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Height and health – in the Danish case

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Abstract

This paper reviews (mostly) Danish data with bearing on stature differences within a population both in a synchronic and in a diachronic context. In studies of individual life history, it is shown from data on medieval skeletons that stress in childhood affect body proportions differently in women and men. In women, stature and body proportions were independent on indices of childhood stress where as in men, childhood stress distorted body proportions but did not affect adult stature. Relationship between (nearly) adult female stature and parental stature in late 20th century Great Britain indicates a maternal effect that could epigenetically played a role in shaping the pace of stature increase during the rapid secular trend through the last 150 years. In community level studies it is shown that contemporary Danish children at all ages are taller than medieval Danes were, and that the poorest medieval community was subject to selective mortality for height possibly causing the surviving members of this community to be more than 5 cm taller than members of other communities from the same period. Further it is shown that Gross Domestic Production (GDP) did not explain any of the secular increase in Danish stature during the 20th century. However, GDP did affect the variance for stature, indicating that parts of the variation for income did play a part in formation of adult stature in subgroups of society.

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Introduction

Ever since Quetelet (1835) published his extensive observations on the variation of human height there has been an intense interest in data on and correlates of (male) stature. The principal finding of this early study has been reiterated extensively in recent studies (Eveleth and Tanner, 1976; Steckel, 1995; Bogin, 2001; Steckel and Rose, 2002; Varela-Silva, 2012; and Boix and Rosebluth, 2014). Many of these studies demonstrate beyond doubt that stature both during growth and as adults shows high correlation with in order social, economic and nutritional indicators. In spite of the fact that only few studies (e.g. Bogin 2001 and Varela-Silva, 2012) actually has demonstrated the effect of specific environmental factors on human growth both on the individual and group level, it is nearly universally assumed that mean stature and to a certain extend variance for stature can be used as indicators of socio-economic conditions and well-being.

Danish researchers were relatively quick to pick up on Quetelet's (1835) early study (Thune, 1848; Trier, 1855; Det Statistiske Bureau, 1859, Gad, 1890; and Hansen, 1893). In the more recent past, Boldsen and colleagues have reanalyzed some of these 19th century data (Boldsen, 1995, Boldsen and Kronborg, 1984, Boldsen and Søgaard, 1998). These studies have been extended to include both older data (Boldsen, 1990a, 1997, 1998) and more modern data (Hasle and Boldsen, 1990, Boldsen and Søgaard, 1998).

Konigsberg et al. (1998) have pointed out some of the difficulties in comparing height estimated from skeletal remains. In order to overcome the problem, regression formulae for stature estimation must be population specific. Based on a combination of archaeological and anatomic work, Boldsen (1984) developed a method for measuring living stature on the skeleton during the excavation before it was removed from the ground. These data were used to develop a regression formula, which he hoped could be used for medieval Danes. However, later research has shown that samples from sites in use during the same centuries and situated less than 50 km apart gave statistically different regression formulae (Boldsen, 1990b). This finding must lead to the conclusion that in comparison between ancient skeletal heights with modern measured heights, the only unbiased ancient data come from stature measured in the grave before removing the skeleton.

Following Fisher (1918) the general understanding is that the variation of stature is primarily/nearly exclusively determined by genetic factors. Although this might be the case in a specific population in a specific time horizon, it cannot be the case over time when, as in many countries, mean stature has increased more two standard deviations in less than two centuries. Accepting that such changes can only be brought about by environmental factors, this paper takes a critical look at the assumptions about a causal relationship between stature and specific environmental factors like income, nutrition and disease based on diverse sets of data primarily from Denmark.

Individual level studies

In a paper primarily aimed at developing a regression formula for estimating stature from femoral length for the medieval Tirup population, Boldsen (1990b) analyzed the distribution of the regression residual and found that it was not normally distributed. In fact it was found that the residual for males had a bimodal distribution. The same and more data from Tirup were subsequently analyzed (Boldsen, 1998) to show that the bimodality of the residual distribution in males was associated with linear dental enamel hypoplasia (LEH). LEH is generated when in childhood calcification of the enamel is disturbed due to the disease, hunger or perhaps even psycho-social stress (Gamble, 2014). In such episodes of ill health the bioavailability of calcium and/or phosphorus is decreased, but tooth growth continues as it is genetically determined. Thus, LEH is often taken as a non-specific indicator of childhood stress.

