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Height as a measure of the nutritional status and health of a population

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Abstract

The average height has increased dramatically in many populations over the last two hundred years as a result of improved nutrition and living environments. It is difficult to disentangle the exact underlying causes of the increase since the number of factors that are known to influence growth and height is so large and the analyzable variation is low. We can still learn much about living conditions, nutrition and disease exposure in the past by studying the historical developments of heights, especially if we use individual level data. This is important also for understanding the long-term increase in longevity. The trends in height and in longevity most likely share some underlying causes but they were also affected by unique, unshared factors. Mortality and height are not interchangeable measures of human health or living conditions. We should therefore not be expecting to always find the same results when we analyze the two different outcomes.

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Macro level associations and micro level influences

The average height of people in Western Europe today is at least 12 centimetres – almost two standard deviations[1] – taller than it was two hundred years ago (Garcia and Quintana-Domeque 2007; Hatton and Bray 2010).[2] The populations in present-day high income countries were shorter in the eighteenth and nineteenth centuries than almost any population even in low-income countries during the twentieth century (Floud, Wachter and Gregory 2006[1990], fig. 1.1). Variations in height among individuals are largely determined by influences that are not environmental, including genetics, but systematic differences among social groups, populations and differences over time are the results of environmental influences (e.g. Mueller 1976; Silventoinen et al. 2000; Silventoinen 2003; WHO Multicentre Growth Reference Study Group and de Onis 2006). The increases in average height

1. The standard deviation of adult height in a population is almost always between 6 and 7 centimeters. The Clio Infra project (2015) has published a collection of 706 decadal observations of average adult male height and "height gini" from 125 countries from between 1810 and 1989. The standard deviation can be derived from this information through the following transformation; standard deviation = ((height gini + 33.5) / 20.5) * height / 100. The average (and median) standard deviation in this sample is 6.3 cm. The distribution of standard deviations has in itself a standard deviation of 0.59.

2. The discussion of the secular trend in height and influences on growth and achieved height presented below is further developed and is more thoroughly referenced in Öberg (2014a, Introduction).

over time have also been too fast to have been caused by genetic factors, and must therefore reflect environmental influences on growth. A large number of factors are known to influence growth and achieved height, including nutrition, disease, toxins and pollutants, and stress (see Öberg 2014a, pp. 20-34 and references there for further discussion).

Information on the average height of populations and groups therefore provides some insight into their standards of living and health status. Investigating trends in height enables us to gain some knowledge about changes in living conditions and health for historical populations when this kind of information is scarce. Knowledge of historical heights also makes it possible to compare their development with the development of mortality rates and to discuss how improvements in living conditions have contributed to the mortality decline (e.g. Floud et al. 2011). From the differences in height among groups and over time we learn about living conditions linked to growth and achieved height. To use this knowledge to inform our discussions on the influence of living conditions on changes of longevity, we need to assume that the same factors influence both height and longevity. It will be argued here that even if some of the influencing factors are common to both growth and height, and health and longevity, there are also factors that influence them in different ways or that influence one but not the other. We can still learn a lot from studying these trends separately and jointly, but we should not consider them to be interchangeable measures of the living conditions or health status of a population.

To know how we should interpret the secular trend in height we need to try to establish the causes behind the increase in height and their relative importance. We have no reason to expect the secular trends to be results of any single cause, but the relative importance of different causes still has implications for how we should interpret the trend and its relation to other contemporary fundamental changes, such as the mortality decline. It is difficult to analyse the underlying causes of a linearly trending variable, such as the average height in Sweden and other high-income countries during the last 100–200 years, since the number of factors that are known to influence growth and height is so large and the analyzable variation is low. Societies experiencing increasing average heights were changing dramatically in many ways during the same period, with industrialization, increasing productivity, rising real wages, changing consumption patterns and diets, and falling mortality rates (see e.g. Easterlin and Angelescu 2012). The average height among conscripted men in Sweden from the early nineteenth until the late twentieth century is extremely closely correlated with a large number of indicators of the social and economic development of the country (Pearson's correlation coefficient for height with: urbanization rate, $r = +0.993$; GDP per capita (log), $r = +0.963$; fertility rate, $r = -0.945$; infant mortality rate, $r = -0.983$). The extremely close associations in the macro-level data prevent most meaningful statistical analyses of the aggregated trends.

