prevalence of OA in the shoulders of men from the plains. The few exceptional cases where OA scores were lower than those of the people from settlements on the floodplains of major rivers were from sites located in rolling hills, which had otherwise similar OA scores. These scores were also significantly lower for most joints and vertebral bodies than the scores of their counterparts from coastal sites, or sites on plains or in valleys of major rivers.

In summary, the analyses of topographic variation revealed that topography contributed to a more nuanced understanding of variation of severity of OA between the sexes, as well as within each sex across the topographic categories. We learned that OA scores were somewhat similar at sites located in plains and valleys of major rivers. Coastal sites exhibited the least differences between the sexes for all joints and vertebrae.

5.4 Discussion

This study reveals a great diversity in lifestyle, including the type of activity practised, and quality of life in Europe from Late Antiquity through the industrial era. The pre-medieval period involved the retraction of the Roman Empire and the fall of Rome, resulting in great social change, dramatic shifts in settlement, subsistence economy, and social structure (e.g. Bowersock 1988). During the Early Middle Ages, relationships with nearby people and those who migrated into or near existing communities dictated the direction people took and to some degree the level of success they experienced. Later in the High and Late Middle Ages, further disruption occurred to the degree that this period is known as the 'Dark Ages' in Europe. The process of industrialization changed the human experience in Europe still further. The broad comparisons provided by the *Global History of Health Project* give a platform from which to document and interpret the human biological outcomes and consequences necessary for a nuanced understanding of these periods of upheaval and the degree to which populations succeeded or failed.

In this chapter, we considered the age-adjusted mean OA summary score for the shoulder, elbow, wrist/hand, hip, knee, and ankle/foot joints as well as the mean OA score for cervical, thoracic, and lumbar vertebrae as indicators of OA severity. Collectively, we refer to 'mean OA score' as referring to these two scores. We considered these scores between and within the sexes with regard to temporal, socio-cultural, and geographic variation. This approach provides a window into the history of OA across much of Europe from Late Antiquity to recent industrial times.

5.4.1 Temporal variation

The results of these analyses demonstrated a general pattern of higher mean OA scores during the Early Middle Ages (6th–10th centuries) and then again during the early modern period (16th century until about 1750) for both sexes. The Late Middle Ages (14th and 15th centuries) and the industrial period (beginning around 1750) had the lowest mean OA scores.

Males and females experienced some differences in mean OA scores for many joints and vertebrae during Late Antiquity, but it was not until the Early Middle Ages that scores for all joint surfaces and all vertebral bodies differed between the sexes, suggesting dramatically different lifestyles or activity patterns based on sex. By age-adjusting the mean OA scores, the resulting residual provides a measure of OA affectedness that reveals that not only did males have substantially more OA throughout the skeleton compared with females, but also that males had more OA than would be expected given their chronological age (higher OA scores than expected for chronological age are reflected in positive residual values). Females, on the other hand, had smaller residuals in absolute terms. That is, close to zero or negative residuals indicate typical or less OA than expected for age. This outcome of our study suggests that the dramatic change that precipitated such disparate changes in lifestyle between the sexes during the Early Middle Ages was due to a change in activity primarily experienced by males. This change suggests that during the Early Middle Ages, males led lives that involved more intense and more demanding physical activity than the lives of females.

The pattern of affectedness for the knee is an especially robust finding that is consistent with our interpretation of the patterns of OA that we see in Europe over time. Moreover, these findings are consistent with the biology of joint degeneration as it relates to activity and to differences between males and females. We know that osteoarthritis is an age-progressive, complex disease process. The greatest contribution to the prevalence of osteoarthritis is mechanical wear-and-tear (Hough 2001). These mechanical insults are comprised from both normal use (e.g. expected use of joints from weight-bearing or normal lifelong use of non-weight-bearing joints) and from cumulative mechanical insult from those behaviors that exceed the demands of simply walking or standing. Knee osteoarthritis is one of the most common locations for degeneration, and this condition is ubiquitous among both sexes in modern aging populations (Felson, Lawrence, et al. 2000). The lack of statistically significant differences between the sexes except for during the Early Middle Ages (6th to 10th centuries) may indicate that with the exception of that single time period, risk factors for development of knee OA were similar for both sexes and may reflect simply the normal joint loading. During the Early Middle Ages, males and females experienced substantial increases in OA of most joints and the mean score for all joints and vertebral bodies was significantly different between the sexes. The pattern of sex differences for hip OA is similar. The hip joint is also a load-bearing joint of the lower limb and degeneration of this joint surface over a lifetime is expected. Only during Late Antiquity and the subsequent Early Middle Ages were there significant differences in the mean OA hip score between the sexes.

Following the fall of Rome there was substantial movement of people throughout Europe (Fleming 2010). In many areas this caused significant upheaval in settlement patterns and subsistence strategy. Despite this general circumstance, it is not clear how widespread or uniform these changes may have been. Some locations would certainly have seen continuity in a good quality of life while others saw significant upheaval (e.g. Winks and Ruiz 2005). Groves et al. (2013) used isotope profiles to document population movement to English sites during the early medieval period. This study revealed differential health status between locals and non-locals. Certainly this may have implications for occupational or labor burdens. Graham (1992) highlights what this may have meant for women in particular –- those who moved into towns, villages, and urban centers in search of work and whose work could vary dramatically depending on their social and/or marital status.

Although we have little direct evidence of what this population movement meant for occupational stress, we can infer quality of life from diets and other lines of evidence in order to further develop hypotheses about how work and physical activity may have changed. For example, in Bavaria, there are data that indicate that diet changed little between the pre-medieval (Late Roman) and early medieval periods (Hakenbeck et al. 2010). The authors suggest that this supports population continuity in this region. If so, then it seems likely that related occupational activities may not have fluctuated in this region. This work also revealed evidence of exogamous female mobility which has potential implications for differences seen between males and females in all areas that relate to quality of life. In Croatia, there is evidence that the change between Late Antiquity and early medieval times was not uniformly disruptive. Rather, there was continuity in experience at inland sites and significant disruption at coastal Adriatic sites (Šlaus 2008). While these results deal with non-specific physiological stress (cranial porosities and linear enamel hypoplasia) and trauma, there are clear implications for quality of life in general.

Differences between the sexes in OA clearly declined as time proceeded, suggesting a reduction in labor demands that had once been more pronounced between males and females. What might explain the decline in sexual dimorphism as it relates to mechanical loading of mobile articular joints? During the Late Middle Ages (14th and 15th centuries), only the elbow OA scores differed between males and females: males had a higher mean OA score than females. Mays (2006) found a high prevalence of pars interarticularis defects at the High Middle Age village of Wharram Percy, which he attributes to especially elevated workload during late adolescence. This behavioral record provides some perspective about age of entry into the workforce and further supports the notion that farming during the Middle Ages was difficult and impacted physical and social relationships. Oliveira (2007) (after Cardoso and Garcia 2009) suggests that children during this time would have entered the work force early as supplementary labor for their families. While this labor may have been modest compared with that expected of young people entering urban workforces several centuries later (Cardoso and Garcia 2009), agricultural work is demanding by any standard and children learned to work from an early age. This period of 10–15 years of physical labor prior to reaching adulthood coupled with the cumulative effects of marginal nutrition, elevated disease, and occupational stress would certainly conjoin to compromise articular joint health.

Generally, OA scores increased in the pre-industrial era to levels similar to those seen in the Early Middle Ages. Sofaer Derevenski (2000) compared the High Middle Ages Wharram Percy rural English site with the pre-industrial site on the island of Ensay in Scotland. Vertebral OA results from her study showed that people living on Ensay had both a higher degree of gendered division of labor compared with the High Middle Ages site and more OA, indicating a more occupationally stressed population during the early modern era than in prior times. This conclusion conforms well with the results documented in the current study.

Several researchers have examined the impact of rapid urbanization and industrialization on health. For example, Lewis (2002) examined child health during this highly dynamic period , finding that industrialization had a far greater impact on child health than urbanization. While health may have been especially compromised during the industrial era [2], occupational stress and its effects on joint health were more substantial in the immediately preceding early modern era, possibly due to rapid population expansion and the physical demands of building urban centers, harvesting food to feed the ballooning population, and the increased labor and effort to transport goods produced in urban centers.

Finally, in the industrial era, OA scores for every joint were significantly lower for both sexes compared to the preceding early modern era.

European populations across all of these time periods did not easily fit into specific occupational categories. In fact, most people engaged to some extent in farming and animal husbandry, even if that was not their primary occupation. Rather, they provided labor for some degree of subsistence and in other cases, farmers would regularly sell their surpluses (e.g. Watkins 1998; Hamerow 2002). Despite this fact, we compared farmers to non-farmers (people who may have engaged in small scale personal farming, but whose primary work was in the non-farming sphere). These results elucidated the very specific effect of farming on patterns of axial and appendicular joint degeneration. For males, OA of the joints of the upper body (shoulder, elbow, and wrist/hand) there showed no significant differences temporally between farmers and non-farmers except for the industrial era and the Late Middle Ages. These results support the notion that while farming was not necessarily the primary occupation of people across all time periods and location, it was a part of the daily life of all people to some degree. This finding implies that for men, frequently gendered farm-related activities (e.g., plowing, heavy lifting) may have been performed to some degree, despite being engaged in other occupations for many settings.

Females also engaged in significant farming duties, but their work also extended into domestic activities that kept them closer to home. Female non-farmers had higher mean OA scores of the wrist/hand than female farmers during Late Antiquity and the Early Middle Ages.

