REVIEW ARTICLE

Growth and Puberty in German Children

Is There Still a Positive Secular Trend?

Bettina Gohlke, Joachim Woelfle

SUMMARY

Background: Since the mid-19th century, growth in German children has accelerated and final height increased. Possible causes of this secular trend include improvements in nutrition, hygiene, and health care. While the upward secular trend still continues in some parts of the world, it seems to be slowing in industrialized countries.

Methods: Selective literature review.

Results: Reliable data on growth that have been published since the middle of the 19th century reveal an increase in final height by 1 to 2 cm per decade in most European countries. Recent epidemiological studies, however, suggest that human height may be nearing an upper limit, beyond which it cannot increase even with further improvements in nutrition and health care. In Germany and other northern European countries, the upward trend in final height has slowed significantly over the last 30 years; in Germany, it now stands at less than 1 cm/decade. In the same interval, the age at menarche has remained constant at just under 13 years (currently 12.8).

Conclusions: In Germany, as elsewhere in northern Europe, the upward secular trend in height is slowing (ca. 2 cm/decade up to the mid-20th century, currently less than 1 cm/decade), and the age at menarche has stabilized at just under 13 years. It remains an open question whether the observed slowing will merely be temporary, or whether it indeed represents the near-attainment of an endpoint owing to relatively stable environmental conditions.

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Key words: puberty, growth, child health, quality of life, short stature

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The secular trend (ST) for height and puberty describes the change in physical development from one generation to the next (1) and is an important parameter for the socioeconomic conditions of a society. The ST is not necessarily positive, but can also be negative or stable—the term "acceleration" should therefore be avoided.

Genetically determined height and development ("maturation") are modified by several factors acting independently or in concert. Nutrition, hormonal status, and psychosocial situation play a prominent role.

The development of human height is characterized by several growth phases (e1). Changes in growth and maturation behaviour during all growth phases contribute to secular changes in height, with particular importance attaching to secular changes in early childhood (2). Birth sizes are determined to a great extent by intrauterine and placental factors, correlate closely with maternal height and maternal body weight, but only slightly with the newborn's later adult height (correlation coefficient r~0.25). In contrast, the height of a two-year-old correlates closely with the adult height (r=0.8) (3).

Based on the observation that human height is increasing and sexual maturation is occurring earlier in many countries with a favorable socioeconomic development, Tanner—one of the pioneers of auxology—called growth the "mirror of the conditions of society" (4). From this perspective, the ST for height and development is also used in sociological research as an indicator of conditions of a society in terms of nutrition, hygiene, and state of health.

The ST is also important from the auxological viewpoint. In this context a positive ST indicates that the reference values of a population have to be periodically re-determined in order to define short or tall stature.

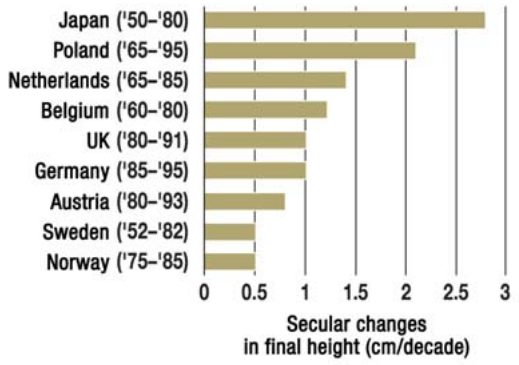
The purpose of this study is to present the current state of knowledge regarding ST based on a selective review of the literature.

Secular trend of the final height of adults

Analyses of final height development have been performed in many European countries. A comparison of these analyses reveals differing results (5) *(Figure 1)*.

Early data for height development based on longitudinal measurements of school children are available from the Carlsschule school in Stuttgart (e2); a historical

FIGURE 1



Secular trend of the average height of adult males—an international comparison. The increase in height (in cm) per decade within the bracketed time frame (years) is shown (from [5])

overview of the ST in Germany is provided by Jaeger (6). Reliable figures for adult height have been available since the mid 19th century. In the majority of European countries, progeny height increases compared to the parents of the same sex. In most European countries, between 1880 and 1980 height increased by about 1.5 cm/decade during childhood, by about 2.5 cm/decade during youth and by about 1 to 2 cm/decade in adulthood (5, 7). In the nation which at present has on average the world's tallest people, the Netherlands, the height of a military draftee increased from 165 cm in 1860 to 181 cm in 1990 (8). In 1997, a Dutch man was on average 184 cm tall, and a woman 171 cm (8). But ST was not consistently positive in Europe. Komlos showed that during periods of drought towards the end of the 18th century the height of the population decreased again (9). Following a pronounced ST in longitudinal growth at the beginning of the 20th century and immediately after the world wars, it has decreased in the last few decades. It now ranges from 3 mm/decade in the Scandinavian countries to 30 mm/decade in parts of southern and eastern Europe (5).

Interestingly, height development is regressive in the USA, where there is currently a negative ST (10) *(Figure 2)*. Japan showed a pronounced ST between 1950 and 1960 (~8 cm/decade for 14-year-olds), which declined in the subsequent decades. At present, the ST in Japan is comparable to that of European countries (8).

Particular attention was directed towards the relationship between social changes and height development in the new German federal states. Military recruitment examinations performed after the reunification showed a positive ST.

