Health and Nutrition in the Preindustrial Era:

Insights from A Millennium of Average Heights in Northern Europe

by

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Abstract

This essay places the debate over human welfare during industrialization in the context of very long-term economic developments by examining an important aspect of living standards--health and nutrition--since the Middle Ages. I use average stature determined from military records along with heights inferred from skeletal data, a neglected source in economic history. Based on a modest sample of skeletons from northern Europe, average heights fell from an average of 173.4 centimeters in the early Middle Ages to a low of roughly 167 centimeters during the seventeenth and eighteenth centuries. Much remains to be learned about the chronological and spatial details of European height patterns prior to the eighteenth century, but taking the data at face value, this decline of approximately 6.4 centimeters substantially exceeds any prolonged downturns found during industrialization in several countries that have been studied. Significantly, recovery to levels achieved in the early Middle Ages was not attained until the early twentieth century. At this point the data are insufficient to test hypotheses, but it is plausible to link the decline in average height to climate deterioration; growing inequality; urbanization and the expansion of trade and commerce, which facilitated the spread of diseases; fluctuations in population size that impinged on nutritional status; the global spread of diseases associated with European expansion and colonization; and conflicts or wars over state building or religion. Because it is reasonable to believe that greater exposure to pathogens accompanied urbanization and industrialization, and there is evidence of climate moderation, increasing efficiency in agriculture and greater inter-regional and international trade in foodstuffs, it is reasonable to link the reversal of the long-term height decline with dietary improvements.

1. Introduction

For over half a century, quantitative economic historians have pondered the fates of workers and other segments in the population during the industrial revolutions of the nineteenth and early twentieth centuries. While everyone agrees that the standard of living eventually improved, much discussion has focused on how various groups fared during the decades that industrialisation actually unfolded. Scholars of the subject have asked who gained and who lost in the process (and why), and whether industrialisation was accompanied by events that adversely affected health and human welfare. In the case of England, debate has been particularly lively and factions have coalesced into camps of optimists and pessimists. Controversy persists because evidence about the past is often meagre and, in any event, health and human welfare are complex and difficult to assess under the best circumstances of data availability (for a discussion of issues, see Engerman 1997).

This paper places the debate over human welfare during industrialisation in the context of very long-term economic developments by examining an important aspect of living standards - health and nutrition - since the Middle Ages. I use average stature determined from military records along with average heights estimated from a neglected source, skeletal data.[1] Average height measures a population's history of *net* nutrition—diet minus claims on the diet made by work and by disease. [2] Considering the industrial period as a backdrop for comparative study, I describe the U-shape that average heights took over the past millennium in northern Europe and suggest a research agenda for analysing this remarkable time trend in health and nutrition.

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[1] Average heights calculated from skeletal data have long been used by physical anthropologists but little used by other social scientists. For a study of England oriented toward medical historians, see Stephen Kunitz (1987).

2. Background

Although lacking survey results on the subject, I suspect that few scholars would challenge whether the substantial resources allocated to the standard of living debate have been worthwhile investments as a whole. No doubt, many would object to some books or papers, but all would recognise that industrialisation has been the biggest news of the past two centuries on the economic front. Unquestionably, industrialisation transformed social and economic life, and even poor groups within modern industrial countries have greater access to most types of material goods and live longer lives than the upper classes in the pre-industrial era. Study of industrialisation is also warranted for insights that may help guide developing countries now undergoing the process.

Considerable devotion to the subject of welfare during industrialisation is justified, but the neglect of the pre-industrial era is curious. The lack of attention cannot be explained by a supposition that industrialisation was the only major dynamic feature of social and economic life over the past several millennia. Earlier transformations were arguably on par if not more significant, including the shift from foraging to farming, the rise of cities, and European expansion and colonisation that began in the 1400s.

The neglect might be explained by temporal distance from the present, a forceful point among those scholars who believe that modern policy implications should flow from the work of most if not all economists, including economic historians. People of this persuasion may ask what

[2] Readers unfamiliar with the methodology of anthropometric history may want to consult the discussion and references in Steckel (1995).

could possibly be learned about problems in the modern world by studying the pre-industrial era. In reply, one might observe that the pre-industrial world of the past is relevant because parts of today's developing regions approximate pre-industrial conditions of the eighteenth or nineteenth centuries. More importantly, study of pre-industrial economies is justifiable as a form of basic research. All social scientists understand the value of large, diverse samples for generalising about human behaviour, and the past is certainly diverse. In any event, economic historians, and historians, are seldom beholden to arguments that research must demonstrate immediate applications. Many are content in viewing research purely as consumption, or satisfying desires of intellectual curiosity.

On a practical level, data availability is a problem, at least for the type of monetary measures that economists are accustomed to using, such as real GDP, real wages, or wealth. While it is certainly not true that abundant data exist for the taking, it is also not true that evidence is completely lacking. Over the years I have been impressed by the ingenuity of historians and economists in developing new data resources, a record that leads one to doubt whether most useful sources have been exploited. Recently, the frontiers of research were extended backward in time and over space, at least in the dimension of wages and prices (Allen 1998).

Finally, new data sources and methods have been developed for assessing human welfare. Speaking metaphorically, one may think of the history of human welfare in a country or region as a long sausage or salami; each slice represents a year (or other time unit) of social performance that can be divided into broad categories of health, material goods, and psychological elements, which may have spiritual or metaphysical components. The example of the new anthropometric history shows that a significant portion of the health component is measurable from military records and other sources of height data (Steckel 1998). Skeletal evidence greatly extends backward in time the portion of the salami that is visible, broadens it to include women and children, and unlike stature alone, includes information on degenerative health processes associated with hard work and ageing. This paper makes a small down payment on the larger research agenda of integrating the analysis of pre-industrial height data from skeletal records and military sources into the literature of economic history.

3. Height Patterns during Industrialisation

Before attempting to study human health and nutrition in pre-industrial times, it is necessary to determine when the industrial period began. Although some scholars debate whether “revolution” should be appended to “industrial” in describing the process, the changes were revolutionary from the perspective of several centuries of history. Because it was a complex phenomenon involving many dimensions of change that occurred at different rates in various countries, its chronological dates and its nature are inevitably ambiguous. Most economic historians view Rostow’s stages of economic growth as inordinately rigid, and they are sceptical of its implications for an inevitable sequence of well-defined steps that each country experienced. But most economic historians do agree that the process had a significant chronological structure: at a minimum, England was the first industrial country and the phenomenon spread from west to east across Europe.[3]

In order to fold heights into the debate over socio-economic performance during industrialisation, it is useful to divide the process of change within each country into three chronological parts (early, middle, and late) based on an intuitive rather than a formulistic mix with an emphasis on dates of achieving modern economic growth. Also considered were the extent of mechanisation, urbanisation, percent of the labour force involved in agriculture, and the amount of technological change, which have in varying degrees been part of the process of industrialisation or modernisation in all countries that underwent the experience. Assigning dates and phases is inevitably a matter of judgement, but the contributors to *Health and Welfare during Industrialization* were comfortable with three rough categories. In the early industrial period, the transition to a modern industrial economy began. Industrialisation and modernisation spread geographically and diversified in the middle period, and became widespread and dominant in the late industrial phase. Notably, a few countries do not fit well with this conception of industrialisation. Because they retained large agricultural sectors or experienced little mechanisation and developed few factories, the term "modernisation" may be more appropriate in describing their experiences. Australia, for example, relied extensively on agriculture and mining, while the Netherlands (lacking coal and waterpower), developed banking, shipping, and services.

3.1 Height and Economic Growth

Table 1 depicts average heights and other information during the early, middle and late stages of industrialisation in 8 countries whose adult male heights were studied in Steckel and Floud (1997) *Health and Welfare during Industrialization*.

Table 1 about here

[3] For a contrary view of European industrialisation see Komlos (2001).

In examining the table, one is struck by the diversity of experience across countries in heights, and in life expectancy and the percent urban. Average heights varied by over 15 centimetres within each phase, while the percent urban differed by as much as 30 percentage points in the early phase (the Netherlands versus the United States) and nearly 50 points in the late phase (Japan versus Sweden). While all life expectancies were somewhat compressed in the pre-industrial phase, differing by less than 13 years (Australia versus the UK), by the late phase Australia had leaped ahead of the pack (65.4 years) while Japan lagged nearly 20 years behind (47 years).