Some of the associations, even the very plausible ones like the association between the average height and GDP per capita or the infant mortality rate, do not hold up in all contexts. There is a close log-linear association over time between average income and average height in European countries as well as across countries (see Öberg 2014a, pp. 24-26 and references there for further discussion). But there is no similar close cross-sectional association in samples of low- and middle-income countries, and the effect of the average income level on the prevalence of undernutrition in these countries is not very strong (Deaton 2007). Countries that have made rapid progress have made interventions specifically targeting the nutritional status of the population (Bhutta et al. 2013, p. 471). Hatton (2014) also questions the seemingly close association between average income and height historically in Europe, and argues that the average height is better predicted by the infant mortality rate than the income level. But the association between the infant mortality rate and adult average height is again less strong in populations in present-day low- and middle-income countries (Deaton 2007; Akachi and Canning 2010).

Several of the suggestions in the previous literature on associations between height and environmental influences, and the causes of the secular trend in height, can only be tested using individual-level data covering a long period. For my dissertation I linked information from lists from universal conscript inspections to a sample of men in the Scanian Economic Demographic Database born between 1797 and 1950, who were inspected in 1818–1968 (Öberg 2014a). In this way I could combine the data on the heights with detailed information on the family background and community context of these men.

The secular trend in height in Sweden

Figure 1 summarizes what is known about the development of the average height of men in Sweden born in the nineteenth and twentieth centuries from conscript data (see also Hultkrantz 1927; Sandberg and Steckel 1997). The secular increase in average height in Sweden started among men born in the second quarter of the nineteenth century. Universal conscription had already begun for men born in 1791, but the published national statistics unfortunately only start with the men born in 1819. We therefore do not know if the lack of a clear trend seen for the Scanian data for men born in the period 1797–1818 is representative of the country in general.

Sandberg and Steckel (1980) took part in pioneering historical research on heights by collecting information on recruited soldiers in Sweden born in the eighteenth and nineteenth centuries. They did not find any clear trend in the average height during the eighteenth century (Heintel, Sandberg, and Steckel 1998). What is known about the even earlier trend is mostly based on estimating heights from skeletal remains. Even though the heights estimated from skeletal remains are uncertain and cannot easily be compared with measured heights, it seems that there was no clear trend in the average height in the nine centuries before 1700 either (Gustafsson et al. 2007). The secular increase in height in Sweden therefore seems to have started among men born in the second quarter of the nineteenth century, about the same time as real wages started to increase in southern Sweden (Bengtsson and Dribe 2005).

The large difference in average height among men born around 1850 in the SEDD parishes compared with the national trend is most likely a consequence of the differences in who is included in the data. The Scanian data include the height of men who were shorter than the minimum height requirement, while the national series is then based only on men accepted for conscription. The subsequent linear trends are very similar for the Scanian parishes and for Sweden. The median height of the Scanian population shifts abruptly a couple of times, especially in the early nineteenth century. This is due to lack of precision in the measurement – heights were measured in inches, not centimetres – and random variation in combination with small sample sizes. The underlying trend in the population height was as gradual as the national trend. This is clearer when we use more fine-grained but less robust techniques to estimate the trend (Öberg 2014b, fig. 1).