Like the joints of the upper body, male and female farmers had mostly higher OA of every joint of the lower body compared with their non-farmer counterparts, the difference being statistically significant mostly during the industrial period. This finding suggests that during the industrial era a farm-

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[2] This will be discussed in detail in another chapter of *The Backbone of Europe*.

ing lifestyle was dramatically different from a non-farming lifestyle. We suggest that this pattern reflects a time when large cities were more common and occupations became increasingly specialized.

Finally, some key findings emerge from the comparison of the farming and non-farming occupational activities. With regard to OA of the vertebral bodies there are considerable temporal differences between male farmers and non-farmers. Male non-farmers during Late Antiquity had higher thoracic and lumbar vertebral OA scores, and male farmers had higher thoracic vertebrae OA during the Early Middle Ages and more OA of all vertebral bodies during the early modern and industrial periods. OA of all vertebral bodies was higher for female farmers than non-farmers during the Early Middle Ages only, but higher with few significant differences in the early modern and industrial periods. These results are fully consistent with the notion that farming was a more physically demanding occupation for males during Late Antiquity compared with other periods. They are also consistent with the notion male farmers experienced more variation in occupational stress during other periods, possibly due to maintaining farming activities in addition to other primary occupations. The scarcity of significant differences in OA of the vertebral bodies except during the Early Middle Ages suggests that female behaviors that influence degenerative changes of the vertebral bodies varied little over time and between the broad categories of farmer and non-farmer.

5.4.2 Socio-cultural variation: settlement pattern and socio-economic structure

5.4.2.1 Settlement pattern

Settlement pattern, socio-economic structure, and the geographic variables considered in this chapter are closely related. As they pertain to the sample used for this investigation, analyses of mean OA summary scores revealed that for males, living in smaller settlements (rural areas, villages, or towns) typically led to higher mean OA scores. In the three settlement patterns with the greatest population density (small, major, and major cities) males typically exhibited comparatively lower mean OA scores compared to males from more rural locations. On the other hand, females did not have higher mean OA scores in the smaller settlements. Modern U.S. data from North Carolina reveals that rural populations have substantially higher hip and shoulder OA prevalence compared with urban populations (Jordan et al. 2007). Larsen (2015) also observes that OA in urban New York African Americans from the African Burial Ground (Wilczak et al. 2009) was higher than the contemporary African American rural Cedar Grove population (Rose 1985). The results presented here contribute to this discussion and demonstrates that rural and urban lifestyles are far from uniform.

In the rural communities, males had more OA of all joints and the vertebral bodies than females. The rural sample in this dataset consisted primarily of farming populations, although a small number of other types of sites were also rurally located. While farming is a diverse activity, the physical labor it requires results in heavy wear and tear of the joints. The fact that females experienced higher OA scores (except for the shoulder and hip) in urban locations provides some insight into the gendered work experience in rural versus urban locales.

As settlement size increased, the situation is not as clear cut. In villages, the only significant differences between males and females were in the shoulders and lumbar vertebrae, suggesting that both sexes experienced similar work and lifestyles. In towns, males and females differed in the same joints and the wrists and hands and thoracic vertebrae. Most people living in towns engaged in trade or craft production (craft or artisan workers) which would have required specific skills and these may have been gender-specific occupations.

In small cities, males had higher mean scores for all joints and vertebrae. Major cities (including the single 'mega city') were the first settlement category to see females with higher OA scores compared with males, though significantly so only for knees,

With regard to the trend of degeneration of the vertebral bodies, males and females demonstrated an identical pattern. While males generally had higher scores than females, both sexes expressed consistent decrease in severity of degeneration of the vertebral bodies as the community size increased from rural to major cities.

For males, OA of the upper and lower limbs was highest in smaller communities: rural, village and town settlements compared with the 'city' categories. This pattern is not as definitive for females. Like the males, females generally had lower OA scores for both the upper and lower limbs in smaller communities except for females who lived in 'major cities.' These women experienced higher upper and lower limb (except the hip) OA scores in these settlements compared with females in all other settlement types. Mean summary OA of the hip for females in major cities was similar to the rate seen in all other categories of settlement.

5.4.2.2 Socio-economic structure

The categories of 'farmers' and 'craft or artisan workers' are informative, yet confounded by a number of factors. These confounding factors include the kind of crop farmed, farming implements used, seasonality of labor for farmers, and the type of goods produced, and the conditions under which they were produced for craft or artisan workers. Yet, despite the complexity and range of possible activities that are not explicit in these definitions, generalizing about these occupations can be valuable to understand how different lifestyles produced certain patterns of OA.

Djurić et al. (2006) found that rural agricultural sites from Serbia spanning the High Middle Ages through the pre-industrial era (11th–19th c) had trauma patterns that closely align with what one would expect due to the risk of accidental farming injuries. Judd and Roberts (1999) found the same type of evidence of farming accident trauma in a High Middle Ages site in England. They elaborate on these injuries by providing some specific occupational conduct which could lead to the fractures observed and emphasize the physical difficulty of farming. Over the course of history in Europe from Antiquity through the industrial era, farming innovations developed which may have eased the burden of some aspects of agricultural life. These include the heavy plow, windmill (c. 1200 CE), variable field systems (e.g. strip fields, infield/outfield, pasture, and plowland), crop husbandry, and reliance on farm animals for plowing and animal husbandry regimes (Hamerow 2002; T. Williamson 2004). Carts and horses aided transportation of goods, and horses were used with the plow by the 13th century (Dyer 2005).

One limitation of the current study is the inability to pinpoint where and when each of these technologies was adopted across Europe and over time. Despite this limitation, we have examined temporal patterns associated with farming and non-farming populations over time. These comparisons are very important for revealing when farming was more or less of an impact on certain joint surfaces possibly due to the adoption of technologies that aided farmers. The results of these analyses are remarkable in that they show clear differences between farmers and non-farmers.

The results of these analyses show that male farmers and craft or artisan workers experienced higher mean OA scores for all joints and vertebral bodies compared with females from the same populations. Furthermore, within sex, these analyses show that there were basically no differences between male farmers and male craft or artisan workers or between the females of settlements where these occupations were the most common. These results suggest that males and females within each of these groups engaged in sex-specific activities that did not differ in appreciable ways between those who were primarily farmers and those who were primarily craft or artisan workers. These activities impacted the severity of OA for every joint and for both sexes, but the impact of these lifestyles did not produce substantial differences in joint degeneration within the sexes and across these two socio-economic structures.

The only other differences in mean OA scores with regard to SES came from comparisons with populations from military contexts and religious orders. Each of these specific categories is comprised of demographic features which may heavily influence the expected mean OA summary score. For example, the military populations are typically comprised of relatively young males and some females, but their roles in the military operations would generally be highly sex-specific. The conditions surrounding a military individual's death would stem from both the operations they were engaged in as well as the living conditions of these forces. As such, one might expect to see lower mean OA scores because of a young age-at-death. On the other hand, military life may lead to specific repetitive activities that would cause significant stress to some joint surfaces (see discussions in Larsen 2015; Owsley et al. 1991; Stirland 2000).

Males in religious orders had very low levels of OA, while females had higher OA scores than men for some joints, an exception to the general pattern. This suggest that the lifestyle of females in religious orders led to significant wear and tear for most joint surfaces, and for some of them even at the level seen in female farmers and craft or artisan workers. Sullivan (2004) found that males from the medieval Gilbertine Priory at Fishergate, York, England lived long and relatively comfortable lives. In addition, moderate status females benefited from religious life at this location whereas low status females suffered difficult and short lives here. Our work supports the notion that males in religious orders lived comfortable lives at a variety of religious orders and that females in the same communities did not enjoy such ease of life.

5.4.3 Geographic variation: topography and elevation

5.4.3.1 Topography

Topography and the elevation categories discussed below are closely related. Despite this interrelatedness, some nuances were observed by examining summary OA scores using these categories and considering where and how they are inextricably linked with one another. Five topographical categories were examined: coastal, floodplains of major rivers, valleys of major rivers, plains, and rolling hills.

The mean male and female OA scores for vertebral bodies and the upper and lower limbs followed similar patterns depending on topography. Despite the similar pattern of OA scores between the vertebrae and the upper and lower limb joint surfaces, there is even less variation within the sexes with regard to the vertebral scores than with the upper and lower limb joints. Within each sex, there was near identical patterns of variation for all three vertebral types. Males had consistently higher OA scores for all the vertebrae, with the highest scores for both males and females from sites in the valleys of major rivers. These scores were significantly higher than those of populations of coastal sites, sites from major river floodplains, and areas with rolling hills. People from the plains had the second highest scores of all the topographical categories. The residual values for the samples from sites among rolling hills demonstrate that the men and women in those regions had far less OA than expected for age, indicating a potentially biased sample, with too few people from the more rugged terrain represented.

5.4.3.2 Elevation

There is no common relationship between mean summary OA scores and elevation category of the burial sites. However, in both sexes, most of the upper limb joints of males and females from sites at higher elevation received lower OA scores. As with most other comparisons, males had higher mean summary OA scores in these categories as well, with some exceptions in the middling category (100–300m). There is little work that directly addresses the role that elevation plays in OA. Williams (2005) found that heterogeneity in elevation produced a pattern of elevated OA prevalence compared with more homogeneous terrain where consistency in terrain is determined by changes in elevation over the extent of an exploited space. This is an area of research that has yet to see much attention from researchers, both with regard to bioarcheology and living populations.