3.2 Height and Life Expectancy

In arguing for average height as a general welfare measure, it is useful to consider its relationship to a more widely employed measure of health - life expectancy at birth. Understanding of average height as a population's history of net nutrition implies that a positive correlation should exist. Biological deprivation that retards human growth also increases the risk of death, a relationship that is magnified by the synergy between diet and disease (Scrimshaw et al.1968). Several studies on modern data confirm that average height declines as mortality rates increase (Waaler 1984; Fogel 1993; Steckel 2001).

Some critics of anthropometric history base their doubts on a selective effect of height on survival. Because studies on individual data have found that short people are less likely to survive (Waale 1984; Friedman 1982), high mortality erodes the left tail of the height distribution. If this was the only effect of higher mortality, then taller heights would indicate poorer health. But it is not the only effect: survivors also grow less because they endured the biological stress causing higher mortality. The former effect is rather small because under conditions of increasing biological stress, many tall people also fail to survive. The selective effect of higher mortality on height is rather small. Empirically the second effect far outweighs the former. At the national level, heights and life expectancy are highly and positively correlated in late twentieth century data (Steckel 2001).

Figure 1 about here

Data for estimating the relationship between average height and life expectancy in a historical setting is meagre, but available for all of the countries the late industrial periods. Figure 1 shows the scatter diagram for the US, UK, the Netherlands, France, Sweden, Germany, Japan, and Australia, which incorporates data taken from Table 1. The estimated regression line is (t-values in parentheses):

$$\underset{(18.03)}{\text{Height} = 152.48} + \underset{(1.98)}{0.330}\ (\text{Life Expectancy}),\ N = 8,\ R^2 = 0.40$$

The average height of adult men increased by 0.33 centimetres for every year by which life expectancy increased. The scatter diagram reveals that Japan is a substantial “outlier”, and if this country is omitted, the R^2 rises to 0.79 and the regression coefficient is statistically significant at 0.01. Japan’s stature was much too low, given its life expectancy, probably because the time frames of the two measures are different. Conditions in the 1930s and early 1940s, when the young adults of mid-century were growing children, were likely worse than those forming the basis for life expectancy in 1950, a few years following the end of World War II. It is also possible that the height-life expectancy relationship is somewhat non-linear at low levels of health.

3.3 Height and Urbanisation

Historical demographers have long observed the adverse effect of urban areas on health prior to the early twentieth century (see, for example, United Nations, 1973: 131-2; Preston and Haines 1991: chaps. 4 and 5). Numerous factors explain the connection, including congestion in factories and places of living, which promoted the spread of communicable diseases. Accumulation of waste, impure water supplies and inflows of people importing goods increased the urban population's exposure to pathogens. High poverty levels and high prices for food (relative to rural areas) also acted to increase mortality rates.

Table 1 shows that average male height and per cent urban (towns or cities of 2,500 population or more) varied widely across the countries during the middle phase of industrialisation, a period of intense change. The extremes in stature were established by the Australians (172 cm) and by the Japanese, who fell more than 13 cm below. In urban development, the Swedes had the smallest share living in towns or cities (only 17.2%) while the Japanese were the most urban (60%).

It was not accidental that the Japanese were both the shortest and the most urban. In an era before widespread, effective investments in public health and personal hygiene, the congestion and turnover associated with urban living increased the chances of exposure to pathogens. Other features detrimental to health are often found in cities, such as a large number of poor people who lacked access to food, clothing and shelter that would have increased resistance to disease.

Figure 2 about here

The scatter diagram in Figure 2 confirms the adverse effect of urbanisation on health. The estimated regression equation is (t-values in parentheses):

$$\underset{(40.69)}{\text{Height} = 174.07} - \underset{(-1.47)}{0.153} \text{ (Per cent Urban)}, N = 8, R^2 = 0.27$$

For every percentage point increase in the degree of urbanisation, average male height fell by about 0.15 centimetres. This magnitude is significant in a practical sense because the transition from a low (say, 20%) level of urbanisation to a moderately high level (say 50%) would have decreased average height by 4.5 centimetres. The notable "outlier" to the inverse relationship was Australia, which had the tallest population and the second highest level of urbanisation. If Australia is dropped from the regression, the t-value rises to –2.60, R^2 increases to 0.57, and the regression coefficient increases (in absolute value) by 50%.

What factors explain the exceptional nature of health and urbanisation in Australia? One was the relative geographic isolation of the country from major disease currents that affected cities in Europe and in North American. Another is the remoteness of the major cities within Australia from each other, which helped to reduce the spread of infectious disease. Moreover, Australia's industrialisation (or modernisation) occurred late enough to benefit from significant investments in public health. This last feature distinguishes Australia from Japan, which was also a country late to industrialise within this group.

3.4 Temporal Patterns

Additional factors that influenced heights during industrialisation, and possibly in the pre-industrial period, can be discerned from study of temporal patterns within countries. Although the various series might be arranged on a continuum in terms of depth and duration of cycles, the patterns are readily grouped into three categories: (a) significant and prolonged declines in health during a large phase of industrialisation; (b) a mixture that included a short and modest downturn during industrialisation; and (c) sustained, but not necessarily monotonic, gains in stature.

Figure 3 about here

The US and the UK fit the first pattern, which is given in Figure 3. Americans were very tall by global standards in the early nineteenth century as a result of their rich and varied diets, low population density, and relative equality of wealth. Between 1830 and roughly 1890, however, the average height of American men fell by 4.4 centimetres, a reversal that was not offset until the 1920s. Consistent with this height decline, life expectancies tabulated from genealogies also show deterioration near the middle of the century (Pope 1992). Researchers in the field have suggested numerous possible causal factors for the decline, including the spread of disease affiliated with the development of railroads, canals, and steamboats (for discussions, see Steckel 1995; Komlos 1998). Also mentioned are higher food prices; growing inequality; increasing market integration; the emergence of business cycles that led to malnutrition during contractions, urbanisation, and the rise of public schools that exposed children to major diseases. Unfortunately, research has not advanced to the point of assigning plausible weights to these factors, but some progress is being made by examining the relationship between local (county) agricultural, socioeconomic and demographic conditions and the height of recruits from the county (Haines, Craig and Weiss 2000).

Although health deterioration of about 9 centimetres in average height among soldiers also occurred in Britain during the early-mid nineteenth century, the timing is probably more coincidental than emblematic of linkage among similar causal factors across the two countries.[4] While it is possible that growing trade and commerce spread disease, as in the United States, it is more likely that a major culprit was rapid urbanisation and associated increased in exposure to diseases (Floud and Harris 1997). This conclusion is reached by noting that urban born men were substantially shorter than the rural born, and between the periods of 1800-1830 and 1830–1870 the share of the British population living in urban areas leaped from 38.7 to 54.1%.

Figure 4 about here

Australia and Württemberg illustrate pattern (b) of short, modest cycles shown in Figure 4. Both realised gains in health during industrialisation, but progress was choppy, or otherwise interrupted by relatively brief cycles in height. Adult males reached about 162.8 centimetres (average of rural and urban) in the province of Württemberg for cohorts born on the eve of

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[4] The height estimates are from Floud, Wachter and Gregory (1990), but there has been a lively exchange over the timing and extent of the height decline in Britain (Komlos 1993a, b; Floud, Wachter and Gregory 1993a, b). Komlos agrees a decline occurred near mid-century, but places it at a lower level and within the context of his estimates of an overall decline after 1760.

industrialisation, which began in the 1860s (Twarog 1997). A small spurt in average heights occurred during the early 1860s to 166 centimetres, which was followed by a decline over the next decade of 1 centimetre. Recovery but stagnation at 166 centimetres occurred in the 1880s and 1890s. This temporal pattern was related to the financial crash of 1873 and the subsequent depression that lasted into the early 1890s. Occupational differences in stature indicate that the professional classes were protected during the early phases of the economic depression and the loss in health was concentrated among the middle and lower classes. Thus, growing inequality played an important role in Germany's health trends during industrialisation.