Some of the increase in average height was the result of earlier physical maturation of the inspected men. When growth is slowed during infancy and childhood, people can also continue to grow for a longer time and reach their final adult height later (see Öberg 2014a, pp. 31-34 and references there). Today most men reach their final adult height in their late teens. In the early nineteenth century people continued to grow into their twenties. Improved conditions for growth result in both taller average stature and faster physical maturation. Parts of the increase in the average height during the nineteenth century are therefore a result of earlier maturation with an increasing share of the inspected men having reached their adult height at inspection. The estimated height presented in Figure 1 is therefore not an estimate of the average *adult* height in the population. The average adult height of the men is likely to have been one or a few centimetres taller than the average at the conscript inspections during most of the nineteenth and early twentieth centuries. The increase still reflects an improvement among the factors influencing heights but might not reflect changes in the final adult height in the population.

The secular trend in height slowed down in Sweden among men born in the 1950s. There was no

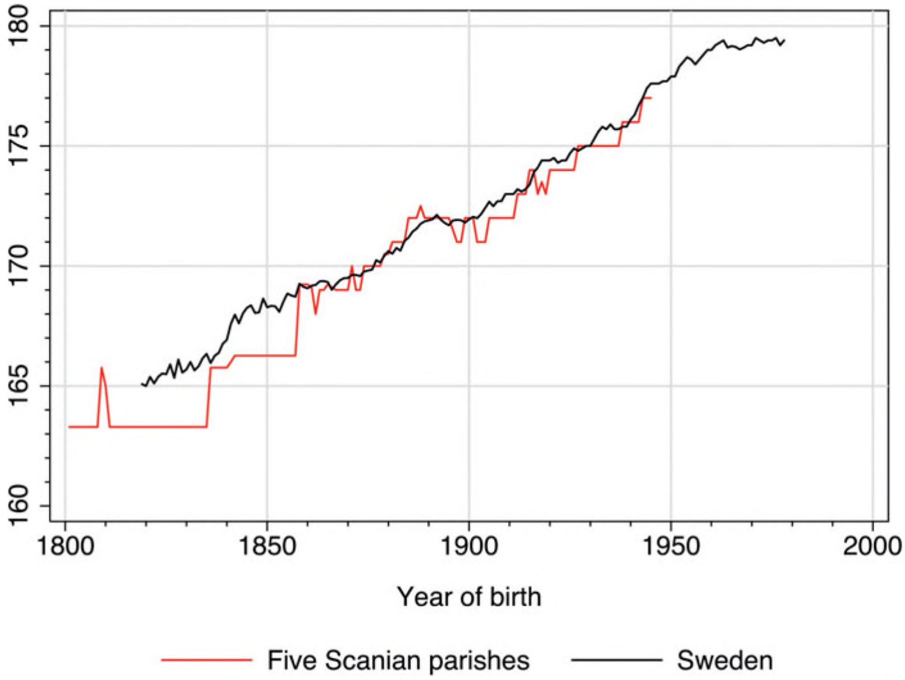


Fig. 1 The secular trend in height in Sweden among young adult men born between 1797 and 1978.

Note: The figure shows the median height among all inspected men in the five parishes in the Scanian Economic Demographic Database (Bengtsson, Dribe, and Svensson 2012; Öberg 2014a). The median was calculated for 145 samples, each including men born within a moving ten-year period. The national height series includes, as far as possible from the published data, only men born in one year. The series for Sweden are: for men born in 1819–1906 the median height of men accepted for conscription, and for men born in 1907–1978 the average of all inspected men. For sources on the national series see Öberg (2014b, fig. 1).

change in the median height among young adult men born in 1953-1978 even if the average increased slightly (Värnpliktsverket/Pliktverket 2013). The slowing-down or cessation of the secular trend in the mid- and late twentieth century has also been observed in Norway, Denmark, the Netherlands and Italy, while heights otherwise continue to increase in today's still shorter populations in eastern and southern Europe (Larnkjær et al. 2006). It is still not yet clear whether this is a result of a maximum achievable average size of humans, even if this seems likely.

