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Growth variation, final height and secular trend. Proceedings of the 17th Aschauer Soiree, 7th November 2009☆

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ABSTRACT

Growth and body height have always been topics interesting to the public. In particular, the stupendous increase of some 15–19 cm in final adult height during the last 150 years in most European countries (the "secular trend"), the concomitant changes in body and head proportions, the tendency towards early onset of sexual maturation, the changes in the age when final height is being reached, and the very recent trend in body mass index, have

☆ Since 1990 we have regularly arranged the Aschauer Soirees. These small, but international annual meetings are held in the private atmosphere of our house at Aschauhof where we find ample time for informally discussing various current topics in child development, growth and nutrition.

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generated much scientific literature. The marked plasticity of growth in height and weight over time causes problems. Child growth references differ between nations, they tend to quickly become out of date, and raise a number of questions regarding fitting methods, effects caused by selective drop-out, etc. New findings contradict common beliefs about the primary importance of nutritional and health related factors for secular changes in growth. There appears to be a broad age span from mid-childhood to early adolescence that is characterised by a peculiar insusceptibility. Environmental factors that are known to influence growth during this age span appear to have only little or no impact on final height. Major re-arrangements in height occur at an age when puberty has almost been completed and final height has almost been reached, implying that factors, which drive the secular trend in height, are limited to early childhood and late adolescence.

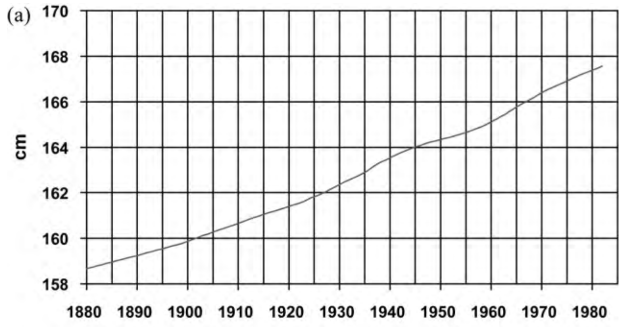
Position statement

The so-called secular trend in human growth is not a consistent and homogeneous event uniformly occurring in height, weight, body shape, various circumferences, and other anthropometric characters. The trend has exhibited distinctly dissimilar dynamics in the various traits, during the economic transition of the past 150 years. While the trend in height has come to a halt within most Western countries, differential trends are observed in weight and in various circumferences. The authors provide new evidence suggesting that not only the traits, but also the age groups differ in susceptibility, with infancy and early childhood, and late adolescence being most vulnerable to those socio-economic and environmental factors that drive the secular trend.

Presentations

The symposium started with a short overview of recent directions of the secular trend in height, by *Elena Godina* (2009). The secular trend occurs early in life and becomes greater during puberty. Children on average have increased in height by about 1–2 cm per decade at age 5–7 years, and by 2–3 cm per decade at age 10–14 years. Adults have shown a 1 cm increase in height per decade. Apart from increases in body height, the trend includes changes in body and head proportions, a tendency towards early onset of sexual maturation, and changes in the age when final height is being reached. Whereas secular increases in stature have slowed down or completely stopped, there is an ongoing increase in body fatness in many European countries. However, recent evidence has been presented for an inverse trend in young women towards an increase in slenderness in various parts of Eastern Europe. Whereas body height increased in 15-year-old Moscow women, a decrease in weight by 2 kg, a decrease in chest circumference by 3 cm since 1975, and a decrease in pelvic breadth were noted. In young Saratov women BMI decreased from 21 to 20 kg/m^2.

Frank Rühli presented collaborative work (K. Staub and C. Pfister, Institute of History University of Bern; U. Woitek, Institute for Empirical Research in Economics; University of Zurich) on 19-year-old Swiss male conscript data (*N* = ca. 23,000, Staub et al., 2010) from various cantons from 1875 to 1879 until 2005 to 2006. Mean BMI of 19-year-old men in Switzerland increased between the 1870s and the 1930s by 0.80 kg/m^2 and between the 1930s and 2005 by 1.45 kg/m^2. The modern BMI sample is much more right-skewed and its variability is generally larger. The obesity prevalence (according to WHO classification) has increased by a factor of more than 100 since the late 19th century. The trend towards increase in weight rather than height continues even in the most recent decade. Currently, more than 20% of 19-year-old Swiss men have a BMI above 25 kg/m^2. Unskilled workers are much heavier than university students, in contrast to the 19th century, when the prevalence of overweight was the reverse.