Two features distinguish the Australian experience: the tall stature (about 172.5 centimetres) on the eve of modernisation that was followed by a large cycle in heights whereby the average height of the mid-1870s was not attained again until the second decade of the twentieth century (Whitwell et. al. 1997). The tall stature is undoubtedly related to an inexpensive but diverse diet that was also rich in protein, a phenomenon supporting the view that Australia was a workingman's paradise. Even though the share living in urban areas was relatively high (about 50%), overall population density was low and the country and its major cities were relatively isolated from globalisation, which hampered the spread of communicable diseases.

But some troubles occurred even in these relatively idyllic circumstances. The height downturn of 1.8 centimetres in the 1880s and 1890s was the result of a double whammy. The share living in urban areas was already high (43% in 1881) and then jumped eight percentage points in the decade following. A sanitary crisis ensued and typhoid fever, which disproportionately affected the young, was epidemic in the cities. Although the pace of urbanisation fell considerably during the 1890s, GDP declined and remained relatively low for a decade, thereby dampening any hopes for quick recovery in heights and health.

The Netherlands, France, Sweden and Japan fall into the last category: sustained increases in stature, interrupted at most by brief, tiny declines or modest stagnation. Prominent in the Dutch experience was a 20-year pre-industrial height decline of 1.9 centimetres that began in 1815, which was caused in part by rising food prices and stagnating nominal wages (i.e. a decline in purchasing power). Thereafter, average heights increased more or less continuously into the twentieth century with the exception of small reversals in the early 1840s and in the early 1870s. The former was probably affected by harvest failures (the “hungry forties”) and latter was associated with the economic depression of the 1870s (Drukker and Tassenaar 1997).

Figure 5 about here

Similarities and contrasts in the Dutch and the French experiences are shown in Figure 5. The French did not have the small and brief cycles of the Dutch before mid-century, but they did experience considerably less height gain thereafter. While the Dutch gained 3.8 centimetres between birth cohorts of 1850 and 1890, the French increase was slightly less than one third as much. In France, the modest advance in heights was accompanied by progress in performance measures such as GDP per capita and life expectancy. France also experienced a decline in economic conditions that contributed to slow growth in average heights. In the 1860s, a downturn in real wages was followed by 15 years of economic stagnation (Weir 1997).

Figure 6 about here

Japan opened the industrial era at end of the nineteenth century with the smallest stature (about 157 centimetres) of any industrialising country (see Figure 6). Hampered by a low protein diet, thereafter progress was slow and significantly correlated with per capita GDP but adversely affected by economic policy that diverted resources to the military (Honda 1997). Its high level of urbanisation and modest investments in public health were an obstacle to human health and physical growth. Economic stagnation in the 1920s and the depression of the 1930s (which was rather mild in Japan) brought the modest gains in height to a halt in the mid-1930s.

Sweden realised the most sustained increase in health during the most intense period of industrialisation (late nineteenth century). Figure 6 shows that average adult male heights rose from 168 to 172.5 centimetres between 1860 and 1900. The only downturn was the small reversal that occurred during the crop failures of the late 1860s, which had little to do with industrialisation (Sandberg and Steckel 1997). Paralleling the growth in stature were declines in childhood mortality rates of roughly 50%. It is notable that Sweden had the least urbanised population among the eight countries studied, and it also benefited from public health measures such as vaccination, and from relatively low food prices created by the spread of potato cultivation and imports of food from America.

3.5 Generalisations

Study of height and mortality patterns in counties diverse by time period of industrialisation and by environmental factors indicates that a combination of general tendencies and idiosyncratic factors affected health during the industrial revolutions of the nineteenth and early twentieth centuries. In an era when public health policies were often lacking or meagrely enlightened by theories of disease causation, urbanisation was a widespread culprit in ill health within countries studied in Europe and in the Pacific, and within the US. Height was inversely correlated with degree of urbanisation across countries, and rising urbanisation led to health deterioration, especially in England, Australia, and Japan.

Major business cycles also affected heights and health. France, the Netherlands, Germany, and Australia were victims of major downturns. Changing economic opportunities, in the form of growing inequality, adversely affected heights in Germany and the US.

Diets were important for health and human growth. Countries with the tallest men (Australia and the US) had excellent access to a variety of foods, including several rich sources of protein. Food was expensive and the diet was low in protein in the country with the smallest stature (Japan).

Lastly, public health policy (or lack thereof) was also important for heights. Countries that industrialised early, such as the US and the UK suffered the most, in part because the adverse effects of trade and population concentrations on health could not be offset by health policies informed by reliable theories of disease causation. Merely arriving late on the scene was no guarantee of protection against the by-products of industrialisation, however, as shown by the Japanese case where resources that could have been used for public health and human growth, were diverted to the military.

4. Pre-industrial Heights

Among the 8 countries studied in *Health and Welfare during Industrialization*, all but Germany have some military height data that cover small portions of the pre-industrial era. In the absence of detailed information, economic historians may tend to view the pre-industrial world as a vague but homogeneous lump defined by its heavy reliance on agriculture, the preponderance of home manufacturing, and antiquated methods of production. Table 1 shows, however, that on the eve of industrialisation, average heights ranged widely from 155 centimetres in Japan to approximately 173 in the United States and Australia. Most European countries clustered near 164 or 165 centimetres, but the Swedes reached 168.

In all but the United States, the pre-industrial populations were also smaller, often by several centimetres depending upon the exact years of the comparisons. Considering the pre-industrial and middle phase, for example, the height differences shown in Table 1 were about 2 centimetres in France, roughly 4 centimetres in Japan, the Netherlands and Sweden, and about 5 centimetres in Britain (but note that average heights declined significantly in Britain for cohorts born in the 1840s and early 1850s). Average heights in the US were about 3 centimetres lower in the middle compared with pre-industrial times.

What were the important socioeconomic conditions affecting pre-industrial heights? It would seem appropriate to begin with mechanisms that were powerful in explaining height differences during industrialisation—urbanisation and abundant access to land. The two countries with the tallest people (Australia and the US) score well on the latter category and Sweden was the tallest and least congested of the European countries. Access to land tended to ameliorate poverty, helped promote dietary diversity and reduced the spread of disease by lowering population density. Countries with the shortest populations were relatively urban, a feature long known to have impaired health. Australians were tall despite a large (30%) urban population, likely because the cities were isolated from each other and from much of the rest of the world.

If low urbanisation and low population density were good for health, it is a fair question to ask why so many of the pre-industrial populations were so short, compared with their industrial counterparts. After all, the adverse factors of urbanisation and population density tended to increase with industrialisation. With the exception of the US and Britain in the late industrial phase, there must have been something good for health about industrialisation that more than offset the features that were bad.

4.1 Extending the Record

Before attempting to generalise, or even begin to formulate a research agenda on the possible causes of small stature in the pre-industrial era, it is essential to inspect additional evidence. Figures 3-6 make clear that the time span available for study of pre-industrial heights from military records is rather short (or non-existent) in all countries.[5] Skeletal data, in which stature is inferred from long bone (femur) lengths, provide information on the more distant past. Before examining the results, however, it is worth discussing the methodology of using skeletons to estimate heights.

[5] Some 17th century military records in France contain measurements of soldiers, which are useful for studying pre-industrial trends in heights. Komlos, Hau and Bourguinat (2001) report an upward trend (with moderate fluctuations) in average height for birth cohorts of the late 17th century to the mid-18th century. Further search efforts might reveal additional pre-industrial height records for other countries.

Valid use of skeletons requires knowledge of sex and age at death.[6] For all parts of the skeleton, the female elements typically have smaller size and lighter construction. These differences become pronounced in the skull and the pelvis beginning in late adolescence, but before these ages, sex cannot be accurately determined. The skeletal features of robust adult females may resemble those of small and light adult males, but using multivariate analysis, it is possible to estimate sex of adults with a high degree of accuracy in well-preserved remains.

Over a person's lifetime, the skeleton undergoes sequential chronological change. The changes are pronounced in dentition among children and in fusion of the epiphyses (or "growth plates") in various bones of children and in young adults. Among older adults, there are systematic changes in the shape of the pubic symphysis that are used as a guide to age. Above age 50, however, these techniques (and others) become increasingly unreliable, and for this reason, older adults are often grouped together for analytical purposes. In estimating the height of adults, it is the fusion of epiphyses in the long bones that is the key for estimating adult height. Once fusion has occurred, growth ceases and length does not change even with increasing age. On average, approximately 26 per cent of an adult person's height is contained in the femur bone. Trotter and Gleser (1952) developed the most widely used formula for converting femur length into height.