5.5 Limitations of current study and future work

There are many strengths of the current work. Assembling a large database and conducting analyses across a broad spectrum of communities over time, space, and with regard to social structure helps us to understand how lifestyle, behavior, and quality of life varied over large regional and temporal spans. Still, there was substantial variation in each of these factors depending on a host of local conditions that are impossible to account for on this scale. The limitations to the current work suggest important avenues for future work with these data especially with regard to appreciation of social status and small regional or local environmental and cultural conditions. For example, much of European history that we have examined here is characterized by feudal hierarchy that shaped relationships in complex ways (Singman 1999). Land ownership versus farming rights versus slave labor are important distinctions that directly impact occupational stress (and see Steckel, Sciulli, et al. 2002). Clearly, settlement size is an important consideration in these analyses. Community size and the related division of labor between the sexes and within the sexes were clearly related to the number adults and children available for labor and in meeting the needs of the community. These labor requirements changed over time and varied by location, sometimes in substantial ways. Although the overall trend may have been toward increasing population sizes, larger cities, and complex economies over time especially in the Middle Ages (Bardsley 1999; Fleming 2010; Le Goff 1982), this was certainly not a uniform experience and rural communities would certainly still vary in size. Division of labor between the sexes and between different segments of the workforce would have differed based on one's social, marital status, or age. Finally, the timing and location of agricultural intensification evidenced by such things as turf manuring, perpetual cultivation, adoption of new field systems, the heavy plow (and mouldboard), and crop rotation (Hamerow 2002) is not readily clear for all of the study area examined here.

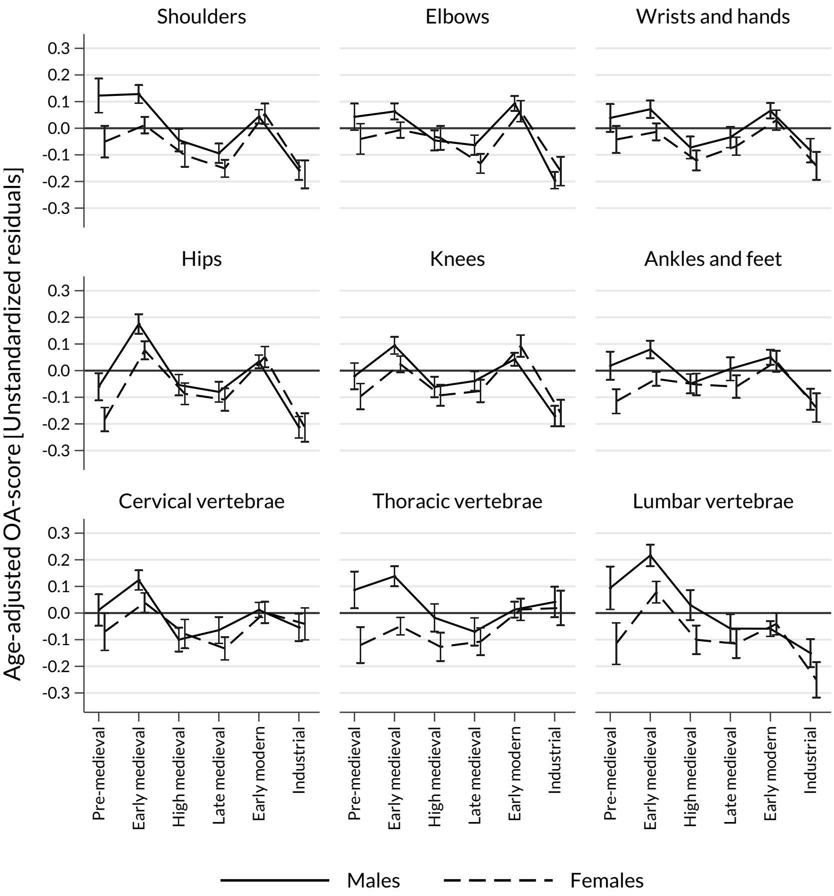
5.6 Conclusions

This work is an important contribution to our understanding of the variation in osteoarthritis and its role in drawing inferences about behavior, lifestyle, and occupational stress over a broad temporal and geographic space in Europe. This work identified the Early Middle Ages and the Late Middle Ages/early modern period as the times when occupational stress was greatest for the populations of Europe. This corresponds to wide-scale social reorganization following the fall of Rome and both agricultural intensification and urbanization. As expected, the demands of farming played a significant role in the level of physical activity and resultant joint degeneration for both sexes. During the Early Middle Ages it is clear that both sexes experienced significant physical demands that led to joint degeneration. While males had higher mean OA scores compared with females in most comparisons where there was a difference between the sexes, this was especially pronounced during the Early Middle Ages when every OA of every joint surface and vertebral body was significantly higher in males compared with females. In no other time period were the differences between the sexes as pronounced. Gendered occupational stress is also evident in other types of comparisons. When farmers and non-farmers are compared across time we can see that there were no intrasex differences for males in upper body OA until the industrial era when work in urban centers and farming locales finally became distinct from one another. This is the not the case for females, suggesting that the work that female farmers and non-farmers engaged in varied before industrialization. The reverse is true for the joints of the lower body. Here, female farmers and non-farmers did not differ except during the industrial era (and then only for OA of the hip), but males did vary in mean OA score for these joints over time. These results present robust evidence for the way that physical activity and labor changed or did not change over time.

A significant consideration for all of these results is the varied lifestyle, subsistence practices, and adoption of technology over time. It is impossible with a project of this size to consider the specifics of each site and that is not the intention of this current study. This perspective allows us to examine geographic variables such as topography and elevation and to discern patterns of OA severity that may be related not only to regional practices but also to the physical geography of where people lived and worked. This work has demonstrated a remarkable similarity in OA pattern of affectedness when viewed through the lens of topography. These results suggest that when settlement size, time period, and socio-economic status are not considered, topography alone produces patterns of OA affectedness that are relatively constant across all joint surfaces. This result suggests important future work that explores the impact of the environment as a life-long force impacting joint health.

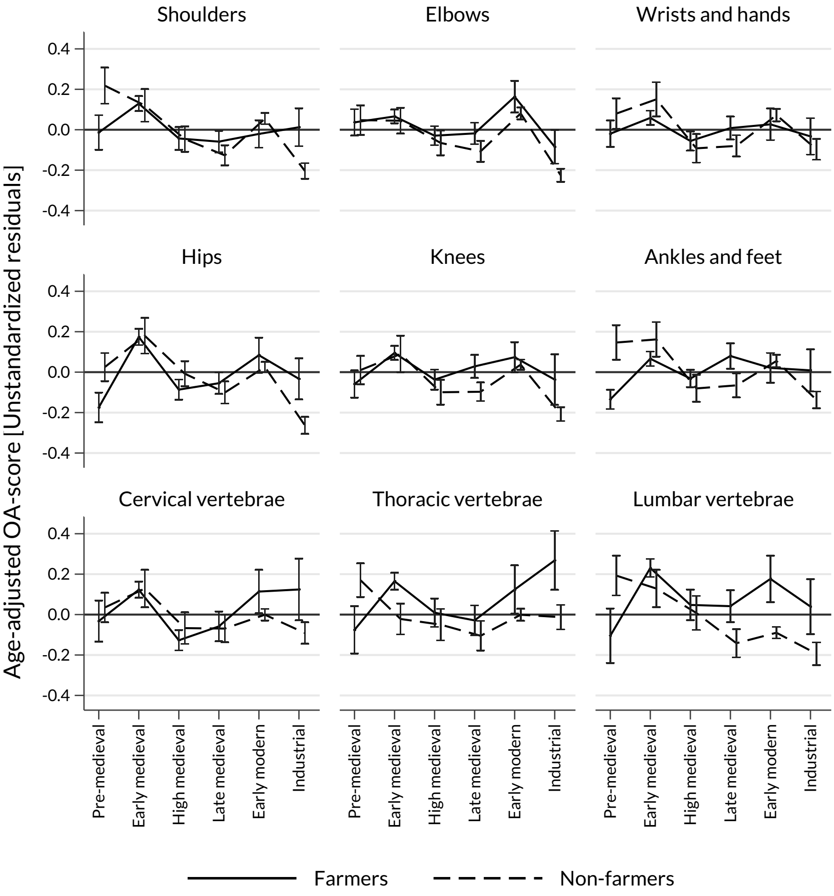
5.7 Figure and tables

Figure 5.1: Mean age-adjusted OA scores by time period, with 90% confidence intervals.



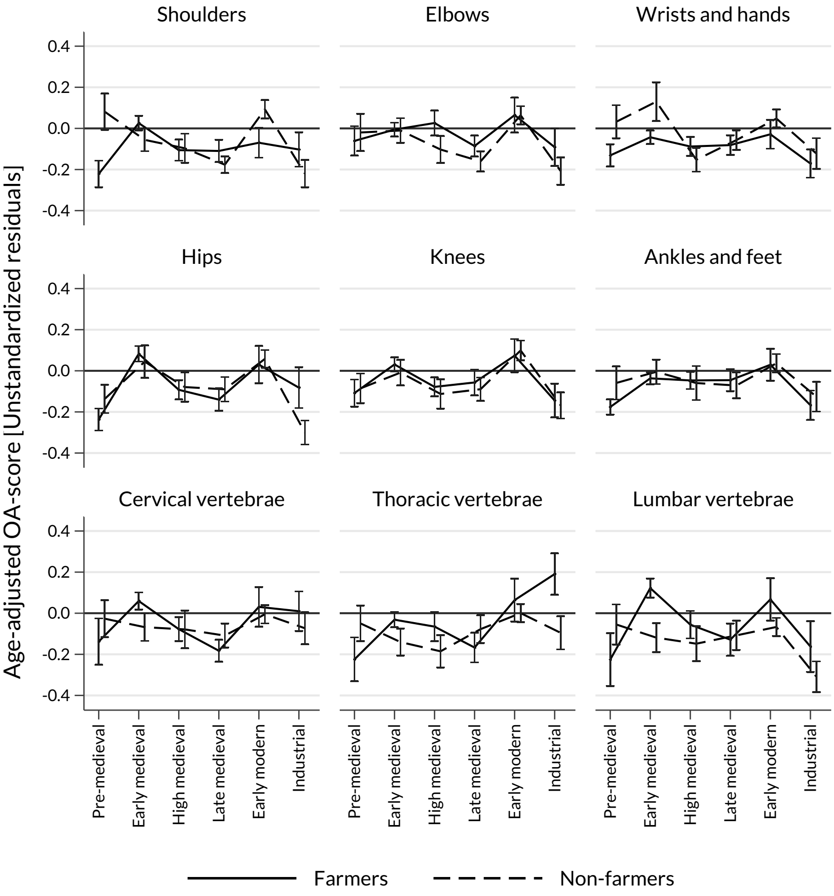
– Higher residual values indicate more OA than expected for age and lower residuals indicate less OA than expected for age.