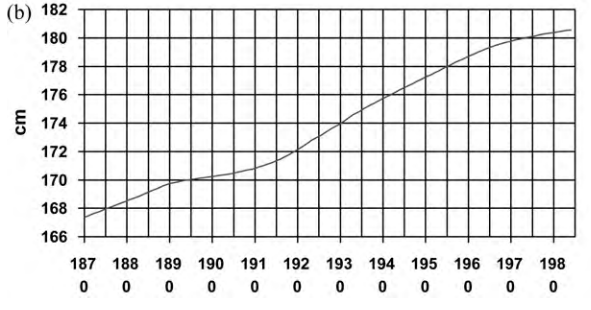


Fig. 1. (a) Height of Czech mothers born between 1880 and 1984. Height of mothers increased from 158.7 to 167.6 cm. (b) Height of Czech fathers born between 1870 and 1984. Height of fathers increased from 167.4 to 180.6 cm.

Pavel Blaha evaluated parental data (324,155 fathers and 334,043 mothers) obtained from the Nationwide Anthropological Surveys of Children and Adolescents, and discussed trends in height of the Czech population during the last century (fathers born between 1870 and 1984, mothers born between 1880 and 1984). Height of fathers increased from 167.4 to 180.6 cm, height of mothers increased from 158.7 to 167.6 cm (Fig. 1a and b). Depending on physical stress endured, body height differed by some 2 cm in fathers, and by 1.7 cm in mothers in 1951. The differences in body height between fathers and mothers changed. Between 1880 and 1960, the differences increased up to 13.7 cm, and thereafter dropped to 12.8 cm in 1984. Since 1951 the frequency of obese fathers has increased, whereas the frequency of obese mothers has declined. In the surveys of 1981 and 2001 the prevalence of obesity increased with age.

Jesper L. Boldsen concentrated on formulating relevant research hypotheses and the feasibility of establishing truly longitudinal studies of growth, health and mortality in past populations. The vast majority of the skeleton undergoes constant remodelling through the action of osteoclasts and osteoblasts. This remodelling takes place at different speeds in different parts of the skeleton. As a rule of thumb trabecular bone tissue remodels at a quicker pace than compact bone tissue. In mature individuals it can be assumed that trabecular bone chemically reflects the individual some 5 years prior to death, whereas compact bone tissue is generally 10 years old at death. However, certain parts of the human hard tissues are chemically and morphologically fixed in various periods of childhood and adolescence.

The trace element profile in a given bone or tooth sample carries a signature of the food and environmental exposure of the individual at the age when it was formed and fixed. Permanent teeth mineralize from just before birth (the tip of the crown of central incisors and first molars) to adulthood (the root tip of the third molar). Pars petrosa of the temporal bone (the bone surrounding the inner ear) is the only bone that does not remodel after it is formed at the age of 2 years. These facts facilitate the writing of an individual chemical life history of a human being who lived many hundreds of years ago. The research potential is tremendous—not only for historical studies of health but also for finding

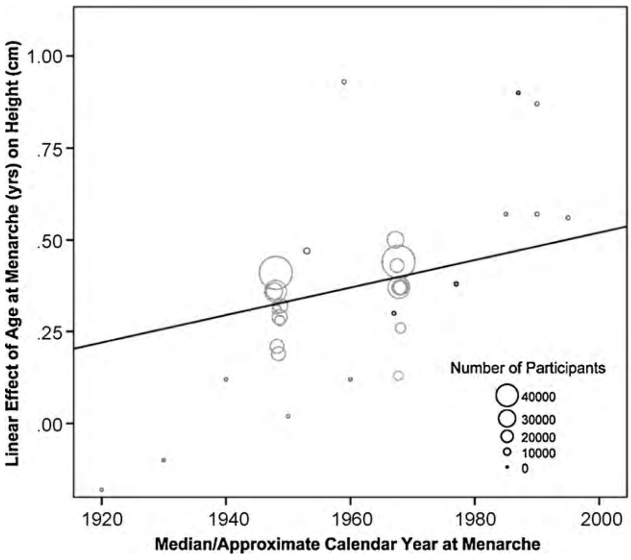


Fig. 2. Linear slope of age at menarche on final height by median calendar year of menarche of study participants.