Excavated burials may not reflect the once-living population if burials were geographically dispersed, excavation was incomplete or quality of preservation of the bones was poor. Therefore, in this line of work it is useful to compare results from a particular site with those from sites where these problems are thought to be minimal.

[6] For discussions of these issues see White (1991: 308-20) and Buikstra and Ubelaker (1994: chaps. 3-4).

Table 2 about here

Table 2 gives details from individual studies found in a search of the literature in physical anthropology from sources easily accessible in the United States. Although some results were available for other parts of Europe, only northern Europe had studies that span the entire period from the early Middle Ages to the present. My first effort leaves a gap for the 15th and 16th centuries, which additional search may fill.

Table 3 about here

Table 3 summarises results by era for those studies that give evidence for time periods as small as two or three centuries. Studies reporting results for burials during "Medieval Era" or the "Middle Ages" are lumped together in the middle of the table. It is remarkable if not stunning that the average heights during the early and late Middle Ages exceeded those observed for the eve of industrialisation by several centimetres. While one should always devote some attention to the issues of representativeness and sampling in skeletal data, the large number of studies covering several northern countries suggests that the results cannot be dismissed as a statistical fluke or aberration. It is conceivable that all of the estimated heights for the Middle Ages were biased upward by some as yet undiscovered process of selection, but one would then wonder why that selection process ceased to be a factor in the centuries immediately prior to industrialisation.

Generalising about pre-industrial height trends will be difficult without more evidence for the 15th through the 18th centuries. It seems reasonable to suggest, at least tentatively, that net nutritional conditions of the past millennium reached a low point in Europe prior to the onset of industrialisation. Between the Middle Ages and the twentieth century, heights were U-shaped with a minimum attained sometime between 1450 and 1750, when historical heights become widely available from military records. The onset of the decline (and ultimately its causes) can be established only by a search for more evidence from published or unpublished sources.[7]

Taking the evidence at face value indicates that average heights fell from an average of 173.4 centimetres in the early Middle Ages to a low of 165.8 centimetres during the seventeenth and eighteenth centuries. This decline of 7.6 centimetres exceeds by a factor of two any fluctuations observed during industrialisation. Recovery to levels achieved a millennium ago was not attained until the early twentieth century. Both the extraordinary level relative to recent times and the U-shaped time trend, are remarkable phenomena worthy of considerable study.

Some people may claim that genetic factors are responsible for the tall statures observed during the Middle Ages, pointing to the fact that northern Europeans are taller, even today, than those from more southern European countries (Schmidt, Jorgensen and Michaelsen 1995). But the southern Europeans of the modern period, who tend to be poorer, are catching up, and in any event, studies of children around the globe indicate that children who grow up under similarly good environmental conditions have about the same heights (Malcolm 1974; Martorell and Habicht 1986). If genetic factors were relevant, presumably they had little or no effect on the trend within areas surrounded by the North Sea and the Baltic. Thus, I seek environmental explanations for northern Europe's U-shaped trend in stature.

In suggesting candidates for further study, it is relevant to recall that average height measures a population's history of *net* nutrition - diet minus claims on the diet, made by work

[7] The National Science Foundation recently funded an extensive project that will collect and analyze data from skeletons covering the last 10 millennia in Europe. The effort will obtain not just heights (from femur lengths) but also information on degenerative joint disease, dental decay, anemia, and other skeletal indicators of chronic biological stress. A module in a larger project envisioned on a global history of health, I will work with 3 co-

and by disease. Urbanisation and growing population density, which occurred during industrialisation, increased exposure to disease. Could the diet have been poorer and work more arduous in pre-industrial times, by enough to offset the benefits of lower population density? And if the diet was poorer and work was more arduous, why was net nutrition so good before the sixteenth century?

The data at hand confront conventional wisdom about changes in living standards since the Middle Ages, and lead one to ask: Why did net nutrition decline sometime between the Middle Ages and the pre-industrial period? Why did heights generally improve during the nineteenth century, albeit with interruptions in some countries, when some factors adverse to heights (urbanisation, inequality and business cycles) were getting worse?

As I do not have convincing answers to these questions, I look forward to additional research. It seems to me, however, that the millennium long U-shape of average stature in northern Europe might have been connected with seven major phenomena: climate change; growing inequality in real incomes after 1500; urbanisation and growth of trade that spread diseases; wars of state building; religious conflicts; the global spread of new varieties of disease associated with European expansion and colonisation; and population cycles. We are faced, then, not with a dearth of plausible explanations but rather measuring their impacts on health and weeding out influences among those that were unimportant.

4.2 Possible Causes of Good Net Nutrition during the Middle Ages

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investigators and numerous collaborators in Europe in gathering and analysing skeletal data that will be matched with socio-economic and climate information.

At the outset, it is useful to consider why average heights were surprisingly large during the Middle Ages. One might debate the representativeness of the results, something that is useful more generally of findings so at odds with preconceptions. Because numerous skeletal studies are essentially uniform in reporting statures in the Middle Ages that were tall by standards of the late nineteenth century, however, it seems prudent to accept them at face value (at least provisionally) and move to possible explanations.[8]

According to the data at hand, northern European heights did not consistently exceed those of 800-1300AD until the early twentieth century. One important factor in this remarkable may have been climate. Agriculture during the period from about 900 to 1300AD benefited from what climate historians call the "Medieval Warm Period" (see Figure 7).

Figure 7 about here

Based on ice cores, tree rings and other sources, climate historians believe that temperatures during this era were as much as 2-3 degrees (centigrade) warmer than a few centuries later, and 0.7 to 1.0 degrees above 20th century averages (see Fagan 2000). At the beginning of this era, the Vikings settled Iceland and later Greenland. This temperature change may not appear to be significant, but it was enough to extend the growing season by 3-4 weeks in many settled regions of northern Europe. The weather was sufficiently warm that commercial vineyards were viable 300 to 500 kilometres north of their range in the 20th century. Moreover, it allowed cultivation of previously unavailable land at higher elevations. Therefore, a population that was probably

[8] This is not the first time that anthropometric historians have found surprising if not startling results. The very small statures of slave children followed by remarkable catch-up growth, the American height decline during the mid-nineteenth century and the very tall statures of the Equestrian Plains tribes in the United States are three additional examples.

smaller relative to later eras, quite possibly had a portfolio of better land from which to choose in producing crops. A result would have been more agricultural output (at the same or less work effort) compared with the centuries immediately following the Middle Ages.

It is well known that economic isolation, in the form of little trade beyond local interaction, also characterised life during the Middle Ages, at least relative to later centuries when regional commodity markets developed significantly. Anthropometric historians have noted the benefits to health and average heights of geographic isolation, low population density, or lack of commercial development for outlying areas within Sweden, Austria-Hungary, Japan, Ireland, and the United States (Sandberg and Steckel 1987; Komlos 1989; Shay 1994; Margo and Steckel 1982, 1992; Nicholas and Steckel 1997; Cuff 1998). The protective effect of isolation, in the era before effective public health, probably operated through insulation from communicable diseases. In this regard, it is notable that the bubonic plague made its dramatic appearance in the significant revival of trade during the late Middle Ages.

Urban areas were bad for health, as established from their high mortality rates and the small statures of those who resided in such places for a significant portion of their childhood growing years. To my knowledge, this demographic phenomenon was found in all areas of the world until the late nineteenth or early twentieth centuries, when public health measures and improvements in personal hygiene significantly reduced exposure to pathogens. Moderately large cities were absent from northern Europe until the late Middle Ages (for discussions of urban growth see De Vries 1984; Hohenberg and Lees 1985). As late as the end of the 13th century, significant urbanisation was confined mainly to southern Europe, in northern Italian towns such as Milan, Florence, Venice and Genoa, each of which probably exceeded 100,000 in population. At this time, Paris was the only city in northern Europe that may have fallen into this category. The southern Low Countries were moderately urbanised by the late Middle Ages (the 14th century), but the largest city, Ghent, probably had no more than 50,000 inhabitants, while London and Cologne held fewer than 40,000 people at this time. Therefore, the overwhelmingly rural distribution of the population was an asset for health.