Heights as a measure of nutritional status

Heights are interesting for social scientists because, to some degree, they reflect nutritional status. *Nutritional status* must be "clearly distinguished from nutrition, which is the amount and nature of energy ingested in the form of food and drink" (Floud et al. 2011, pp. 11, see also 41-42). Nutritional status is a result not only of the intake of energy and nutrients but also of the expenditure of these. The body needs energy and nutrients to function, maintain and repair itself. Quite naturally it also needs energy and nutrients to be able to grow. It is intuitive that the body needs energy for growth and physical work, but most energy is actually used in less obvious ways, such as for keeping organs working, keeping the body warm, digesting foods and for the brain. If the balance between inputs and requirements is not sufficiently positive the growth slows down and if the negative influences, such as undernutrition or disease, are repeated, severe or prolonged, they will result in a shorter adult stature.

Nutrition affects growth and achieved height both through the amount of food consumed and through the composition of the diet (see also Öberg 2014a, pp.

27-28 and references there). Intakes of energy and macronutrients (i.e. protein, carbohydrates and fats) need to be adequate for the body to function well and grow. But the quality of the food consumed seems to have at least as strong an influence on growth as the quantity. Some specific micronutrients are also important, such that deficiencies can result in shorter height (see also Bhutta et al. 2013). Heights may therefore have increased historically both because of an increased and more stable supply of food and because over time diets became more diverse, with a higher content of animal products, fruits and vegetables. Children growing up in families with a more variable diet are on average somewhat taller than others (see also Marriott et al. 2012). Monotonous, largely vegetarian, diets may be deficient in vitamins and minerals even when they provide sufficient energy. This situation may be aggravated, as the diet may influence the nutrients that are actually accessible for the human body. A diet consisting of coarse whole-grain cereals may limit the ability to absorb micronutrients such as zinc and iron (e.g. Schneider 2013). The monotonous, coarse and largely vegetarian diets consumed by the majority historically may therefore have contributed to their short stature even in situations where energy intake was sufficient.

The protein content of diets, especially from animal sources, is likely to be especially important for growth (Silventoinen 2003, 273-274; Hörnell et al. 2013). Cow's milk also seems to increase growth, even independently of being a nutritious food and source of protein (Hoppe, Mølgaard, and Michaelsen 2006). The seeming importance of intakes of animal proteins for growth can be a result of both the protein content and the accessible micronutrients in these foodstuffs.

That access to animal proteins, meat and milk, was also important for growth historically has been indicated in several studies. Baten (2009), for example, finds that access to milk explains much of the regional variation in height in nineteenth-century France, Prussia and Bavaria. Steckel and Prince (Steckel and Prince 2001; Prince and Steckel 2003) show that the indigenous population in North America, living on the prairies hunting buffaloes, were among the tallest people in the world in the nineteenth century. Komlos (2003) comments on their findings and shows that tall stature was a common feature of populations with good access to foodstuffs, including meat and milk. These populations have historically also lived in less densely populated areas. This makes it harder to conclude that their taller stature was a result of better access to nutrients and not of the more favourable disease environment they lived in. Even if it is not possible to exclude an influence from disease, several results indicate that the taller stature of people in less densely populated areas is a result of their better access to foodstuffs (Sunder 2004).

The influence of diseases on growth is not uniform either, but can vary depending on the disease, its severity and duration as well as the living conditions of and care provided for the person who is ill (see Öberg 2014a, pp. 28-30 and references there). Disease affects growth in several ways. It can prevent or reduce food intake because of loss of appetite. Some diseases, especially gastrointestinal ones, can lead to direct losses, or to impaired absorption or transportation of energy and nutrients in the body. The body's reaction to disease, for example as a result of fever and other immune system responses, also requires extra energy. Most historical studies can only provide "strong circumstantial evidence" of the influence of disease on growth (Hatton and Martin 2010, 513). That even people from resource-rich backgrounds were short by modern standards is an indication that diseases were an important influence on growth historically.