Figure 5.2: Mean age-adjusted OA (with 90% confidence intervals), comparison of male farmers and non-farmers across time



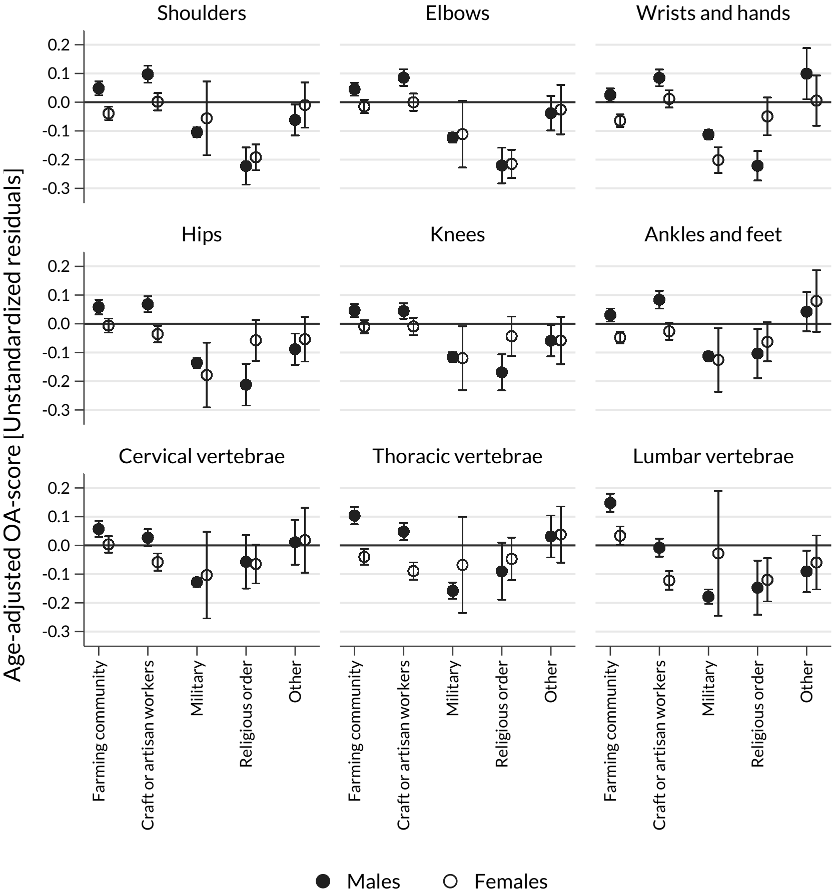
– Higher residual values indicate more OA than expected for age and lower residuals indicate less OA than expected for age.

Figure 5.3: Mean age-adjusted OA (with 90% confidence intervals), comparison of female farmers and non-farmers across time



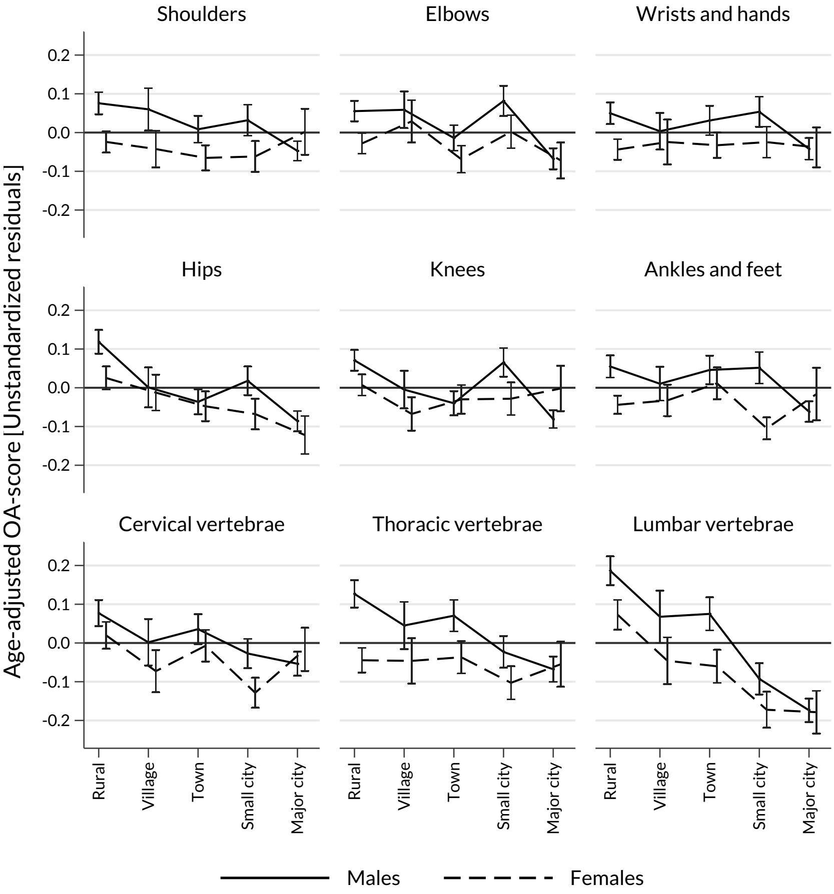
– Higher residual values indicate more OA than expected for age and lower residuals indicate less OA than expected for age.

FIGURE 5.4: Mean age-adjusted OA scores by socio-economic structure of the settlement, with 90% confidence intervals



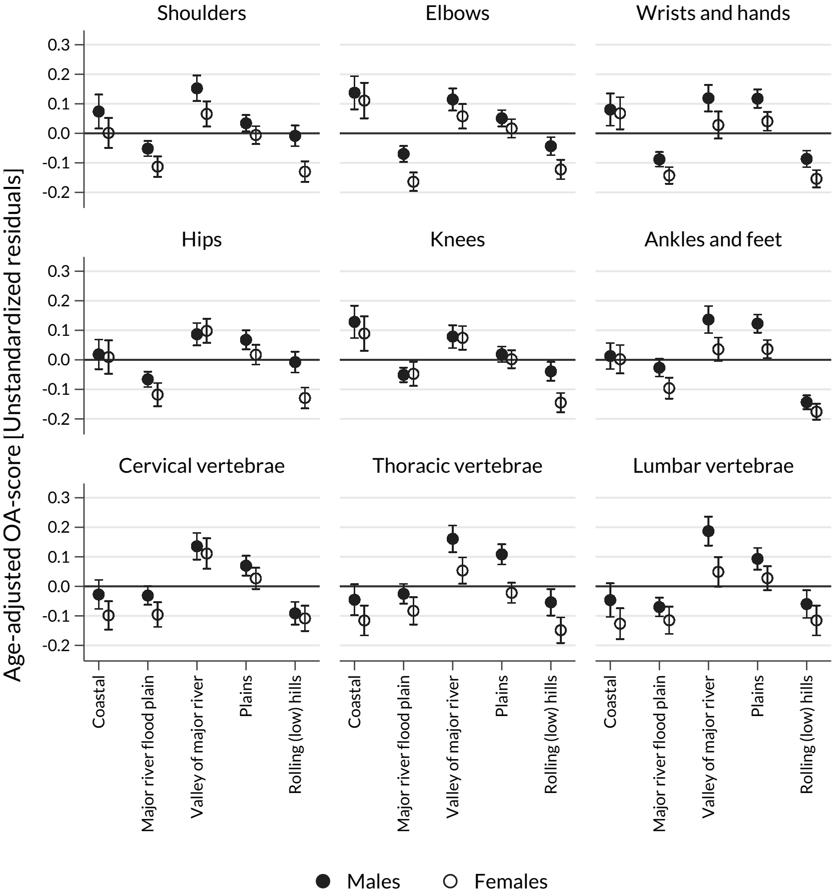
– Higher residual values indicate more OA than expected for age and lower residuals indicate less OA than expected for age.