causal associations. The discovery of this research possibility is relatively new so no published results have yet been produced, but the research catalogue is already long: the age of weaning in children who survived to adulthood, the effect of age of weaning on adult immunocompetence (as measured by expression of leprosy), childhood nutrition and adult stature, medieval nutrition history, etc.

Stef van Buuren analysed why WHO child growth standards of weight for age differed from all national curves, and discussed the effects of fitting methods and selective drop-out. Children of the WHO group are significantly heavier during the months 1–6, the gap widens between months 1 and 3 and closes between months 3 and 6. Thereafter the WHO group is lighter. Whereas curve fitting methods did not cause these differences, selective drop-out proved to be a major source of error.

The WHO sample is highly selected for factors likely to promote growth in breastfed infants and less than 10% of those initially surveyed were included in the final study (Binns and Lee, 2006). Since most mothers and professionals are concerned about the growth of their infants particularly for the first 6 months, they are likely to introduce supplementary foods and discontinue breastfeeding early on the basis of perceived slower growth.

With the example of the Dutch SMOCC study, consisting of 2151 infants born between 1989 and 1990, longitudinally investigated at 0, 1, 2, 3, 6, 9, and 12 months of age, van Buuren showed that up to month 1 exclusively breastfed (EBF) infants are heavier at birth than non-EBF infants. Apparent higher than average growth of EBF infants during the months 1–2 is primarily attributable to selective drop-out. Between months 2 and 6, light non-EBF infants gain more weight than light EBF infants. Selective drop-out continues to operate even thereafter. Thus, the decision to remove EBF strongly depends on infant weight, and may explain why the WHO references show a significant upwards bias especially during the first 3 months. This is a serious issue as the new WHO charts have the potential to undermine breastfeeding during the first 6 months (van Buuren, 2010).

Matthew McIntyre reviewed current evidence that the association between age at pubertal onset and final height has reversed historically from negative to positive (do Lago et al., 2007; Onland-Moret et al., 2005). This finding is interpreted as resulting from the approach towards maximum childhood growth rates in all social classes which eliminates the spurious negative association between age at pubertal onset and final height (via the common cause of prepubertal growth). Remaining variation in final height is more strongly influenced by age at puberty, variation in which is now determined by genetic and early developmental factors and intergenerational factors (Fig. 2).

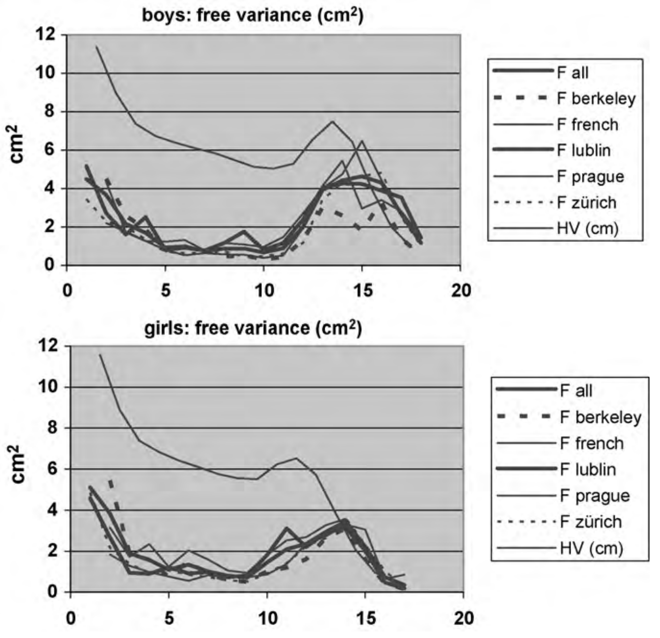


Fig. 3. Changes of "free variance" over the age range. The changes mirror the changes in susceptibility to nutritional, health related, socio-economic and political circumstances that influence growth between birth and maturity. Significant peaks in susceptibility occur early in life and late in adolescence at the age of 16 years in boys, and at the age of 14 years in girls, i.e. some 2 years after the peak height velocity (HV).