Studies of present-day populations in low-income countries have shown convincingly that disease in childhood slows growth in children (Checkley et al. 2008). They have also shown that any infections, even subclinical ones, worsen nutritional status and slow down growth. Checkley and co-authors (2008) estimated that about 25% of stunting among children in low- and middle-income countries can be attributed to having experienced five or more episodes of diarrhea before the age of 2 years. Well-designed studies of the effects of improving water quality, sanitation and hygiene also show positive effects on child growth even over short follow-up periods (Dangour et al. 2013 [1996]). The influence of disease on growth depends on the nutrition, general living conditions and care provided to the person who is ill (Tanner 1990, chap. 9; Golden 1994; Boersma and Wit 1997; Scrimshaw 2003; Silventoinen 2003, 273-274). The influence of disease on growth is therefore weaker in high-income populations, but can still be shown (Dowd, Zajacova, and Aiello 2009).

Disease and living conditions in general, and nutrition in particular, influence not only growth and achieved height, but also health and longevity. Most of the association between nutrition and mortality today is most likely to be found among children in lower-income countries and is generated by the synergistic effects of nutritional status and disease (Black et al. 2008). The sensitivity to and severity of infections is influenced by nutrition (Chandra 1997; 2002; Scrimshaw 2003; Schaible and Kaufmann 2007) even if different diseases are affected differently by the nutritional status of the host (Rice et al. 2000; Chandra 2002; Scrimshaw 2003; Caulfield et al. 2004). This is an important reason why general living conditions influence the effect of exposure to disease on growth. There is no doubt that disease influences nutritional status, but the influence of disease on growth and achieved height comes from frequent, severe and prolonged diseases, especially gastrointestinal ones, and especially in combination with suboptimal nutrition.

Social bodies: Family and community level influences on height

I investigated the influences on height that could be affected by access to resources, i.e. nutrition, housing standard, hygiene, workload etc., by analysing social differences in height in my study population and how these changed over time. There were always socioeconomic differences in height in the studied population (Öberg 2014b; see also Åkerman, Högberg, and Danielsson 1988). The magnitudes of the differences varied over time, but they also show a tendency to become smaller (Figures 2a and 2b). Economic and social changes along with improvements in living conditions over time were important for reducing the socioeconomic differences in height. Improvements in living conditions over time also reduced differences in height depending on the number of siblings (Öberg 2015b). Men with many siblings present during childhood were shorter than others during the nineteenth century and early twentieth century, but not in the mid-twentieth century.

These results show that material resources and factors that could be changed by access to resources were important for growth and achieved height. Still, most of the secular trend in height was shared by all groups in the society studied (Öberg 2014b, fig. 4). All social groups were positively affected as the economy gradually grew, markets and infrastructure improved and society in general developed.