Figure 5.5: Mean age-adjusted OA scores by settlement pattern, with 90% confidence intervals



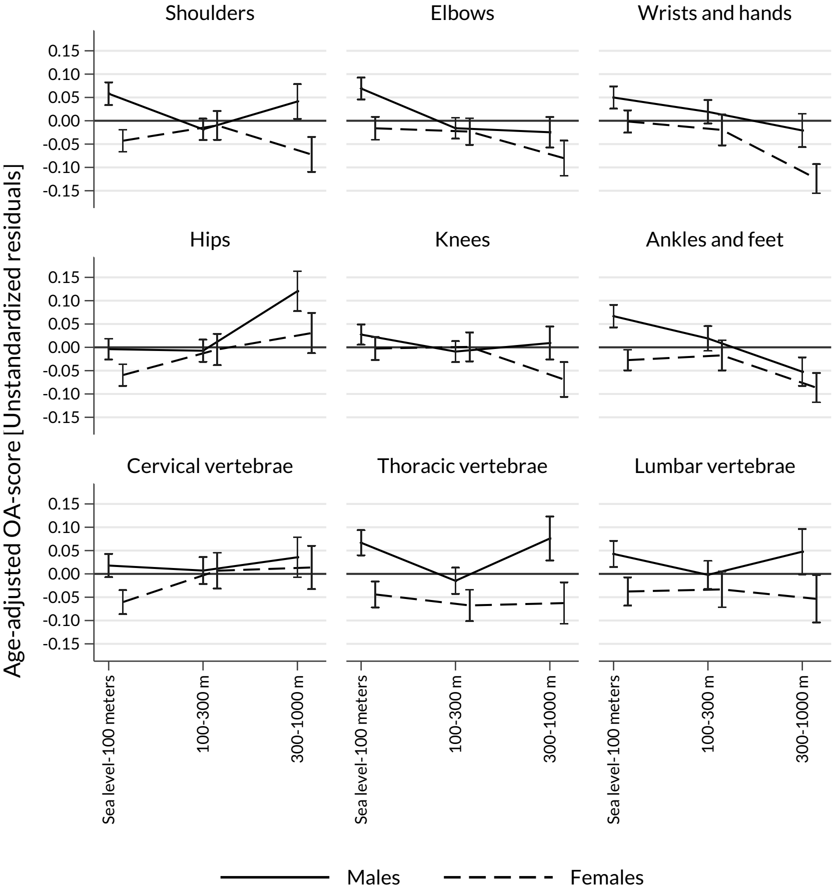
– Higher residual values indicate more OA than expected for age and lower residuals indicate less OA than expected for age.

FIGURE 5.6: Mean age-adjusted OA scores by topography of the settlement area, with 90% confidence intervals



– Higher residual values indicate more OA than expected for age and lower residuals indicate less OA than expected for age.

Figure 5.7: Mean age-adjusted OA score by elevation of the settlement area, with 90% confidence intervals



– Higher residual values indicate more OA than expected for age and lower residuals indicate less OA than expected for age.

Table 5.1: Sites included in osteoarthritis sample (males)

Site	Name	(20,25]	(25,30]	(30,35]	(35,40]	(40,100]	Total
113	Saint Sauver	3	6	3	5	18	35
120	Bobald-Carei	3	1	1	5	2	12
127	Wandignies-Hamage	0	2	0	0	0	2
134	Valkenberg-Breda	0	1	3	1	8	13
141	Bernardinai	0	0	0	1	7	8
148	Mindaugo	26	6	1	1	6	40
155	Latako	4	5	3	1	13	26
169	Pranciskonu	2	1	1	4	7	15
176	Pranciskonu sventorius	1	0	2	3	3	9
183	Subaciaus	6	7	9	7	27	56
190	Katedra	1	4	3	4	10	22
211	Kriveiskiskis	0	4	7	5	24	40
267	Leipalingis	4	3	4	3	13	27
295	Siaures miestelis	196	122	48	22	33	421
344	Trentholme Drive, York	6	14	17	16	17	70
400	Kiskundorozsma Daruhalom	0	3	2	5	20	30
435	Pottenbrun	1	0	6	7	20	34
449	Panevezys	27	18	15	10	7	77
456	Mintoritenweg	15	16	12	16	48	107
470	Lauchheim	22	11	19	21	169	242
477	Rukliai	4	1	3	4	16	28
484	Kaldus	5	15	20	18	82	140
491	Poznan-Srodka	0	2	0	2	12	16
512	Giecz	5	7	5	21	49	87
526	Garbary	0	0	0	0	0	0
533	Wodna	0	0	0	0	1	1
554	Butt Road, Colchester	0	4	6	18	17	45
582	St. Ame	7	1	9	3	26	46
596	Gars Thunau	7	2	2	7	10	28
603	Zwolfaxing	6	4	6	11	38	65
617	Pasydy	0	0	2	4	7	13
638	Slava Rusa	2	3	4	3	20	32
645	Homokmegy-Szekes	2	1	4	5	31	43
652	Spata	0	0	1	0	0	1
659	Thebes	0	0	0	0	0	0

Continued on next page

TABLE 5.1: Sites included in osteoarthritis sample (males)

Site	Name	(20,25]	(25,30]	(30,35]	(35,40]	(40,100]	Total
666	Nagylak Hatarsav	4	8	5	6	35	58
673	Haudricourt	1	1	0	0	0	2
680	Schleswig	3	3	6	8	28	48
694	Franciscan Friary	7	7	5	14	61	94
701	Messene	2	2	4	5	6	19
708	Sourtara	2	3	3	10	21	39
715	Kastella	1	0	1	6	3	11
736	Basel-Barfusserkirche	0	0	0	0	5	5
7361	Basel (Barfusserkirche?)	8	5	4	7	39	63
743	Mangalia	4	2	3	3	37	49
750	Les Rues des Vignes	0	1	3	0	0	4
757	BlackGate	13	9	22	19	82	145
764	Sigtuna	3	23	27	27	9	89
771	Etting	2	3	0	3	3	11
778	Unterigling	15	4	1	13	36	69
785	Plinkaigalis	11	7	11	7	36	72
792	Buren Oberburen	6	6	2	3	46	63
799	Kwidzyn	0	0	0	0	4	4
806	Aguonu	8	7	8	7	18	48
820	Istria	0	1	1	3	15	20
827	Koningsveld	6	3	1	7	20	37
834	Apple Down	5	0	9	0	7	21
855	Santa Clara-a-Velha	0	0	0	0	0	0
862	Xironomi	0	0	2	0	0	2
869	Blackfriars	3	1	7	1	3	15
876	Towton	7	0	12	0	8	27
883	Constancia	2	3	3	3	19	30
890	Szoreg-Teglagyar	1	2	4	1	6	14
897	York, Fishergate House	2	0	1	0	4	7
911	Wenigumstadt	2	5	1	10	35	53
918	Volders	0	5	2	4	16	27
925	Convent Agustins	3	2	5	3	17	30
932	Roquetes	1	7	4	2	6	20
939	Silveirona	0	2	0	0	0	2
953	Kiev-Patorzhinskogo	1	2	1	4	7	15

Continued on next page

TABLE 5.1: Sites included in osteoarthritis sample (males)

Site	Name	(20,25]	(25,30]	(30,35]	(35,40]	(40,100]	Total
960	Cacela Velha	1	3	1	3	10	18
967	Kaminonki Duze	1	2	4	2	17	26
988	Sao Joao de Almedina	0	0	0	0	6	6
995	Boksto	1	2	3	2	5	13
1002	Klaipeda	4	7	12	17	38	78
1009	Bachlechnerplatz	0	0	0	1	1	2
1016	Grossmehring	0	5	4	6	23	38
1023	Quinta do Lago	0	0	1	2	0	3
1030	Doma Laukums	12	21	13	12	42	100
1051	St. Peters	9	8	9	12	31	69
1079	St. Martins	10	4	8	23	88	133
1093	Rua Primeiro de Dezembro	0	0	0	1	2	3
1100	Bowling Green	21	27	50	14	33	145
1107	Dubingiu piliaviete	2	1	3	4	16	26
1114	Plonkowo	5	1	12	3	60	81
1121	Pien	1	2	0	2	6	11
1135	Kernave	4	2	12	12	35	65
1142	Wolverhampton	1	1	2	4	4	12
1149	Convento de Sao Franc.	0	0	0	14	17	31
1163	Selpils	5	8	8	5	23	49
1177	All Saints, Fishergate	12	21	25	7	14	79
1184	Convento do Carmo	1	1	1	4	4	11
1198	Bern-Sidlerstrasse	8	0	0	3	9	20
1205	Alytus	1	3	1	3	7	15
1212	Kiev-Shchekavitsa	2	2	4	7	21	36
1233	Stajky	0	1	2	2	6	11
1240	Bern-Bundesgasse	8	2	3	4	53	70
1247	Altdorf	4	2	1	5	18	30
1254	Convento dos Remedios	0	2	0	0	1	3
1261	Amiens Ilot des Boucheries	10	13	7	11	35	76
1268	Graberfeld Stalden	1	4	2	2	10	19
	Total	602	533	564	596	2028	4323

- Number of female individuals with OA scores for at least one joint or kind of vertebra in the age bracket.