4.3 Possible Factors in the Health Decline

A cooling trend began around 1200 and by the 14th century, weather related events began to cause havoc in northern Europe (Fagan 2000). By the late 14th century, the Vikings had abandoned Greenland and in the next century, England no longer cultivated wine. By 1600, when the coldest two centuries of the Little Ice Age began, pack ice surrounded Iceland for much of the year, the Thames River often froze during the winter, glaciers advanced significantly in the Alps, and vast schools of cod had long since left European waters for warmer temperatures of the western Atlantic. The climate change was likely to have imposed greater economic and health costs on northern Europe where food production existed under weather conditions that were closer to the margin.

Important for agricultural production and health, the climate change was irregular. Imbedded within the general cooling period of 500-600 years were numerous seesaws of 15 to 40 years' duration, several of which are visible in Figure 7. The changing weather patterns made it difficult for individuals alive at the time to identify true long-term trends, which were noticeable only with intergenerational perspective. The lack of knowledge about actual trends postponed adaptations to the cooling climate, and during temporary reversals of cooling, encouraged investments in ways of farming and living that later proved unsuccessful.

Urbanisation and growth of trade that began in the late Middle Ages gathered steam in the 16th and 17th centuries. In northern Europe, there was only one city of 100,000 or more people in 1500 (de Vries 1976, 73). By 1600, the number of people living in such places had quadrupled, and within another century it had tripled again. As height studies for the late eighteenth and early nineteenth centuries show, large cities were particularly hazardous for health, acting as reservoirs for the spread of communicable diseases (Steckel and Floud 1997: chap. 11). Therefore, it would not be surprising if urbanisation following the Middle Ages contributed to an overall decline in health.

The spread of disease that began with revival of trade and urbanisation were reinforced by another source of pathogens that began in the late 1400s, and later intensified: global exploration and trade. The voyages of Columbus and Vasco da Gama were merely the first of thousands by which Europeans acquired global information that was used to build and maintain colonial empires. Within 300 years, Europeans had mapped most of the globe and established numerous colonies or trading centres on all continents or islands significant for producing saleable products. Syphilis is only one of numerous diseases that spread during this era. It is well known that the early stages of globalisation began in the late 1400s and eventually led to the world-wide diffusion of many diseases into previously isolated regions or continents (Crosby 1972; 1986).

As a measure of net nutrition, average height is adept at measuring a population's consumption of basic necessities such as food, clothing, shelter, and medical care. In countries with high levels of per capita GDP, most people have enough of these to satisfy basic needs. But in poor countries or among the poor in moderate-income countries, large numbers of people are biologically stressed or deprived, which leads to stunting. In addition to income, average height is therefore sensitive to the degree of inequality (Steckel 1983; 1995). It is difficult to acquire information about income or wealth inequality in the distant past, but Hoffman et al. (2000) have been ingenuous in assembling related information by using information on the prices of products heavily consumed by the rich or by the poor. In their study of price patterns for staple foods and fuels relative to the prices of luxury goods, such as servants, they find that real inequality rose considerably during the 16th century and remained high until the 20th century. It was during the era from 1500 to 1650, however, that the rich benefited most from soaring land rents (a source of income for many of the well-off) while the poor faced higher prices for food, housing and land. As far as Hoffman et al. can tell, this trend persisted throughout most of Europe. Since the poor comprised a large segment of the population, it is plausible to believe that growing inequality could have increased biological stress in ways that reduced average heights in the centuries immediately following the Middle Ages.

Although state building could be credited, in many cases, with eventually improving economic efficiency, the early stages of the process also absorbed resources, cost human lives in conflict, and may have increased inequality. Someone might be able to argue that religious wars and conflicts improved health when or shortly after they occurred, but I find it difficult to imagine a mechanism. From the War of the Roses in the late 15th century and the Reformation in the early 16th century, many parts of Europe were in sporadic and sometimes protracted conflict or turmoil until the conclusion of the Napoleonic wars in 1815.

Economists and historians have long discussed Malthusian processes affecting population health and growth. Positive checks on growth, in the form of higher mortality rates created by growing pressure of population on resources, likely would have led to diminished stature. John Komlos (2000) has argued that industrialization was an adaptive response to such pressures, but presumably they existed (without or with less adaptive success) in earlier centuries. The course of population over the past millennium is reasonably well chronicled (see McEvedy and Jones, 1978) and plausibly periods of rapid growth that pressed on available resources and given technologies could have been a factor in height trends. The rapid growth of population during the 11th through the early 14th centuries, for example, might have been a factor contributing to height declines of the late Middle Ages.

It would be premature to attempt to identify an era that was the worst in the last millennium for European health and nutrition, but historical evidence suggests that the 17th century is a leading candidate (de Vries, 1976). Contributors to *The General Crisis of the Seventeenth Century* (Geoffrey Parker and Lesley Smith (eds.) 1997), focus on Europe but argue that the hardship probably spread well-beyond this region. During this century numerous adverse forces acted together. It was part of the coldest period of the Little Ice Age, and subsistence crises were numerous. Religious turmoil was raging as signified by the Thirty Years War, and political instability was marked by the English Civil War and by numerous peasant uprisings. Economic inequality was intense as indicated by the rise in the price of necessities relative to luxuries. Global colonisation and the associated spread of diseases were in full swing, as was a rapid increase in the number of large cities. It remains, however, to connect these events to changes in average stature.

4.4 Height Recovery

The forces that led to increasing average heights are difficult to pinpoint without additional evidence on the times and places where increases occurred. It is hard to see how industrialisation could have reduced exposure to pathogens. Growing population congestion, migration and trade associated with the process were likely to have spread communicable diseases. If correct, one must look to other factors, such as the retreat of the Little Ice Age that could have contributed to higher yields in agriculture. There were also other sources of improving productivity in agriculture that began in the 18th century, such as new crops for forage and food, new crop rotations, enclosures, better drainage systems, and mechanical equipment. McKeown (1983) has been the strongest advocate for better diets in improving health in the nineteenth century, and Fogel (1985) has used data on average heights and agricultural production to buttress and quantify this point of view. Razzell (1993) and Livi-Bacci (1983) have downplayed the contribution of nutritional inputs to improving health over the long term, citing factors such as the independence of many diseases from nutrition, human adaptability to food availability, smallpox inoculation, and changing virulence of diseases.

While more research should be done, connections have been made between rising heights and improving diets in specific countries. Weir (1997) argues that growing meat consumption contributed significantly to rising heights in nineteenth-century France. Sandberg and Steckel (1980) suggest that diffusion of potatoes was important to improvements in stature in Sweden in the early nineteenth century. More generally, dietary improvement in nineteenth-century Europe was made possible by technical improvements, such as light iron ploughs, steam threshers, mechanical harvesters, and commercial fertilisers, as well as by agrarian reforms such as enclosures or emancipation of serfs (Jones 1968; Trow-Smith 1967; Tracy 1964). In the middle of the nineteenth century, diets also received a boost from the free trade movement. This and greater speed and lower transportation costs on long ocean voyages made it feasible to import foodstuffs from Australia and from the land-rich countries in the Western Hemisphere, principally the US, Canada, and Argentina (O'Rourke and Williamson 1999). There is also evidence that public health measures, though based on an inaccurate theory of disease causation, were somewhat effective in reducing mortality rates in cities (Szreter 1988).

An increase in average height may have been assisted by gains in consumption per person that followed from reductions in conflicts that absorbed resources. Although there were some revolutions and assorted small wars in Europe during the nineteenth century, the Napoleonic Wars, which ended in 1815, was the last major conflict until World War I. Some religious strife persisted, but in fewer places and at lower levels than existed during the Reformation.

5. Concluding Remarks

While there are certainly qualifications to be noted, the major empirical finding reported in this paper is the U-shaped pattern in average heights from the early Middle Ages through the late nineteenth century in northern Europe. After a long period of approximate stability at levels that were impressive even by standards of the late nineteenth century, heights declined sometime after the end of the Middle Ages. Plausibly, the height decline might be linked with climate change that accompanied the onset of the little ice age; growing inequality; urbanisation; the global spread of diseases after the late 1400s; and conflicts associated with state building and religion. Because it is reasonable to believe that greater exposure to pathogens accompanied industrialisation, and there is evidence of growing efficiency in agriculture and greater trade in foodstuffs, it is reasonable to link height gains during the early and mid nineteenth century with dietary improvements.