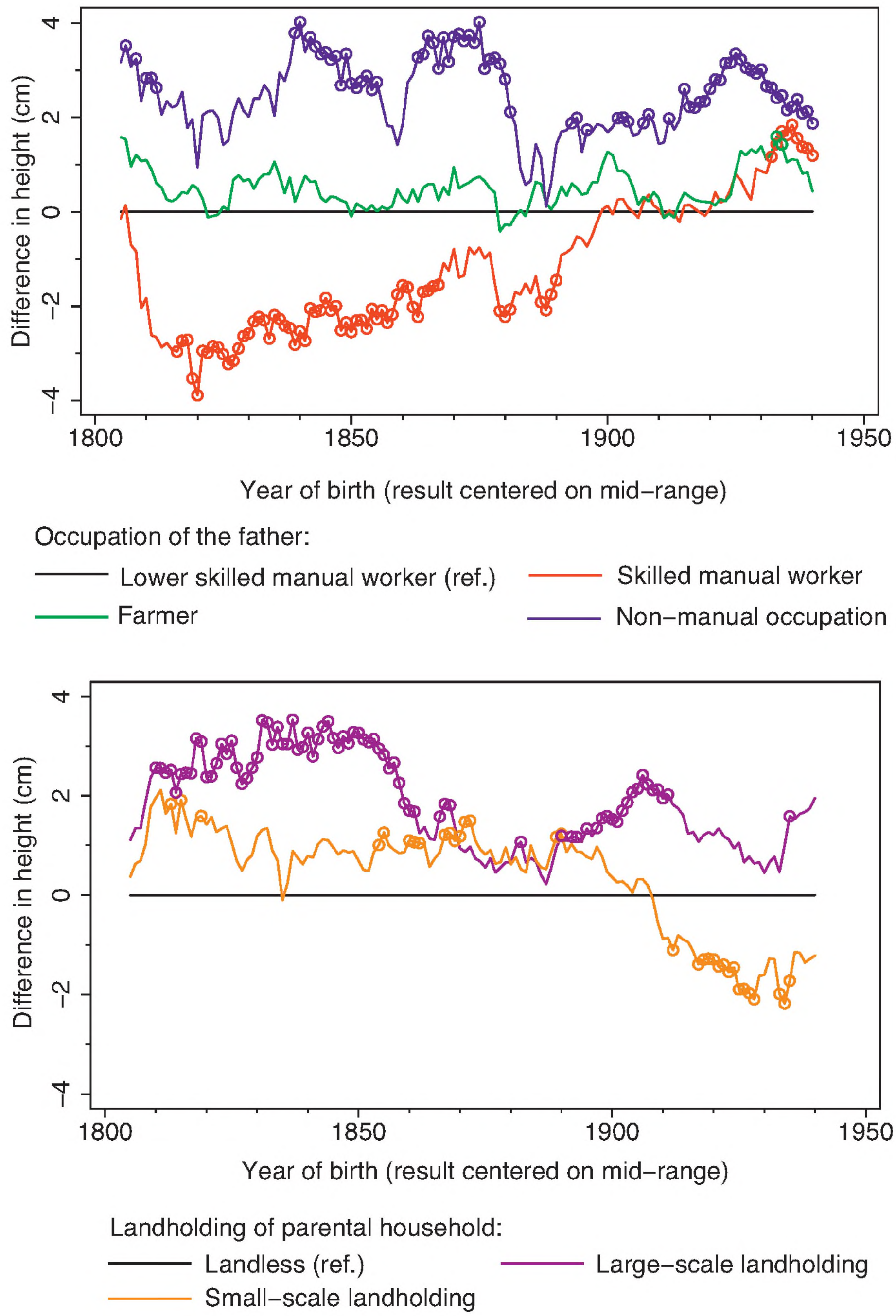
The secular increase in height has been gradual in all populations, with increases per decade of about 2 centimetres at most. The multitude of influences on growth and the long growth period will work to reduce the impact of any sudden changes. But it is also likely that the gradual increases in height reflect the fact that the improvements in living conditions over time have historically been gradual. Healthy growth also seems to require sufficiently good conditions across several different factors. It has been estimated that almost universal (90%) implementation of ten evidence-based interventions to improve nutrition in the worst-off countries would only reduce the prevalence of stunting among children by about 20% (and reduce child mortality by 15%) (Bhutta et al. 2013). That different conditions improve in parallel can also be seen in low- and middle-income countries today. The change between the year 2000 and 2010 in child mortality from diarrhea and pneumonia is very highly correlated across 74 countries (Walker et al. 2013, fig. 2) despite the fact that these diseases are caused by different pathogens and have different ways of transmission. That different influences work in interaction may also be a reason why average income is in many cases a good predictor of average height (e.g. Steckel 2008). Income can affect several different influences on growth, e.g. food availability and diet, but also disease exposure through housing and hygiene conditions.

Figure 2 Socioeconomic differences in height among young adult men in southern Sweden born between 1797 and 1950.