Michael Hermanussen and *Christian Aßmann* re-investigated 5 large national longitudinal growth studies consisting of a historically mixed sample of a total of 735 children and adolescents (350 boys, 385 girls) from Berkeley, Prague, Zurich, Paris and Lublin. The participants were born between 1928 and 1965, were measured at regular annual intervals between the age of 1 and 18 years (boys) and 1 and 17 years (girls), and were brought up under very different historical, socio-economic and political circumstances. The authors assume that the heterogeneity of the environmental circumstances under which these children grew up, should be mirrored in their growth.

All height measurements have been transformed into height SD scores (hSDS) and then changes in hSDS were investigated. The correlation of hSDS at each age with final hSDS was analysed, we then correlated hSDS between subsequent years and determined R^2 and $1-R^2$, and thereafter converted $1-R^2$ into cm^2. $1-R^2$ was called "free variance". High $1-R^2$ indicates vivid hSDS change; low $1-R^2$ indicates stable tracking in hSDS. The changes of $1-R^2$ over the age range mirror the changes in susceptibility to nutritional, health related, socio-economic and political circumstances that had influenced growth between birth and maturity.

Fig. 3 illustrates the changes of "free variance" over the age range. Significant peaks in susceptibility occurred early in life and late in adolescence at the age of 16 years in boys, and at an age of 14 years in the girls, i.e. some 2 years after peak height velocity. The pattern appears similar in both sexes and in all five growth studies.

Quite in contrast to common beliefs, there appears to be a broad intermittent age span of insusceptibility to environmental influences on growth. Influences on growth during this age span appear to have little or no impact on final height. The fact that major re-arrangements in height position occur at an age when puberty has almost finished and final height has been almost reached, implies that factors which drive the secular trend in height are limited to early childhood and late adolescence.

Arnab Ghosh provided an overview on growth and development in children and adolescents of Asian Indian origin from West Bengal, India. Malnutrition is more common in India than in Sub-Saharan Africa using WHO cut-offs. One child in every three malnourished in the world lives in India.

Close to 50% of deaths at under 5 years of age occur during the first months of life. The majority of these children die at home although they have contacted health personnel at least once. But even though the majority of the children still remain undernourished, modern Indian prosperity creates a paradox. The recent economic transition with increasing wealth has resulted in an increase in overweight and obesity, hypertension, diabetes and cardiovascular disease.

Gian Franco de Stefano described growth in a sample of 3547 individuals (1781 males and 1766 females, aged 1–18 years) of a population of African ancestry settled in Esmeraldas, the main urban area of North Western Ecuador. Percentile lines were estimated using a combination of modelling Preece–Baines model 1 (PB1) to the mean values and LMS to estimate the percentile distribution. The goodness of fit was estimated by comparing the number of measurements between the percentile bands with the expected number of observations, and appeared satisfactory. The curves were then compared with the 2000 international reference standard proposed by the NCHS (Kuczmarsky et al., 2000). The fitted PB1 model estimated the age at maximum height increment in males at 13.29 years and in females at 10.95 years.