TABLE 5.2: Sites included in osteoarthritis sample (females)

Site	(20,25]	(25,30]	(30,35]	(35,40]	(40,100]	Total	Grand Total
113	2	12	3	6	15	38	73
120	1	0	3	2	1	7	19
127	3	1	0	0	11	15	17
134	5	3	24	9	45	86	99
141	0	1	1	1	1	4	12
148	0	0	0	0	0	0	40
155	2	1	1	1	4	9	35
169	0	1	2	3	4	10	25
176	1	0	2	0	1	4	13
183	1	9	4	1	16	31	87
190	0	0	0	0	0	0	22
211	3	7	1	3	13	27	67
267	9	2	3	4	3	21	48
295	7	1	1	0	0	9	430
344	4	10	8	9	11	42	112
400	3	2	2	3	10	20	50
435	4	7	9	7	16	43	77
449	0	1	0	1	1	3	80
456	8	8	10	9	37	72	179
470	27	21	22	14	148	232	474
477	1	2	9	8	8	28	56
484	24	39	20	14	50	147	287
491	0	1	2	2	9	14	30
512	2	5	9	3	28	47	134
526	0	1	0	0	1	2	2
533	0	1	0	0	0	1	2
554	0	13	4	10	13	40	85
582	9	5	0	4	11	29	75
596	5	2	3	5	7	22	50
603	6	6	14	4	21	51	116
617	0	5	2	2	5	14	27
638	2	3	5	4	13	27	59
645	10	11	9	8	30	68	111
652	0	0	1	0	0	1	2
659	1	0	2	0	0	3	3

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Table 5.2: Sites included in osteoarthritis sample (females)

Site	(20,25]	(25,30]	(30,35]	(35,40]	(40,100]	Total	Grand Total
666	6	10	10	7	16	49	107
673	0	1	1	0	0	2	4
680	4	4	1	3	15	27	75
694	9	13	18	7	56	103	197
701	2	1	2	5	2	12	31
708	0	1	2	10	3	16	55
715	1	2	0	2	2	7	18
736	0	0	0	1	6	7	12
7361	7	2	3	10	48	70	133
743	9	5	8	13	34	69	118
750	1	0	5	1	0	7	11
757	6	8	19	25	89	147	292
764	4	8	19	16	9	56	145
771	2	3	2	1	5	13	24
778	13	7	1	14	25	60	129
785	10	11	9	7	21	58	130
792	6	3	7	7	36	59	122
799	0	0	0	0	1	1	5
806	1	17	14	11	10	53	101
820	11	3	3	1	17	35	55
827	6	3	6	9	14	38	75
834	3	1	17	1	15	37	58
855	1	5	1	8	15	30	30
862	0	0	0	0	0	0	2
869	1	1	2	0	4	8	23
876	0	0	0	0	0	0	27
883	0	1	1	3	11	16	46
890	2	2	2	4	13	23	37
897	2	0	4	1	8	15	22
911	1	17	5	17	23	63	116
918	0	2	3	3	8	16	43
925	6	4	6	1	6	23	53
932	7	1	2	2	3	15	35
939	0	1	0	0	1	2	4
953	1	1	1	0	6	9	24

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Table 5.2: Sites included in osteoarthritis sample (females)

Site	(20,25]	(25,30]	(30,35]	(35,40]	(40,100]	Total	Grand Total
960	0	2	0	0	3	5	23
967	5	2	8	3	11	29	55
988	0	0	0	0	8	8	14
995	2	1	1	3	4	11	24
1002	2	9	7	4	13	35	113
1009	0	0	1	2	2	5	7
1016	2	4	8	4	14	32	70
1023	0	1	1	3	0	5	8
1030	14	24	7	9	31	85	185
1051	4	4	9	9	15	41	110
1079	11	8	5	16	48	88	221
1093	0	3	0	2	3	8	11
1100	14	23	27	13	6	83	228
1107	2	1	1	2	7	13	39
1114	15	2	9	11	32	69	150
1121	1	1	2	1	4	9	20
1135	7	4	6	13	31	61	126
1142	3	2	3	3	7	18	30
1149	2	2	0	15	13	32	63
1163	0	2	7	6	12	27	76
1177	0	2	0	1	2	5	84
1184	1	2	2	2	0	7	18
1198	5	0	2	4	14	25	45
1205	0	2	0	3	4	9	24
1212	1	2	2	4	15	24	60
1233	1	2	1	1	2	7	18
1240	10	5	5	6	60	86	156
1247	6	7	2	3	12	30	60
1254	0	2	0	0	0	2	5
1261	2	9	9	5	18	43	119
1268	0	0	1	0	1	2	21
	372	447	476	475	1447	3217	7540

- Number of female individuals with OA scores for at least one joint or kind of vertebral body in the age bracket. *Grand total* is the sum of scored male and female individuals from the site.

Table 5.3: Sites included in osteoarthritis sample (context variables)

Site	Time period	Topography	SE structure	Elevation	Settlement
113	Early medieval	River valley	Workers	$100 - 300m$	Village
120	Early modern	Flood plain	Farmers	$100 - 300m$	Rural
127	Early medieval	River valley	Religious	$\leq 100m$	Rural
134	Late medieval	Flood plain	Religious	$\leq 100m$	Town
141	Early modern	River valley	Other	$\leq 100m$	Small city
148	Early modern	Hills	Military	$100 - 300m$	Major city
155	Late medieval	Hills	Workers	$100 - 300m$	Town
169	Early modern	River valley	Other	$100 - 300m$	Small city
176	Early modern	River valley	Workers	$100 - 300m$	Small city
183	Early modern	Hills	Workers	$100 - 300m$	Major city
190	Early modern	River valley	Other	$300 - 1000m$	Major city
211	High medieval	River valley	Workers	$300 - 1000m$	Village
267	Early modern	Plains	Farmers	$100 - 300m$	Rural
295	Early modern	Flood plain	Military	$100 - 300m$	Major city
344	Pre-medieval	River valley	Workers	$\leq 100m$	Town
400	Early medieval	Flood plain	Farmers	$\leq 100m$	Village
435	Early medieval	Plains	Farmers	$100 - 300m$	Rural
449	Industrial	Plains	Military	$\leq 100m$	Small city
456	Early modern	Plains	Hospital	$300 - 1000m$	Town
470	Early medieval	Hills	Farmers	$300 - 1000m$	Rural
477	Late medieval	Hills	Farmers	$100 - 300m$	Rural
484	High medieval	River valley	Farmers	$\leq 100m$	Village
491	High medieval	Plains	Workers	$\leq 100m$	Town
512	Early medieval	Plains	Farmers	$\leq 100m$	Rural
526	High medieval	Plains	Workers	$\leq 100m$	Town
533	High medieval	Plains	Workers	$\leq 100m$	Town
554	Pre-medieval	Plains	Workers	$\leq 100m$	Town
582	Early modern	River valley	Workers	$\leq 100m$	Town
596	Early medieval	Hills	Workers	$100 - 300m$	Rural
603	Early medieval	Plains	Farmers	$100 - 300m$	Rural
617	Early modern	Plains	Workers	$100 - 300m$	Small city
638	Pre-medieval	Hills	Farmers	$\leq 100m$	Small city
645	Early medieval	Plains	Farmers	$\leq 100m$	Rural
652	High medieval	Plains	Farmers	$100 - 300m$	Rural
659	High medieval	Plains	Workers	$100 - 300m$	Small city

Continued on next page

Table 5.3: Sites included in osteoarthritis sample (context variables)

Site	Time period	Topography	SE structure	Elevation	Settlement
666	High medieval	Flood plain	Farmers	$\leq 100m$	Village
673	Early medieval	River valley	Workers	$100 - 300m$	Village
680	High medieval	Coastal	Other	$\leq 100m$	Town
694	Late medieval	Flood plain	Religious	$\leq 100m$	Small city
701	Early medieval	Plains	Workers	$\leq 100m$	Town
708	Early medieval	Plains	Farmers	$100 - 300m$	Rural
715	Early medieval	Coastal	Workers	$\leq 100m$	Town
736	Industrial	River valley	Workers	$100 - 300m$	Town
7361	High medieval	Flood plain	Workers	$100 - 300m$	Town
743	Pre-medieval	Coastal	Farmers	$\leq 100m$	Small city
750	Early medieval	River valley	Workers	$\leq 100m$	Village
757	Early medieval	River valley	Farmers	$100 - 300m$	Rural
764	High medieval	Coastal	Farmers	$\leq 100m$	Town
771	Early medieval	Plains	Farmers	$300 - 1000m$	Rural
778	Early medieval	Plains	Farmers	$300 - 1000m$	Rural
785	Pre-medieval	Hills	Farmers	$\leq 100m$	Rural
792	Early medieval	Hills	Farmers	$300 - 1000m$	Rural
799	Early modern	River valley	Military	$\leq 100m$	Town
806	Late medieval	Plains	Workers	$100 - 300m$	Small city
820	Early medieval	Coastal	Workers	$\leq 100m$	Town
827	Late medieval	Flood plain	Religious	$\leq 100m$	Town
834	Early medieval	Hills	Workers	$100 - 300m$	Rural
855	Early modern	River valley	Religious	$\leq 100m$	Village
862	Early medieval	Plains	Farmers	$100 - 300m$	Village
869	Late medieval	River valley	Religious	$\leq 100m$	Village
876	Late medieval	Plains	Military	$\leq 100m$	Rural
883	Early modern	River valley	Other	$100 - 300m$	Village
890	Pre-medieval	Flood plain	Military	$\leq 100m$	Rural
897	Late medieval	River valley	Workers	$\leq 100m$	Town
911	Early medieval	Plains	Farmers	$100 - 300m$	Rural
918	Early medieval	River valley	Farmers	$300 - 1000m$	Rural
925	Early modern	Plains	Farmers	$300 - 1000m$	Town
932	Late medieval	Plains	Farmers	$300 - 1000m$	Town
939	Pre-medieval	Plains	Farmers	$100 - 300m$	Rural
953	High medieval	River valley	Workers	$100 - 300m$	Town

Continued on next page

Table 5.3: Sites included in osteoarthritis sample (context variables)