Figure 1 illustrates the simultaneous distribution of femoral length and stature measured in the grave for females from Tirup. As expected, there is clear association between femoral length and stature for these women. It is also clear that neither femoral length nor stature is associated with LEH. The relevant statistics are summarized in Table 1.

Figure 2 illustrates the simultaneous distribution of femoral length and stature measured in the grave for males from Tirup. Again as expected, there is clear association between femoral length and stature for these men; the association is even stronger than it is for women. But here LEH is much more common in men who were tall relative to their leg length. The relevant statistics are summarized in Table 1.

There are three important messages to infer from the analysis of the Tirup stature, femoral length and LEH data. The first one is that disease or other kinds of important biological stress in childhood has no effect on adult stature in either sex. The second is that the events leading to LEH affect females and males differently. And the third is that boys when recovering from their stress episode undergo disproportional catch-up-growth viz. they catch relatively more up in their upper body than in their legs.

There are also individual level modern data of relevance for the understanding the dynamics of human growth; but these data are not Danish. They come from the British National Child Development Study (NCDS), which is a very large and rich set of data that has been and continuing can be analyzed in many ways. Figure 3 illustrates the effect of differences in parental height on the stature of their daughters at age 16. It is obvious that women who are very tall relative to their husbands become mothers to taller

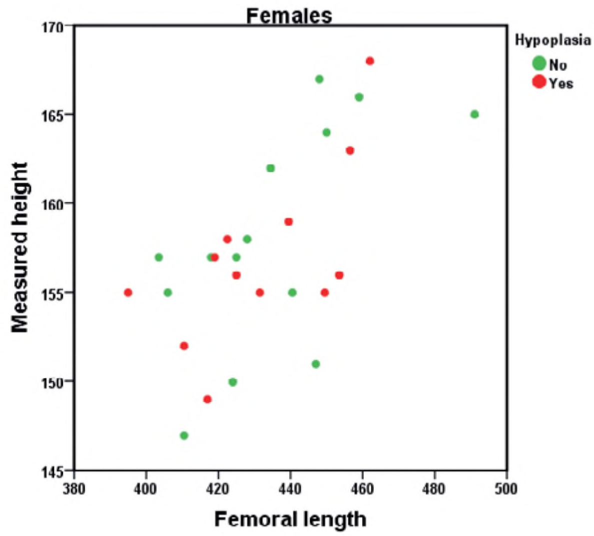

Figure 1: Simultaneous distribution of femoral length and stature measured in the grave for females from Tirup. Green circles women with no LEH on the upper canines, red circles women with LEH on the upper canines (data: Boldsen, 1998).

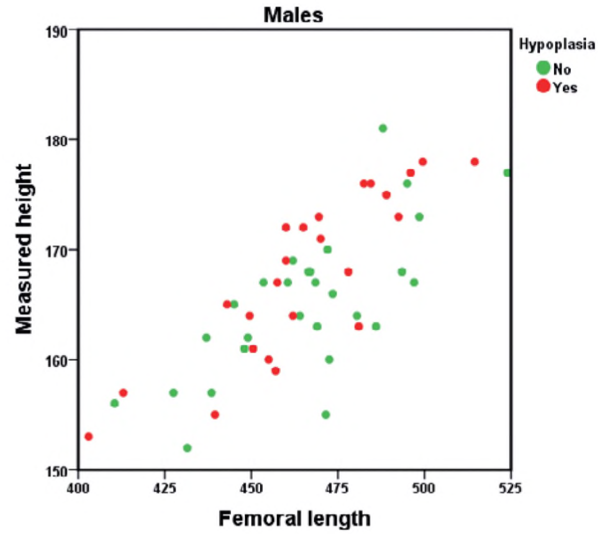

Figure 2: Simultaneous distribution of femoral length and stature measured in the grave for males from Tirup. Green circles men with no LEH on the upper canines, red circles men with LEH on the upper canines (data: Boldsen, 1998).

Table 1: Coefficients and tests for the regression of stature on femoral length (cm stature per mm femoral length) and LEH (cm for positive for LEH)

	Females		Males	
Number of cases	26		52	
	estimate	t-test	estimate	t-test
Femoral length	0.161	3.96^{**}	0.222	9.13^{***}
LEH	-0.553	-0.32^{NS}	2.699	2.21^{*}

daughters than women who are very short relative to their husbands. In the middle of Figure 3 it appears that fathers' relative height is more related to the daughters' height. This is expected as fathers share slightly more genes with their daughters than mothers do. This means that the maternal effect on 16years old girls' stature is an epigenetic effect that could be part of the explanation, why mean stature in Denmark has not increased at a constant rate over the form the onset of the rapid increase around 1900 to the end of it around 1980 (see figure 4).