Much research remains to be done on the exact time-path of average heights, and substantially more information from skeletal evidence is available. A large research program is now in the planning stages to gather this evidence and analyse it in light of related information on climate and of socioeconomic information from historical sources and from the archaeological record.

For over half a century economic historians have focused on the question of whether there was immiserisation during industrialisation, a debate that has split researchers into camps of optimists and pessimists. This is and continues to be an interesting topic for research. But with the perspective of 1000 years of history, whatever happened with regard to downturns in welfare during this era, they were likely small compared to the vast changes that probably occurred since the early Middle Ages. Therefore, economic historians who are inspired by variation and diversity in the historical record would do well to consider this much broader time span of evidence.

Table 1: Average Height of Adult Men, Life Expectancy and Percentage Urban by Stage of Industrialisation

Country	*Dates*	*Stature*	*Life Expectancy*	*% Urban*
		Preindustrial Phase		
UK	1720-1760	165.1	33.7	22.6
US	1800-1820	173	45.3	6.9
France	1800-1820	164.1	36	19
the Netherlands	1830-1850	164	35	38
Sweden	1830-1850	168	42.1	9.7
Germany	1830-1850		36.9	30.5
Australia	1840-1860	172.5	46	30
Japan	1868-1880	155.3	36	34.5
		Early Industrial Phase		
UK	1760-1800	168.2	36	29.4
US	1820-1850	172.4	41.7	10.5
France	1820-1850	164.4	39.3	22
the Netherlands	1850-1870	165.9	40	44
Sweden	1850-1870	169.1	43.9	11.2
Germany	1850-1870	166.2	37.6	34.4
Australia	1860-1890	172	48	42
Japan	1880-1900	157	38	50
		Middle Industrial Phase		
UK	1800-1830	170.7	38.6	38.7
US	1850-1880	170.6	40.9	22.3
France	1850-1880	165.4	41	31
the Netherlands	1879-1900	168.6	45	46
Sweden	1870-1900	171.4	49.3	17.2
Germany	*1870-1890*	*167.5*	*38.9*	*43.6*
Australia	1890-1920	172	59.2	53
Japan	1900-1920	158.8	44	60

Late Industrial Phase

UK	1830-1870	166.9	39.5	54.1
US	1880-1910	170.2	45.6	37.2
France	1880-1910	166.7	45.5	39
Germany	1890-1913	169.7	46.8	56.1
the Netherlands	1900-1925	172	55.2	56
Sweden	1900-1925	173.5	57.4	25.7
Australia	1920-1940	173.2	65.4	60
Japan	1920-1940	160	47	75.5

Source: Steckel and Floud (1997: 425, Table 11.2).

Table 2: Average Heights in Northern Europe Estimated from Adult Male Skeletons

Era	Place	Avg. Height (cm)	Sample Size	Source
9-11th C	Iceland	172.3	22	Steffensen (1958)
9-17th C	Iceland	172.2	71	Steffensen (1958)
10-11th C	Sweden	176.0	8	Gilberg (1976)
11-12th C	Iceland	172.0	27	Steffensen (1958)
11-17th C	Iceland	171.0	16	Steffensen (1958)
12th C	Norway	170.2	42	Hanson (1992)
12th C	Britain	168.4	233	Munter (1928)
12-13th C	Norway	172.2	*	Huber (1968)
12-16th C	Iceland	175.2	6	Steffensen (1958)
13th C	Denmark	172.2	31	Boldsen (1984)
13th C	Sweden	174.3	66	Gejvall (1960)
13-14th C	England	171.8	*	Huber (1968)
Middle Ages	Sweden	170.4	457	Steffensen (1958)
Middle Ages	Denmark	172.0	190	Bennike (1985)
Middle Ages	Denmark	172.6	43	Bennike (1985)
Middle Ages	Norway	172.1	314	Holck &Kvall (2000)
Middle Ages	Denmark	175.2	27	Holck (1997)
Middle Ages	Norway	167.2	1792	Holck (1997)
Middle Ages	Sweden	170.4	457	Werdelin (1985)
13-16th C	Holland	172.5	87	Maat et al. (1998)
11-16th C	Holland	176.2	23	Janssen and Maat (1999)
11-16th C	Sweden	172.8[a]	499	Arcini (1999)
17-18th C	Iceland	169.7	17	Steffensen (1958)
17-18th C	Holland	166.0	41	Maat (1984)

Table 2 (con't)

17-18th C	Holland	166.7[b]	102	Maat (1984)
18th C	Iceland	167.0	4	Steffensen (1958)
18th C	Norway	165.3	1956	Holck (1997)
17-19th C	Iceland	169.2	21	Steffensen (1958)
18-19th C	Britain	170.3	211	Molleson & Cox (1993)

[*] Not available or missing information.

[a.] Simple average across 7 combinations of sites and dates.

[b.] Based on a sample of 102 men and women who were indistinguishable based on skeletal remains, of which about one half were men as determined from written records. The overall average was adjusted upward for typical sexual dimorphism (5 cm), to estimate male heights.

Table 3: Summary of Adult Male Height Trends in Northern Europe

Era	Place	Simple Average of Average Heights (cm)	Source
9-11th C	N. Europe	173.4	Table 2, rows 1, 3, 4
12-14th C	N. Europe	171.5	Table 2, rows 6-8, 10-12
Middle Ages	N. Europe	171.4	Table 2, rows 13-19
17-18th C	N. Europe	167.5	Table 2, rows 23-25
18th C	N. Europe	166.2	Table 2, rows 26-27
17-19th C	N. Europe	169.8	Table 2, rows 28-29
Late 19th C	Sweden, Netherlands, Britain	169.7	Sandberg and Steckel (1997: 129); Drukker and Tassenaar (1997: 341); Floud and Harris (1997: 102).
1930	Sweden, Netherlands	172.5	Sandberg and Steckel (1997: 129); Drukker and Tassenaar (1997: 341).

List of Figures

Figure 1: Life Expectancy and Adult Male Height, Late Industrial Period

Figure 2: Per Cent Urban and Average Male Height

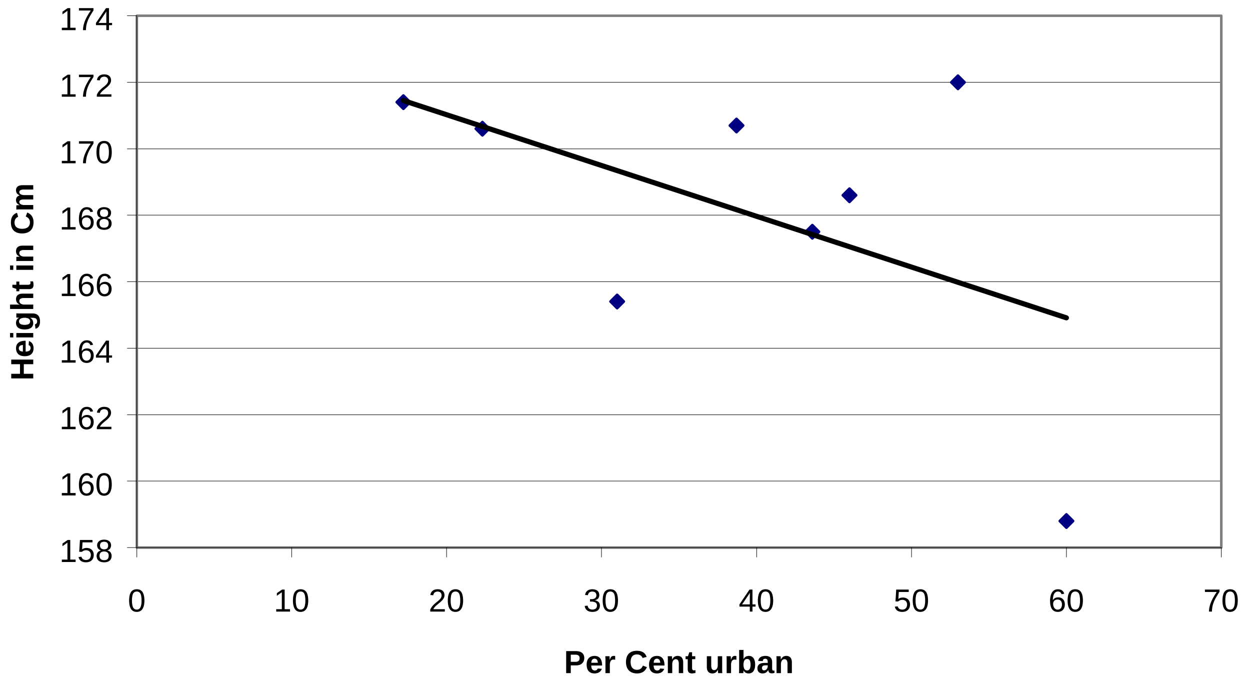


Figure 3: Average Height of Soldiers in Britain and of Native Born American Soldiers