Site	Time period	Topography	SE structure	Elevation	Settlement
960	Late medieval	Coastal	Farmers	$\leq 100m$	Village
967	Early modern	Plains	Farmers	$\leq 100m$	Rural
988	Late medieval	Hills	Workers	$100 - 300m$	Major city
995	High medieval	Hills	Workers	$300 - 1000m$	Town
1002	Early modern	Coastal	Workers	$\leq 100m$	Small city
1009	Industrial	River valley	Workers	$300 - 1000m$	Town
1016	Early medieval	Plains	Farmers	$300 - 1000m$	Rural
1023	Early medieval	Coastal	Workers	$\leq 100m$	Rural
1030	Early modern	Coastal	Workers	$\leq 100m$	Small city
1051	Early modern	Flood plain	Workers	$\leq 100m$	Small city
1079	Industrial	Plains	Workers	$100 - 300m$	Major city
1093	Early modern	River valley	Other	$\leq 100m$	Rural
1100	Early modern	Flood plain	Workers	$\leq 100m$	Major city
1107	Late medieval	Hills	Farmers	$100 - 300m$	Rural
1114	Late medieval	Plains	Farmers	$\leq 100m$	Rural
1121	Early modern	Plains	Farmers	$\leq 100m$	Rural
1135	Late medieval	Hills	Farmers	$100 - 300m$	Rural
1142	Industrial	Plains	Workers	$\leq 100m$	Major city
1149	Late medieval	Flood plain	Farmers	$\leq 100m$	Major city
1163	Early modern	Flood plain	Farmers	$100 - 300m$	Rural
1177	Early modern	Flood plain	Workers	$\leq 100m$	Small city
1184	Early modern	River valley	Workers	$\leq 100m$	Town
1198	Industrial	Hills	Farmers	$300 - 1000m$	Small city
1205	Late medieval	Plains	Workers	$\leq 100m$	Town
1212	Early medieval	River valley	Farmers	$100 - 300m$	Rural
1233	Early modern	River valley	Farmers	$100 - 300m$	Rural
1240	Industrial	Hills	Farmers	$300 - 1000m$	Small city
1247	Early modern	Plains	Farmers	$300 - 1000m$	Town
1254	Early modern	Plains	Farmers	$100 - 300m$	Town
1261	Pre-medieval	River valley	Workers	$\leq 100m$	Town
1268	Pre-medieval	River valley	Farmers	$300 - 1000m$	Village

- Context variables: *River valley* refers to sites located in a *valley of a major river*, *Flood plains* are *major river flood plains*. *Workers* refers to the category of *craft and artisan workers*.

Appendix 5.A

Table 5.4: Mean age-adjusted OA score differences, by time period

Category	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
Pre-medieval (male/female)	0.17^{***}	0.08^{*}	0.08^{*}	0.12^{***}	0.08^{*}	0.13^{***}	0.08	0.21^{***}	0.21^{***}
Early medieval (male/female)	0.12^{***}	0.07^{***}	0.09^{***}	0.10^{***}	0.07^{***}	0.11^{***}	0.08^{***}	0.19^{***}	0.14^{***}
High medieval (male/female)	0.06	-0.01	0.05	0.03	0.03	0.00	-0.02	0.11^{**}	0.13^{***}
Late medieval (male/female)	0.06^{*}	0.07^{**}	0.03	0.03	0.04	0.07^{*}	0.07^{*}	0.04	0.06
Early modern (male/female)	-0.01	0.03	0.04	-0.02	-0.05^{*}	0.02	0.01	-0.00	-0.02
Industrial (male/female)	0.02	-0.03	0.06	0.00	-0.01	0.03	-0.01	0.02	0.10^{**}
Males, comparisons across categories									
Pre-medieval/Early medieval	-0.01	-0.02	-0.03	-0.24^{***}	-0.12^{**}	-0.06	-0.11^{*}	-0.05	-0.12^{*}
Early medieval/High medieval	0.17^{***}	0.11^{**}	0.14^{***}	0.23^{***}	0.16^{***}	0.13^{***}	0.22^{***}	0.16^{***}	0.19^{***}
High medieval/Late medieval	0.05	0.02	-0.04	0.03	-0.02	-0.06	-0.04	0.05	0.09
Late medieval/Early modern	-0.14^{***}	-0.16^{***}	-0.10^{*}	-0.11^{**}	-0.08	-0.04	-0.08	-0.08	0.00
Early modern/Industrial	0.20^{***}	0.29^{***}	0.15^{***}	0.25^{***}	0.21^{***}	0.16^{***}	0.07	-0.03	0.09
Females, comparisons across categories									
Pre-medieval/Early medieval	-0.06	-0.03	-0.03	-0.26^{***}	-0.12^{**}	-0.08	-0.11	-0.07	-0.19^{***}
Early medieval/High medieval	0.11^{*}	0.03	0.11^{*}	0.16^{***}	0.12^{*}	0.02	0.12	0.08	0.18^{***}
High medieval/Late medieval	0.05	0.10	-0.05	0.02	-0.02	0.01	0.05	-0.02	0.01
Late medieval/Early modern	-0.20^{***}	-0.20^{***}	-0.10	-0.16^{***}	-0.17^{***}	-0.10	-0.14^{*}	-0.12	-0.07
Early modern/Industrial	0.23^{***}	0.23^{***}	0.17^{***}	0.27^{***}	0.25^{***}	0.17^{***}	0.04	-0.01	0.21^{***}

- Corresponds to figure 5.1. The stars indicate statistical significance, based on Tukey's Honest Significant Difference test, on the 10% (*), 5% (***), and 1% (***) levels.
- Results for comparisons between non-consecutive time periods have been omitted.

TABLE 5.5: Differences between mean age-adjusted OA scores of males and females by categories of socio-economic structure, and between farmers and non-farmers by time period

Category	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
Farming community	0.09^{***}	0.06^{***}	0.09^{***}	0.06^{***}	0.06^{***}	0.08^{***}	0.05^{**}	0.14^{***}	0.11^{***}
Craft or artisan workers	0.10^{***}	0.09^{***}	0.07^{***}	0.10^{***}	0.05^{**}	0.11^{***}	0.08^{***}	0.14^{***}	0.11^{***}
Military context	−0.05	−0.01	0.09^{**}	0.04	0.00	0.01	−0.02	−0.09	-0.15^{**}
Religious order	−0.03	−0.01	-0.17^{***}	-0.15^{**}	-0.13^{**}	−0.04	0.01	−0.04	−0.03
Other	−0.05	−0.01	0.09	−0.04	−0.00	−0.04	−0.01	−0.01	−0.03
Males, comparisons between farmers and non-farmers within time periods									
Pre-medieval	0.23^{***}	0.01	0.10	0.20^{***}	0.07	0.28^{***}	0.07	0.25^{***}	0.30^{***}
Early medieval	−0.01	−0.02	0.09	0.01	−0.01	0.10	0.01	-0.19^{***}	−0.10
High medieval	−0.00	−0.04	−0.04	0.08	−0.06	−0.05	0.06	−0.06	−0.04
Late medieval	−0.07	-0.09^{**}	-0.09^{*}	−0.05	-0.13^{***}	-0.15^{***}	−0.01	−0.08	-0.18^{***}
Early modern	0.08^{*}	-0.08^{*}	0.05	−0.06	−0.04	0.03	-0.11^{**}	-0.12^{**}	-0.27^{***}
Industrial	-0.22^{***}	-0.14^{***}	−0.06	-0.23^{***}	-0.17^{***}	-0.15^{**}	-0.22^{***}	-0.28^{***}	-0.23^{***}
Females, comparisons between farmers and non-farmers within time periods									
Pre-medieval	0.30^{***}	0.04	0.16^{***}	0.10^{*}	0.02	0.12^{**}	0.11	0.17^{**}	0.17^{*}
Early medieval	−0.08	−0.00	0.17^{***}	−0.04	−0.04	0.03	-0.13^{**}	-0.11^{**}	-0.24^{***}
High medieval	0.01	-0.13^{**}	−0.06	0.01	−0.03	−0.01	−0.00	-0.12^{*}	−0.09
Late medieval	-0.07^{*}	-0.07^{*}	0.02	0.05	−0.03	−0.03	0.07	0.09	0.02
Early modern	0.16^{***}	−0.00	0.08	0.03	0.03	0.01	−0.04	−0.06	-0.13^{**}
Industrial	-0.12^{*}	-0.12^{*}	0.05	-0.22^{***}	−0.02	0.04	−0.08	-0.29^{***}	-0.15^{*}

- Corresponds to figures 5.4, 5.2, and 5.3, results for comparisons between non-consecutive time periods have been omitted.

TABLE 5.6: Mean age-adjusted OA score differences, by socio-economic structure

Category	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
Males, comparisons across categories									
Farmers/artisan workers	-0.05	-0.04	-0.06	-0.01	0.00	-0.05	0.03	0.06	0.16^{**}
Farmers/military context	0.15^{***}	0.17^{***}	0.14^{**}	0.19^{***}	0.16^{***}	0.14^{**}	0.19^{***}	0.26^{***}	0.33^{***}
Farmers/religious order	0.27^{***}	0.27^{***}	0.25^{***}	0.27^{***}	0.22^{***}	0.13^{**}	0.11	0.19^{***}	0.29^{***}
Farmers/other	0.11^{*}	0.08	-0.07	0.15^{***}	0.10^{*}	-0.01	0.05	0.07	0.24^{***}
Artisan workers/military	0.20^{***}	0.21^{***}	0.20^{***}	0.20^{***}	0.16^{***}	0.20^{***}	0.15^{**}	0.21^{***}	0.17^{**}
Artisan workers/religious	0.32^{***}	0.31^{***}	0.31^{***}	0.28^{***}	0.21^{***}	0.19^{***}	0.08	0.14^{*}	0.14^{*}
Artisan workers/other	0.16^{***}	0.12^{**}	-0.01	0.16^{***}	0.10^{*}	0.04	0.02	0.02	0.08
Military context/religious	0.12^{*}	0.10	0.11	0.08	0.05	-0.01	-0.07	-0.07	-0.03
Military context/other	-0.04	-0.08	-0.21^{***}	-0.05	-0.06	-0.16^{**}	-0.14^{**}	-0.19^{***}	-0.09
Religious order/other	-0.16^{***}	-0.18^{***}	-0.32^{***}	-0.12^{**}	-0.11^{*}	-0.15^{**}	-0.07	-0.12	-0.06
Females, comparisons across categories									
Farmers/artisan workers	-0.04	-0.01	-0.08	0.03	-0.00	-0.02	0.06	0.05	0.16
Farmers/military context	0.02	0.10	0.14	0.17	0.11	0.08	0.11	0.03	0.06
Farmers/religious order	0.15	0.20^{*}	-0.02	0.05	0.03	0.01	0.07	0.01	0.15
Farmers/other	-0.03	0.01	-0.07	0.05	0.05	-0.13	-0.01	-0.08	0.09
Artisan workers/military	0.06	0.11	0.21^{**}	0.14	0.11	0.10	0.05	-0.02	-0.09
Artisan workers/religious	0.19^{*}	0.21^{**}	0.06	0.02	0.03	0.04	0.01	-0.04	-0.00
Artisan workers/other	0.01	0.03	0.01	0.02	0.05	-0.11	-0.08	-0.13	-0.06
Military context/religious	0.14	0.10	-0.15	-0.12	-0.08	-0.06	-0.04	-0.02	0.09
Military context/other	-0.05	-0.09	-0.21^{*}	-0.13	-0.06	-0.21^{**}	-0.12	-0.11	0.03
Religious order/other	-0.18	-0.19^{*}	-0.05	-0.00	0.01	-0.14	-0.08	-0.08	-0.06