Valentin D. Sonkin presented data on the nutritional status of Russian school children based on questionnaires of 70,000 pupils of the first and second and the tenth and eleventh forms of 56 regions of the Russian Federation (Bezroukich et al., 2004). Nearly 20% of Russian school children were not adequately nourished while nearly 2.5% had insufficient rations. Food quality partially depended on family economics, but most children and their parents did not know how to organize a regular nutritional regimen. School nourishment was often poor in quality and organization. Meat or fish, and potatoes were consumed daily by 50–60%, milk, cheese and eggs by 70–80% of children of all ages. Bread and wheat products were daily consumed by about 40% of the children, whereas 30% of the 1st form pupils, but less than 10% of the 10th form pupils consumed fruit or fruit juice on a daily basis. About 30% of the 1st and the 10th form pupils had three meals per day, 30% of the 1st, but only 10% of the 10th form pupils had more than three meals. About 50% of the 10th form pupils had meals at irregular intervals. Almost 40% of this age group had no lunch. The effects of malnutrition were usually evident in physical performance, rate of sickness and the number of accidents. It was amazing to find that in contrast to common expectations (Godina and Miklashevskaya, 1989; Lisovskii et al., 2002), the quality of nutrition appeared to have no impact on body height and weight.

Jesus A.F. Tresguerres presented new data on the anti-inflammatory action of growth hormone (GH) and melatonin on the cardiovascular system. Many age-related alterations of the cardiovascular system are due to oxidative stress or inflammation. GH, melatonin and sex hormones are reduced with age. Replacement therapy with growth hormone or melatonin is able to, at least partially, revert oxidative stress and inflammation thus, reducing the age-related alterations. The author discussed the role of growth factor withdrawal during the process of natural ageing on apoptotic pathways with particular emphasis on the mitochondrial and cytosol cytochrome c fraction, on immunoreactive TNF, IL-6, iNOS, BAX, Bcl2, NFkB2, and their importance in the pathway of melatonin action.

Christof Meigen provided evidence in 471,477 single height measurements of children and adolescents aged 0–18 years, that the Zodiac sign (month of birth) associates with body height. Due to legal cut-off ages, children born in May enter school at an age of 6 years, whereas children born in July enter school 1 year later. Thus, the Zodiac sign influences a child's age among his/her classmates. Fig. 4 illustrates that the month of birth effect rapidly increases at the age of 6 years in both sexes, tends to decline during prepuberty, and reaches a new maximum late in adolescence explaining some 0.1% of height variation. Due to large sample size, the effect of the Zodiac sign on height appears significant in late adolescence. Yet, its clinical relevance needs to be elucidated.

Christiane Scheffler presented new 2009 data on body composition of 6–12-year-old children (680 boys, and 592 girls) from Brandenburg (Germany), and compared them with a 1999 sample from the same geographic regions consisting of 1398 boys and 1462 girls, aged 6–12 years (Schilitz and Greil, 2000; Greil and Schilitz, 2000). Between 1999 and 2009, weight and BMI, and the percentage of body fat had increased. Today's children are smaller, and their skeletal robusticity had significantly decreased. Currently it remains to be elucidated whether this novel trend is caused by decelerating rate of economic development, or whether there is a truly new negative trend in height in modern 6–12-year-old children. This trend may be caused by a decrease in physical activity (Scheffler et al., 2007).