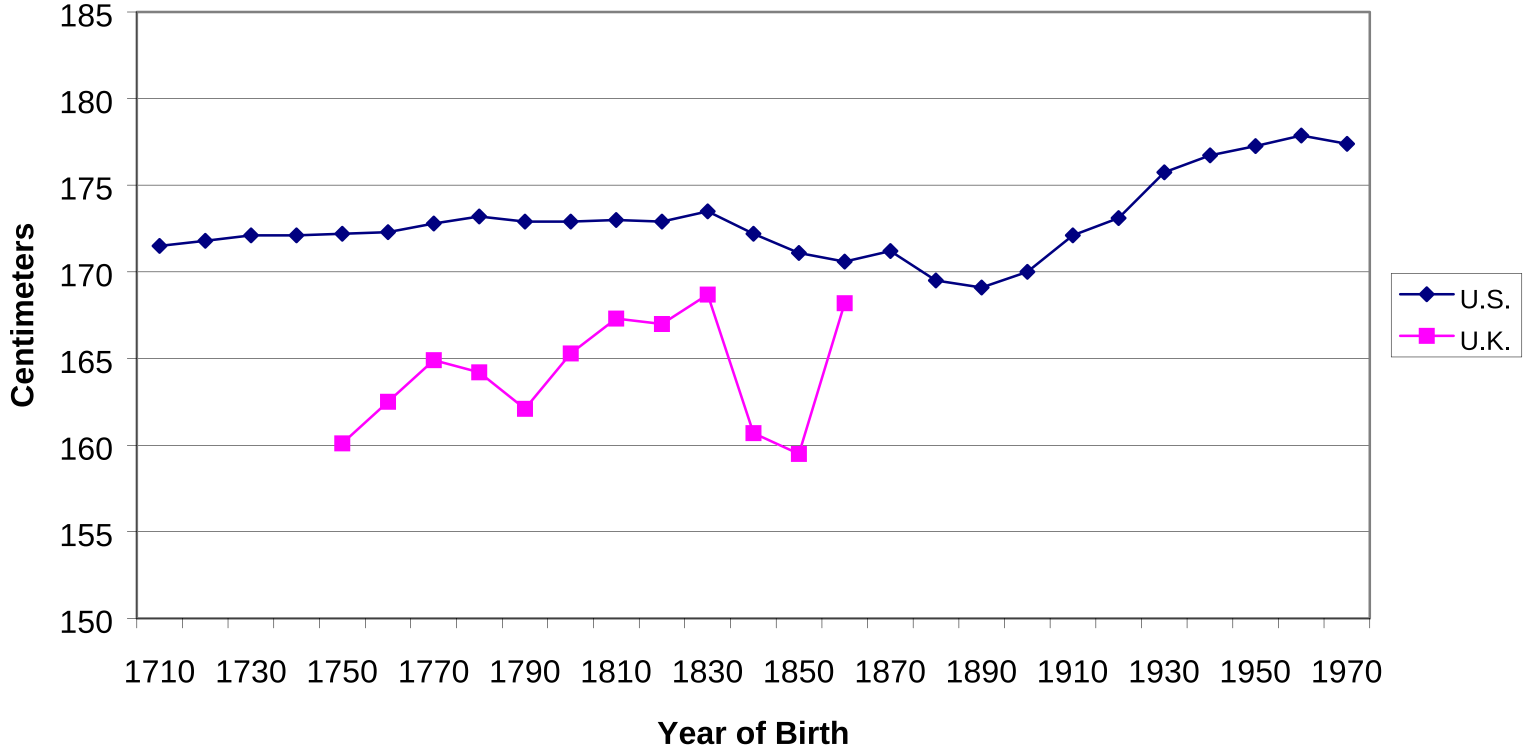


Figure 4: Average Height of Soldiers in Australia and in Wurttemberg

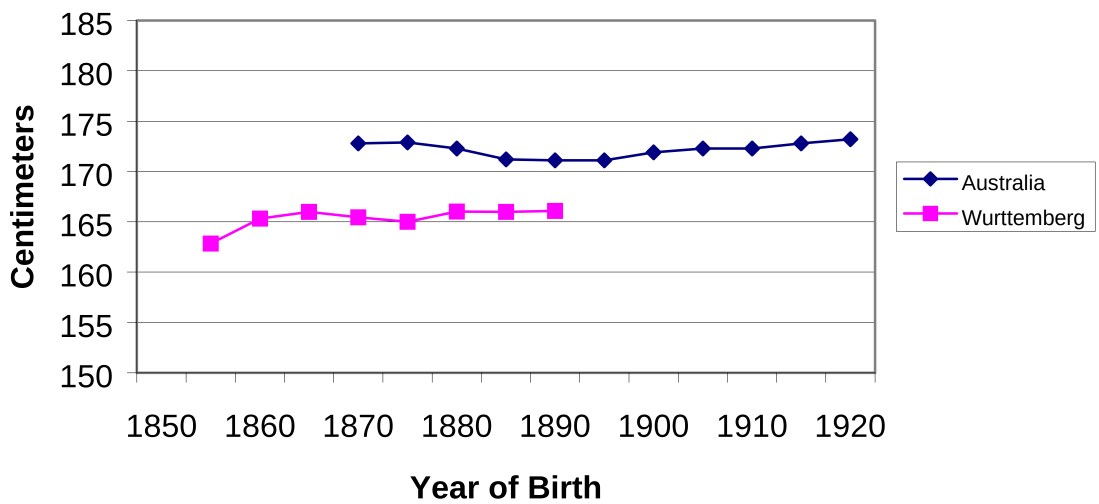


Figure 5: Median Height of Conscripts in the Netherlands and in France

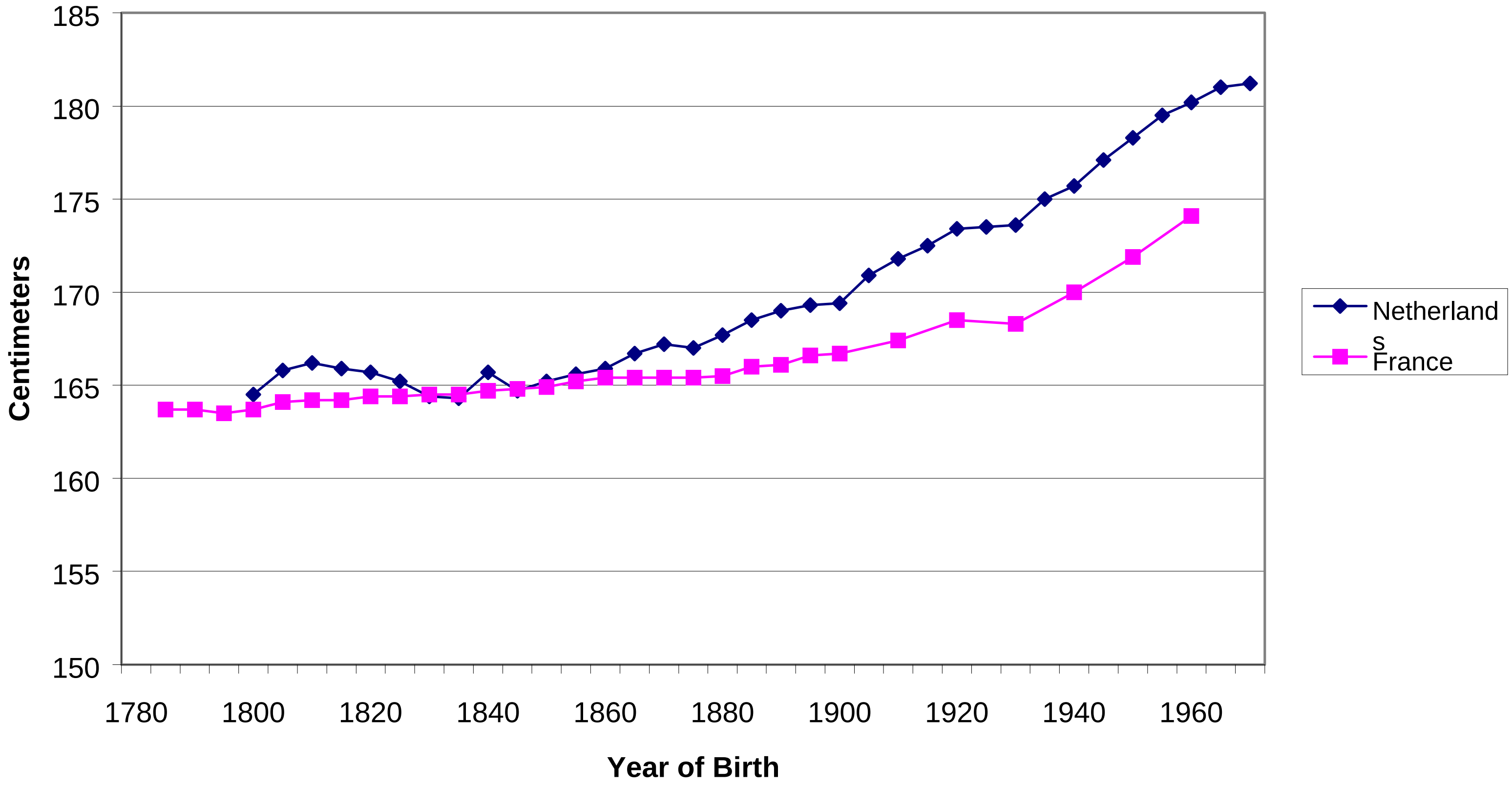
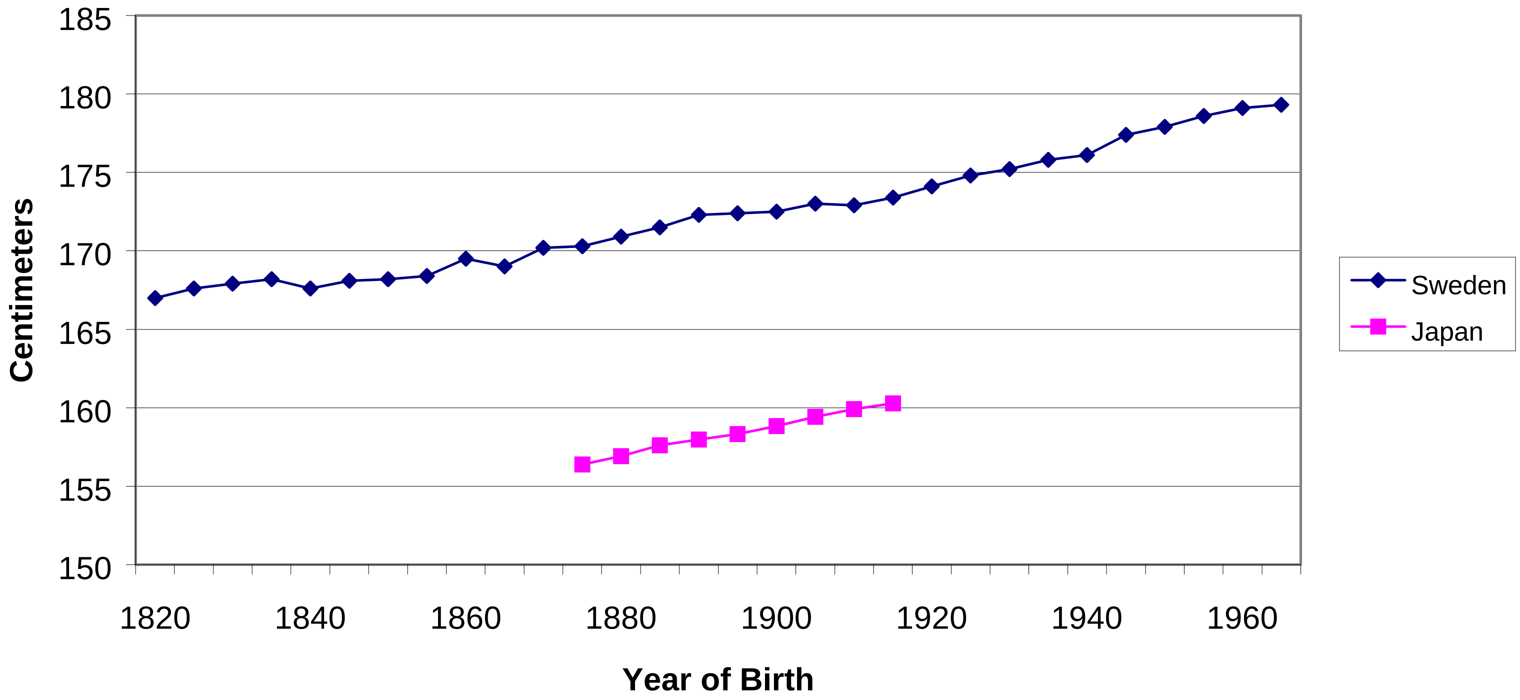


Figure 6: Average Height of Conscripts in Sweden and in Japan



HISTORICAL EVENTS

2000

- World War II (1939-45)
- World War I (1914-18)

1900

- Large scale European emigration
- Irish Potato Famine (1845-49)

1800

- Napoleonic Wars (1798-1815)
- Industrial Revolution
- Great Storm of 1704

1700

- Faeroes cod fisheries fail
- Thirty Years War (1618-1648)
- Jamestown Colony settled (1607)

1600

- Spanish Armada (1588)
- Roanoke Colony (1587)
- All Saints Flood (1570)
- Spanish settlement at Santa Elena (1565)

1500

- Columbus lands in the Bahamas (1492)
- Wine cultivation abandoned in England (1469)

1400

- Norse Western Settlement in Greenland abandoned (c.1350)
- Black Death (1348)