- Corresponds to figure 5.4. The stars indicate statistical significance, based on Tukey's Honest Significant Difference test, on the 10% (*), 5% (***), and 1% (***) levels.

Table 5.7: Mean age-adjusted OA score differences, by settlement size

Category	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
Rural (male/female)	0.10***	0.08***	0.09***	0.09***	0.06***	0.10***	0.06*	0.17***	0.11***
Village (male/female)	0.10**	0.03	0.03	0.01	0.06	0.04	0.07	0.09*	0.11**
Town (male/female)	0.07**	0.05*	0.06**	0.01	−0.01	0.03	0.04	0.11***	0.14***
Small city (male/female)	0.09***	0.08**	0.08**	0.09**	0.09***	0.16***	0.10***	0.08**	0.08**
Major city (male/female)	−0.05	0.00	−0.00	0.04	−0.08**	−0.05	−0.04	−0.01	0.00
Males, comparisons across categories									
Rural/village	0.02	−0.00	0.05	0.12***	0.08*	0.04	0.08	0.08	0.12**
Village/town	0.05	0.07	−0.03	0.04	0.04	−0.04	−0.03	−0.03	−0.01
Town/small city	−0.02	−0.10**	−0.02	−0.05	−0.11***	−0.01	0.06	0.09	0.17***
Small city/major city	0.08	0.15***	0.10**	0.10**	0.15***	0.11***	0.03	0.04	0.08
Females, comparisons across categories									
Rural/village	0.02	−0.06	−0.02	0.04	0.07	−0.01	0.09	0.00	0.12*
Village/town	0.02	0.10*	0.01	0.04	−0.04	−0.04	−0.07	−0.01	0.01
Town/small city	−0.00	−0.07	−0.01	0.02	−0.00	0.12***	0.12**	0.07	0.11
Small city/major city	−0.06	0.07	0.01	0.05	−0.03	−0.09*	−0.11*	−0.05	0.01

- Corresponds to figure 5.5. The stars indicate statistical significance, based on Tukey's Honest Significant Difference test, on the 10% (*), 5% (***), and 1% (***) levels.
- Results for comparisons between non-neighboring categories have been omitted.

Table 5.8: Difference between male and female mean age-adjusted OA score by topography and elevation category of the settlement area

Category	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
Coastal	0.07	0.03	0.01	0.01	0.04	0.01	0.07^{*}	0.07	0.08^{*}
Major river flood plain	0.06^{**}	0.09^{***}	0.05^{**}	0.05^{*}	−0.00	0.07^{**}	0.06^{**}	0.06^{*}	0.04
Valley of a major river	0.09^{**}	0.06^{*}	0.09^{**}	−0.01	0.00	0.10^{***}	0.02	0.11^{***}	0.14^{***}
Plains	0.04	0.03	0.08^{***}	0.05^{*}	0.02	0.09^{***}	0.04	0.13^{***}	0.07^{*}
Rolling (low) hills	0.12^{***}	0.08^{***}	0.07^{***}	0.12^{***}	0.11^{***}	0.03	0.02	0.09^{**}	0.06
Sea level – 100m	0.10^{***}	0.09^{***}	0.05^{**}	0.06^{***}	0.03	0.09^{***}	0.08^{***}	0.11^{***}	0.08^{***}
100m – 300m	−0.01	0.01	0.04	−0.00	−0.01	0.04	0.00	0.05^{**}	0.03
300m – 1,000m	0.11^{***}	0.06^{*}	0.10^{***}	0.09^{**}	0.08^{**}	0.03	0.02	0.14^{***}	0.10^{**}
Males, comparisons across categories									
Sea level – 100m/100m – 300m	0.08^{***}	0.09^{***}	0.03	0.00	0.04	0.05	0.01	0.08^{**}	0.04
100m – 300m/300m – 1,000m	-0.06^{**}	0.01	0.04	-0.13^{***}	−0.02	0.07^{**}	−0.03	-0.09^{***}	−0.05
Females, comparisons across categories									
Sea level – 100m/100m – 300m	−0.03	0.01	0.02	−0.05	−0.00	−0.01	-0.07^{*}	0.02	−0.00
100m – 300m/300m – 1,000m	0.06^{**}	0.06^{*}	0.10^{***}	−0.04	0.07^{**}	0.07^{**}	−0.01	−0.00	0.02

- Corresponds to figures 5.6 and 5.7. The stars indicate statistical significance, based on Tukey's Honest Significant Difference test, on the 10% (*), 5% (***), and 1% (***) levels.
- Results for comparisons between non-neighboring categories have been omitted.

Table 5.9: Mean age-adjusted OA score differences, by topography category

Category	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
Males, comparisons across categories									
Coastal/flood plain	0.13^{***}	0.21^{***}	0.17^{***}	0.08^{*}	0.18^{***}	0.04	0.00	−0.02	0.02
Coastal/river valley	-0.08^{*}	0.02	−0.04	−0.07	0.05	-0.12^{***}	-0.16^{***}	-0.21^{***}	-0.23^{***}
Coastal/plains	0.04	0.09^{**}	−0.04	−0.05	0.11^{***}	-0.11^{***}	-0.10^{**}	-0.15^{***}	-0.14^{***}
Coastal/rolling hills	0.08^{*}	0.18^{***}	0.17^{***}	0.03	0.17^{***}	0.16^{***}	0.06	0.01	0.01
Flood plain/river valley	-0.20^{***}	-0.18^{***}	-0.21^{***}	-0.15^{***}	-0.13^{***}	-0.16^{***}	-0.17^{***}	-0.19^{***}	-0.26^{***}
Flood plain/plains	-0.09^{*}	-0.12^{***}	-0.21^{***}	-0.13^{***}	−0.07	-0.15^{***}	-0.10^{**}	-0.13^{***}	-0.16^{***}
Flood plain/rolling hills	−0.04	−0.03	−0.00	−0.06	−0.01	0.12^{***}	0.06	0.03	−0.01
River valley/plains	0.12^{***}	0.06	0.00	0.02	0.06	0.01	0.07	0.05	0.09
River valley/rolling hills	0.16^{***}	0.16^{***}	0.21^{***}	0.09^{**}	0.12^{***}	0.28^{***}	0.23^{***}	0.22^{***}	0.25^{***}
Plains/rolling hills	0.04	0.09^{**}	0.20^{***}	0.08	0.06	0.27^{***}	0.16^{***}	0.16^{***}	0.15^{***}
Females, comparisons across categories									
Coastal/flood plain	0.11^{***}	0.27^{***}	0.21^{***}	0.13^{***}	0.14^{***}	0.10^{**}	−0.00	−0.03	−0.01
Coastal/river valley	−0.06	0.05	0.04	−0.09	0.01	−0.03	-0.21^{***}	-0.17^{***}	-0.18^{***}
Coastal/plains	0.01	0.09^{**}	0.03	−0.01	0.09^{*}	−0.03	-0.13^{**}	−0.09	-0.15^{***}
Coastal/rolling hills	0.13^{***}	0.23^{***}	0.22^{***}	0.14^{***}	0.23^{***}	0.18^{***}	0.01	0.03	−0.01
Flood plain/river valley	-0.18^{***}	-0.22^{***}	-0.17^{***}	-0.22^{***}	-0.12^{***}	-0.13^{***}	-0.21^{***}	-0.14^{***}	-0.16^{***}
Flood plain/plains	-0.11^{**}	-0.18^{***}	-0.18^{***}	-0.14^{***}	−0.05	-0.13^{***}	-0.12^{**}	−0.06	-0.14^{***}
Flood plain/rolling hills	0.02	−0.04	0.01	0.01	0.10^{**}	0.08^{*}	0.01	0.07	0.00
River valley/plains	0.07	0.04	−0.01	0.08	0.07	−0.00	0.08	0.08	0.02
River valley/rolling hills	0.20^{***}	0.18^{***}	0.18^{***}	0.23^{***}	0.22^{***}	0.21^{***}	0.22^{***}	0.20^{***}	0.16^{***}
Plains/rolling hills	0.12^{***}	0.14^{***}	0.19^{***}	0.15^{***}	0.15^{***}	0.21^{***}	0.14^{***}	0.13^{**}	0.14^{***}

- Corresponds to figures 5.6 and 5.7. The stars indicate statistical significance, based on Tukey's Honest Significant Difference test, on the 10% (*), 5% (***), and 1% (***) levels.

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