Group level studies

Due to prehistoric data on height are cross sectional in their nature, it is impossible to follow longitudinal growth in the past. Therefore, the growth curves in Figure 5 are based on cross sectional data. The medieval growth curves were based on measurements of length in the grave to avoid the bias introduced from reconstruction of stature from long bone measurements. They show that modern Danes are taller at all ages (except at birth) than medieval children and adolescents. This is not all that surprising as mean adult

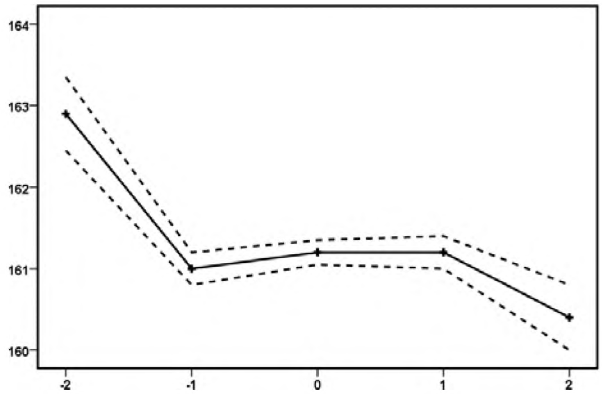

Figure 3: the effect of the normalized parental height difference on the mean stature of 16years old girls from the National Child Development Study. Relatively tall mothers are to the left (with negative parental hight difference scores) and relatively short mothers are to the right, with positive scores. The dotted lines indicate the 95% confidence limits for the estimates. (Data: Boldsen and Mascie-Taylor, 1990).

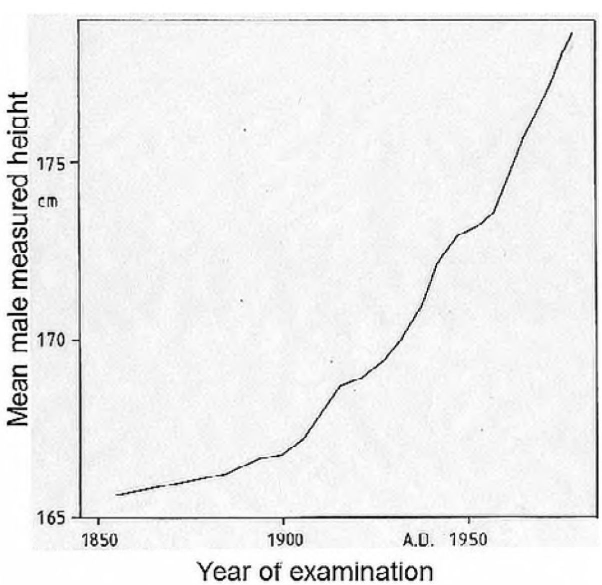

Figure 4: Five year average of male stature by year of examination prior to conscription. There are episodes of relatively slow increase of mean stature in the 1890s, 1920s, and 1950s. These episodes all come just after an episode of relatively rapid increase in mean stature. It is noteworthy that these oscilations has a wavelength more or less corresponding to the time between successive generations.

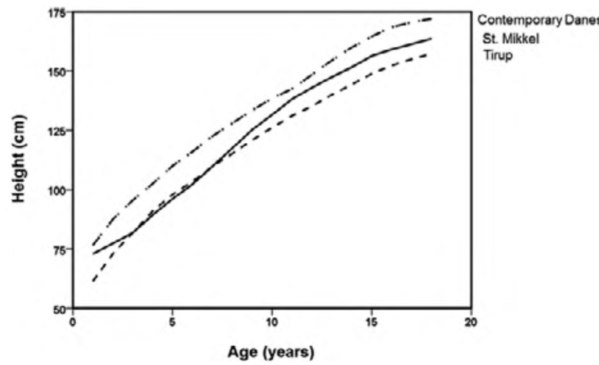

Figure 5: Stature by age for children and adolescents from contemporary Denmark, the lower class St. Mikkel community in medieval Viborg and the Eastern Jutland village community Tirup (Data: Boldsen and Søgaard, 1998).