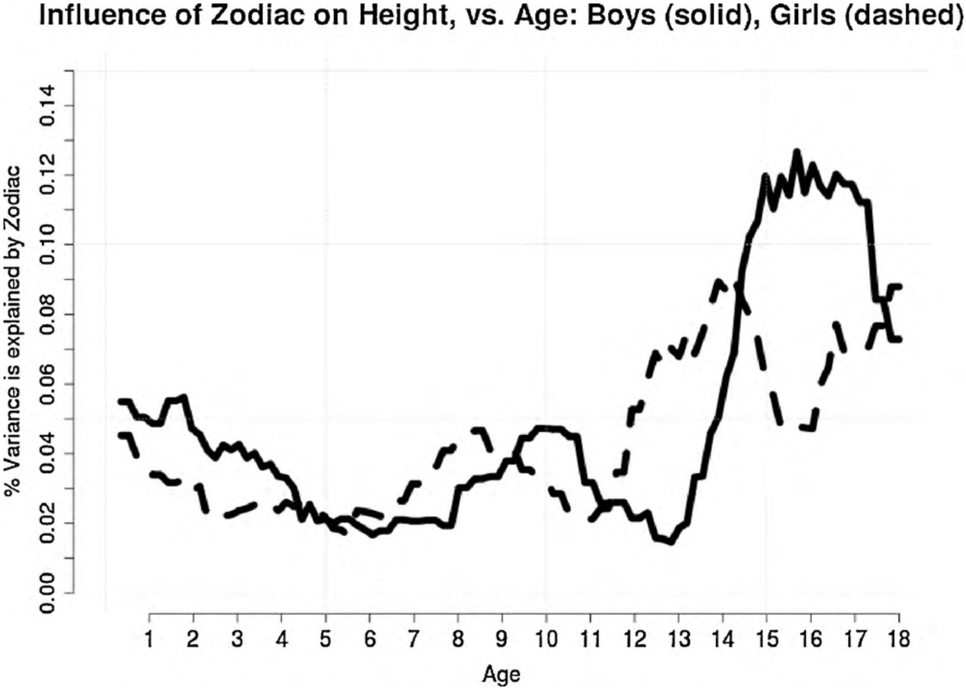


Fig. 4. Zodiac sign (month of birth) effect on height in 471,477 single height measurements of children and adolescents aged 0–18 years. The effect rapidly increases at the age of 6 years in both sexes, tends to decline during prepuberty, and reaches a new maximum late in adolescence explaining some 0.1% of height variation.

Cherie Geiger and *Leslie Sue Lieberman* reported on environmental toxicants with particular focus on polychlorinated biphenyls (PCB) and the heavy metal lead, their remediation and their influence on growth variation, height and the secular trend. PCBs possess high chemical stability, low flammability and low electrical conductivity. They are used in a variety of industrial applications. Through 1976, 600 million kilograms were manufactured (575 million kg in the US). PCBs are considered persistent, ubiquitous pollutants, they are found in nearly all plant/animal life, their concentrations tend to increase travelling up the food chain. Research in remediation technologies for both PCBs and lead in the environment has improved in recent years but still focuses on high-concentration contaminated areas (DeVor et al., 2008; Friesl-Hanl et al., 2009). PCBs are (anti) estrogen-like endocrine disrupting chemicals that interfere with synthesis, metabolism, binding and cellular responses of natural estrogens. Some congeners (PCB configurations) advance and some delay puberty (Chakraborty and Chakraborty, 2009). They may interfere with thyroid function by elevating anti-thyroid peroxidase antibodies and are related to neurobehavioral problems associated with alterations in Ca channel ryanodine receptors and untruncated dendrite growth (Yang et al., 2008).

Major sources of lead are paint, gasoline, water distribution systems, food, and lead used in hobby activities. Between 1976 and 1990, lead used in gasoline declined by 99.8% in the United States, but much lead contamination is still found. Paint with a high lead content is estimated to be in 74% of all housing built before 1980, and causes as much as 90% of childhood lead poisoning. Maternal and infant prenatal and postnatal blood lead concentrations are associated with disruption of thyroid function, physical growth stunting, cognitive development and immune system impairment. Linear growth is impaired due to chondrocyte hyperplasia, hypertrophy and interrupted calcification, thereby stunting long bone growth. Reduced osteoblast proliferation and migration is a secondary cause of stunting (Ignasiak et al., 2006). Body lead burden and child growth are significantly inversely related in some, but not all studies; and therefore, the issue of whether the adverse effects of lead are a threshold effect or dose response phenomena has not been resolved (Little et al., 2009).

There are a number of issues that confound studies of environmental toxicants on human health, growth and development. These include: identifying the sources and timing of exposures, measuring chronic and acute exposures, selection of tissues and reference values, interactions with other environmental and biological variables and the small sample sizes of varying chronological ages and developmental stages (Schell et al., 2009). The paucity of good studies and increasing concern about environmental health issues prompted the National Institute of Child Health and Human Development (National Institutes of Health) to initiate the National Children's Health Study in 1999. This study examines the effects of environmental influences on the health and development of 100,000 children across the United States, following them from before birth until age 21 years (http://www.nationalchildrensstudy.gov). This is a definitive study of unprecedented scope.

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