A. Differences in height related to the occupation of the father.

B. Differences in height related to the landholding of the parental household

Note: Estimates from a rolling regression, i.e. 135 separate regressions each including men born within a 20-year span. Circles on the lines indicate that this group was statistically significantly (90% CI) taller or shorter than the reference category. The results are centred on the year in the middle of the 20-year range used. Data from the Scanian Economic Demographic Database (Bengtsson, Dribe, and Svensson 2012; Öberg 2014a.



The influences on growth, height and weight in historical populations were most likely similar to those in present-day populations. The influences were multifaceted and complex, then as now. Different economic and social developments most likely improved the preconditions for healthy growth prenatally and during infancy, childhood and adolescence at different times and in different ways. The important influence from nutrition was not just a matter of the number of calories consumed; the quality of the food and the diet also played a role. The influence from disease came from common and frequent infections interacting with the nutrition. Other influences, for example housing conditions and behaviours, are also likely to have played a role in gradually allowing healthy growth and improving health.

The association between height and longevity

We can learn much about living conditions, nutrition and disease exposure in the past by studying the historical development of heights. But we need to acknowledge that growth is a complex and specific process and that adult height is the net outcome of a multitude of influences, including random genetic variation. The multitude of environmental influences on growth and achieved height, and the long period during which the body is sensitive to these influences, make achieved height a good summary measure of overall life experiences, but a poor proxy measure of separate influences. While the environmental influences on growth are consistent and theoretically and substantially important, the associations are all quite weak when measured empirically in individual-level data. The multitude of influential factors, the long growth period and genetic variation always work to reduce the associations between separate environmental exposures and achieved height. Height therefore cannot be used as a proxy measure of single or specific experiences, such as exposure to disease around birth (Öberg 2015a). For the same reasons it is a very poor measure of health status or human capital at the individual level.

Growth, height, health and longevity are all influenced by factors that come under the crude headings nutrition and disease (Figure 3). The factors and outcomes also interact and influence one another in different ways. Nutritional factors and exposure to disease contribute to the secular trends in both height and mortality. The two trends therefore most likely share some underlying causes. Still, I think that we also need to investigate the two trends separately. Nutrition is likely to have had a stronger influence on growth than on resistance to disease, which in turn affected mortality rates. Diseases have also had an important influence on growth and achieved height, but mortality has also been influenced by the exposure to and virulence of diseases that are likely to have left little mark on growth (e.g. Öberg 2015a).

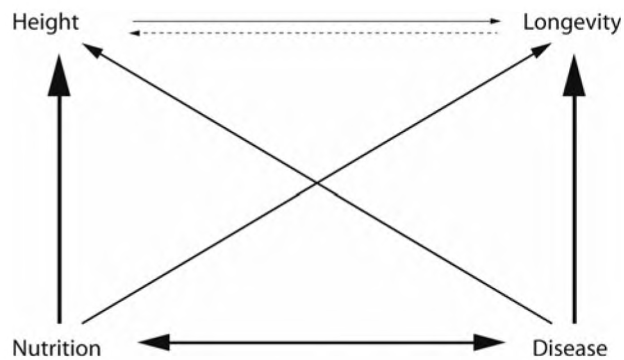


Figure 3 A simplified model of the associations between nutrition, disease, height and longevity.

Influences from nutrition and disease that are shared by height and longevity work as confounders to increase a positive association between the two. Height is indeed positively associated with longevity. The association is consistent and well established for both adults (Alter 2004; The Emerging Risk Factors Collaboration 2012) and children (Olofin et al. 2013). The association is theoretically very important and provides insights into influences on health and longevity (Floud et al. 2011). But the association is weak and height only explains a fraction of the variation in longevity at the individual level. The Emerging Risk Factors Collaboration (2012), for example, finds that an increase in height of one standard deviation is associated with a 3% reduction of all-cause mortality risk. Height also had a very low independent predictive power for individual mortality risk in The Emerging Risk Factors Collaboration data (personal correspondence with David Wormser, Senior Epidemiologist/Applied Statistician, Cardiovascular Epidemiology Unit, University of Cambridge, Oct. 29, 2013). Ganna and Ingelsson (2015) tested the (univariate) predictive ability of 655 measurements of demographic characteristics, health, and lifestyle for five-year all-cause and cause-specific mortality among the participants (aged 37-73 years) included in the UK Biobank. Height is not among the very few variables that have any useful predictive ability. Nor is it among the variables with the least predictive ability; it is typical of the majority of the tested variables in having very little predictive ability.