stature in the medieval period was 7-15 cm less than it is today (Boldsen and Søgaard, 1998). However, it is surprising that it appears that babies in the socially challenged St. Mikkel community (Petersen, et al., 2004) were born more or less the same size as are modern Danes, whereas the socially less challenged rural peasant babies were born significantly smaller and remained short throughout life compared to modern Danes. The growth curve that really stands out is the one for the poor people of St. Mikkel. It is strange their infants are born bigger than infants from the better off Tirup community. It is clear that there must have been selective mortality for size in the St. Mikkel community particularly in ages 2 - 6 years when catch-up-growth seems to have set surviving children back on a growth trajectory more or less parallel to the two others and halfway between them. Following the argument Wood et al. (1992) the greater adult stature in the St. Mikkel community compared to the Tirup community could be an effect of more children between ages 2 and 6 died prematurely compared to their peers; but given the large size of the St. Mikkel infanta it is possible that this population was simply larger from some unknown, perhaps genetic reason.

Modern stature data are much more abundant that ancient data; but in some aspects they are not as

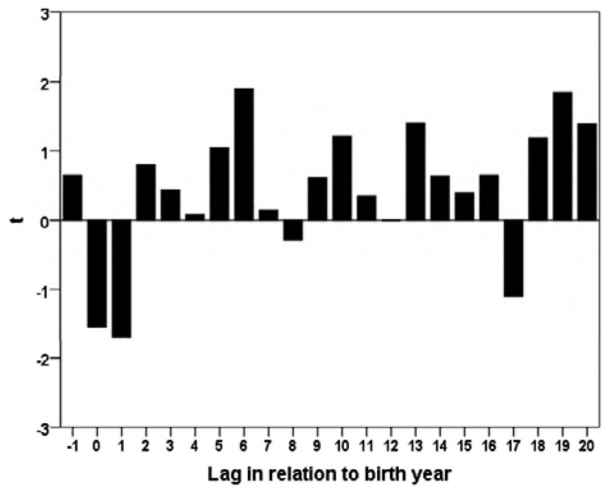

Figure 6: Tests for short term associations between mean stature in birth cohorts and GDP at different lags. The test value (t) follows a t-distribution and none of the tests reach the level of significance (over 2 or under -2).

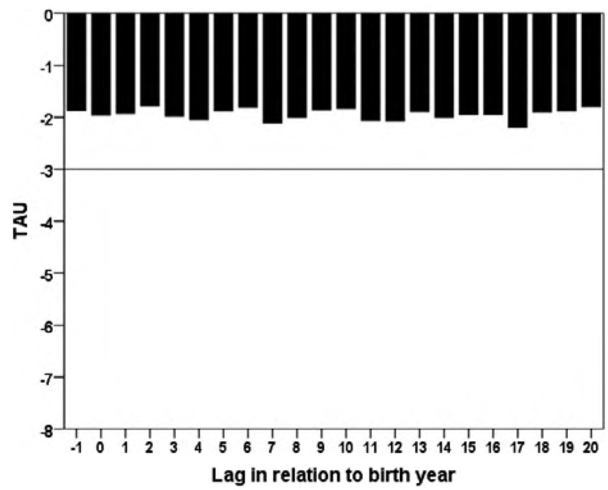

Figure 7: Tests for long term associations between mean stature in birth cohorts and GDP at different lags. The test value (TAU) has a critical value at -3 (See Boldsen and Søgaard, 1998 for details). None of the tests are statistically significant.

rich as the older individual skeletal observations. However, what the modern collective data lack in individual richness they compensate by abundancy and precision of dating. Boldsen and Søgaard (1998) utilized the large sample size and reliable temporal data to carry out a study of co-integration of economic (gross domestic product deflated to 1980 prices per capita – GDP) and stature time series. The stature data, from measurements prior to conscription, used in these analyses were rearranged so they were ordered by year of birth rather than by year of examination. During the period (1915 – 1964) covered by these analyses age at the examination decreased from 20 to 18 years reflecting the secular trend towards earlier maturation during the 20th century. In the middle of the 19th century age of examination was actually as high as 22 years and even at that age, final adult stature was not been reached (Det Statistiske Bureau, 1859).

Even though the distribution of stature in large national samples is not perfectly normally distributed (see e.g. Boldsen and Kronborg, 1984) summary statistics (mean and variance) have been analyzed as if they came from normal distributions. The large number of observations (totally more than two million) compensates for the deviation from normality of the distributions.