- Hundred Years War (1337-1453)
- The Great Famine (1315-21)

1300

- Hanseatic League rise to prominence
- Mongol Invasions

1200

- Crusades in the Holy Land
- Cathedral building

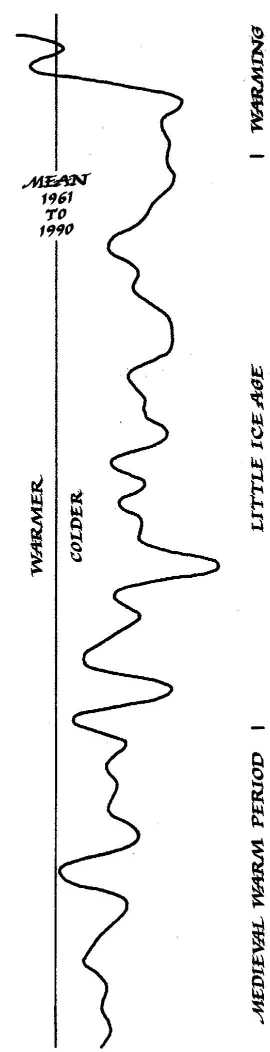
1100

- William the Conqueror invades England (1066)

1000

- Norse settlement of Greenland (980s)

TEMPERATURE



CLIMATIC AND NATURAL EVENTS

2000

- Warming
- Cooler (1960s)

1900

- Warming
- Krakatau eruption (1883)
- Little Ice Age ends (?1850)
- Tambora eruption (1816)

1800

- Glaciers advance in Northern Hemisphere (1740-1760)
- Warmer (1710-1740)

1700

- Coldest period of the Little Ice Age (1670-1710)
- Maunder Minimum (1645-1710)

1600

- Huanyaputina Eruption (1600)
- Alpine glaciers advance
- Cooler conditions after 1580

1500

- Greater storminess and unpredictable climatic shifts

1400

1300

- Little Ice Age begins (c.1300)
- Major volcanic eruption generates a cold snap (1258)

1200

1100

1000

JS

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