The association between height and longevity does not seem to be a result just of confounding (Özaltin 2012). That the association is weak therefore means that most of the influences from nutrition and disease on height and longevity not are shared, or that there are factors that affect height and longevity in opposite ways. There are some factors that seem to have clearly different or opposite influences on height and longevity. Acute epidemic infectious diseases have had a strong influence on mortality rates, but less effect on heights (Steckel and Prince 2001; Prince and Steckel 2003; Oxley 2006; Öberg 2015a). A larger exposure to disease early in life will result in shorter stature and worse overall health but can at the same time reduce the risk of dying from later exposure to pathogens. This is shown by the different death rates of soldiers in the US Civil War (Lee 2003; Smith 2003). Men born in the US, from rural areas, and especially farmers, were, for example, on average healthier and taller than foreign born men from urban areas (Haines et al. 2003). But the US born rural farmers had higher risk of dying from disease while serving in the Union Army. This increased risk of dying from disease was a result of an increased risk of acquiring diseases. The case fatality rates were independent of the previous exposure. Alter and Oris (2005) find similar results for rural-to-urban migrants in nineteenth century Belgium where the migrants with a rural background were especially vulnerable during epidemics.

Protein, especially cow's milk, increases growth (Silventoinen 2003, 273-274; Hoppe, Mølgaard, and Michaelsen 2006; Baten 2009; Hörnell et al. 2013), but animal proteins, and again especially cow's milk, do not seem to have any corresponding positive influence on health and may rather be harmful (Katz and Meller 2014; Michaelsson et al. 2014).

The model presented in Figure 3 is clearly highly simplified. But this model shows us that it is very difficult, perhaps impossible, to accurately estimate the effect on and relative importance of nutrition and disease for height and longevity using crude summaries like this. Historical research therefore also has to move beyond the averages and crude trends with regard to the development of both influences and outcomes. Increases in the quantity of food consumed have probably contributed to rising average heights and to the reduction of mortality rates, but the quality of the diet could have contributed just as much. Rising dietary diversity and refinement, and the share of animal products in the diet could for example have contributed to improvements in nutritional status both through more adequate provision of nutrients and by making them more easily accessible to the body. Reduced deficiencies of micronutrients could very well have contributed to both the secular trends in height and to declining mortality.

Because mortality and height are influenced by different factors they are not interchangeable measures of human health or living conditions. We should therefore not expect always to find the same results when we analyse the two different outcomes. The results in my dissertation from analysing height are, for example, quite different from what has been found by analysing mortality in the same population. Socioeconomic differences in adult mortality emerged only at the time when the socioeconomic differences in height declined substantially (Bengtsson and Dribe 2011; Öberg 2014b). Nor did socioeconomic differences in infant and child mortality change in parallel with the corresponding socioeconomic differences in height (Bengtsson and Dribe 2010; Öberg 2014b). Sibship size was negatively associated with height but the share of children in the household had no strong influence on the mortality risk of children in the mid-nineteenth century (Bengtsson 2009 [2004]; Öberg 2015b). Infant mortality in the year of birth had no direct influence on achieved height, but has been shown to influence mortality in later life as well as, for example, the fertility outcomes of women (Bengtsson and Lindström 2000; Bengtsson and Broström 2009; Quaranta 2013; Öberg 2015a).

Systematic variations in height show how the human body is literally shaped by its living conditions. We need to learn much more about this, and studying historical differences and trends in height can contribute to this. Acknowledging the complexities and specificities of how nutrition and disease affect growth and height, and health and longevity, will help us learn.

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