'Time confounding' is one of the most important factors confusing the debate about the importance of specific environmental factors on parameters of stature distribution. Time confounding is a consequence of the fact that two time series undergo more or less linear development through a historical period necessarily must be highly correlated. One very funny example of such spurious, time confounded, correlations can be found on http://www.tylervigen.com/. Among several other weird associations it is reported that the correlation between Divorce rate in the state of Maine and per capita consumption of margarine in the United States is 0.993 in the period 2000 to 2009. However, if time series are causally related the association must also be significant if the time series are detrended by looking at the difference from year to year rather than at the raw data.

Figures 6 and 7 illustrate tests for possibly causal association between GDP and mean stature in birth cohorts in Denmark from 1915 to 1964. The result of these tests is very clear. No causal association between GDP and mean stature is indicated for this period

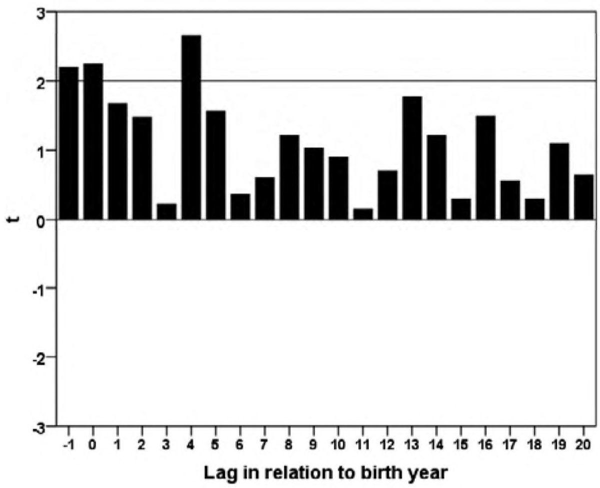

Figure 8: Tests for short term associations between variance stature in birth cohorts and GDP at different lags. The test value (t) follows a t-distribution and the tests reach the level of significance (2 or -2) of the year before birth (the year of pregnancy, the year of birth and the year of age 4).

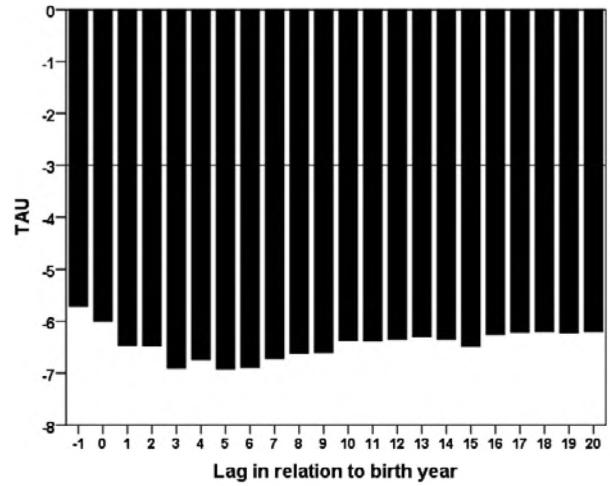

Figure 9: Tests for long term associations between variance for stature in birth cohorts and GDP at different lags. The test value (TAU) has a critical value at -3 (See Boldsen and Søgaard, 1998 for details). All of the tests are statistically significant. This means that economic growth in the long run does affect the variance for stature.

that saw the most rapid increase of mean stature in Danish history (cf. Figure 4).

Likewise, Figures 8 and 9 illustrate tests for possibly causal association between GDP and variance for stature in birth cohorts in Denmark from 1915 to 1964. These figures clearly demonstrates the fact that whereas mean stature is unaffected by changing developments in GDP the variance for stature is clearly dependent on it. In periods with growth in GDP the variance for stature also increases. If, as usually has been the case, that social inequality has grown in periods with rapid economic development, then this can be seen as a direct effect of social inequality on stature.

Conclusions

Several conclusions can be formulated based on the analyses and data presented above:

1. We can be certain that it is environmental changes that brought about the two standard deviations increase in mean male stature in Denmark during the last 5 - 6 generations; but we cannot know which environmental factors have been important for this change and which have not. General income increase definitely does not explain it.
2. Most of the associations between indicators of well-being and stature that are so convincingly presented in the literature are due to confounding with time and/or general social status.
3. Stature is not nearly as genetically determined as is usually assumed. Fisher's (1918) result is partly due to the fact that the data were collected as the population was undergoing a secular increase of mean stature.
4. The environment acts differently on different segments of humanity (females and males), and it seems that it only is part of an environmental spectrum of variation that affects stature.

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