Between 1957 and 1993, the height of West German military draftees increased from 174.0 cm to 179.8 cm (birth cohorts 1938 to 1974; ST slightly above 1 cm/decade) and subsequently remained stable at ~180 cm. In comparison, the military draftees of the birth cohort 1971 in the former German Democratic Republic were 2.3 cm smaller than those of the old German federal states (177.5 cm). After the reunification, the recruits from the new German federal states rapidly caught up, showing an increase in height of 0.86 cm over the previous year. In qualification, it should be mentioned that the East German draftees were called up earlier (age at draft in East Germany 17.8 years compared to West Germany 19.0) (13, 14); the height difference can be partly attributed to this circumstance (13, 14) *(Figure 3, Table)*.

Secular trend in height development of children

An ST in childhood growth accompanied by accelerated development can lead to a transient increase in height compared to same-age children of previous birth cohorts. The final height need not necessarily be influenced. In the past few decades, an accelerated physical development accompanied by a higher childhood growth rate has been observed in many countries. Since accelerated puberty often means that the final height is attained earlier, the differences in adult height are less pronounced. Takaishi showed a markedly positive ST in the birth cohorts of Japanese children between 1950 and 1990. For the girls, this was seen mainly in the 12-year-olds (ST of 30 mm/decade) and for the boys in the 15-year-olds (ST of 35 mm/decade). In post-pubertal adolescents, however, the ST was lower (in 17-year-old girls only 10 mm/decade), so that the final height was reached earlier although the adult height increased only moderately (15).

Interestingly, birth length is constant in almost all the industrialized Western countries and no change in this variable has been detected in Japan either over the last 40 years. On the other hand, a positive ST was detected during the infantile growth phase. At 2 years of age this was about 10 mm/decade and was therefore comparable to the observed change in the final height. This means that the greater ST in the later growth phase is compensated by the more rapid development and the actual ST manifests mainly in the first two years of life (8).

In Germany, two relatively recent surveys have been performed on this topic (e4, e5, 16). In 1984/85 and 1997, Hesse evaluated the effects of the German reunification on height development based on two perinatal surveys and measurements in school children in Saxony. Birth dimensions showed an increase in weight (+151 g) but only a slight change in length (+0.2 cm). In 7- to 10-year-olds a marked increase in BMI was observed (1.1 to 1.8 kg/m^2 gain). The height of German children has therefore increased by 1 to 1.5 cm compared to the data gathered by Brandt/Reinken 30 years ago (~0.5 cm/decade). This was confirmed by the Leipzig Group (e6).

Secular trend in physical maturation

A child's physical maturation can be recorded by, for example, determining bone development ("bone age") or the stages of puberty. In girls, age at menarche is a good indicator of physical development. In Europe, age at menarche has fallen sharply from 17 years since the 19th century. Since the early 1960s, however, age at menarche has remained relatively constant at about 13 years in most European countries *(Figure 4)*.

In the developing countries, however, the situation is different: there is either no or a negative ST—which has been interpreted as reflecting the more unfavorable socioeconomic situation (7).

Summarizing, it can therefore be stated that adult height has increased in most European countries since the mid 19th century, but also that this trend has been slowing over the last few decades of the 20th century. During this time period, a positive ST has been observed during childhood growth which was equalized by an accelerated development in puberty, with the result that the "net gain" corresponded to what was achieved in early childhood (up to age 2 years). The ST in maturation has hardly been detectable in Europe since the late 1950s, and age at menarche is about 13 years (e8). Birth length has not changed appreciably in this time interval. Against the background of this discordant development it can be assumed that there is no common cause to explain or account for these disparate trends.

Potential causes of the secular trend in growth and development

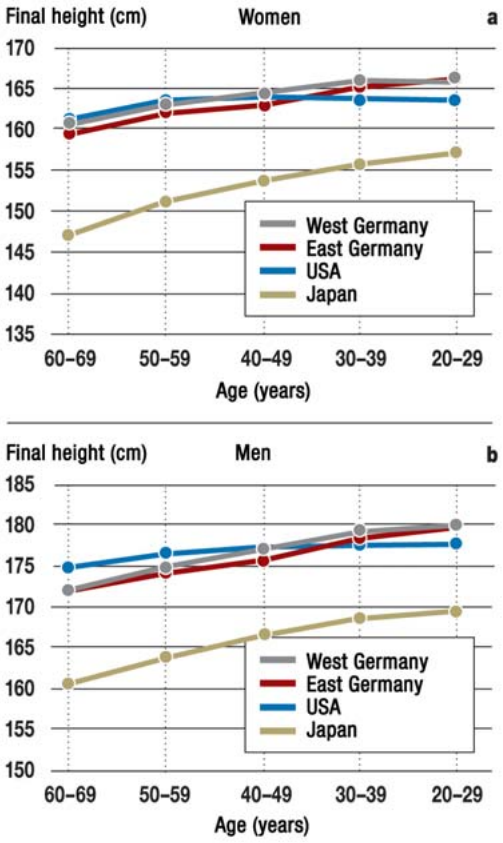
Socioeconomic status

As already mentioned, a relationship exists between height development and socioeconomic status. Nutrition and psychosocial environment are discussed as influencing variables. Komlos proposes using the physical height of a population not only as a biological parameter but also as a measure of its prosperity ("biological standard of living") (9). In his study, this author compared the average height of the US American with the West European population and found that 150 years ago, US Americans were about 7 cm taller than Europeans. Today, however, 20- to 29-year-old Americans are 6 to 7 cm smaller than their same-age European counterparts. Interestingly, stature is not associated with per capita income, in which US Americans continue to be the leading nation. Per capita income does not appear to be a reliable measure for assessing individual prosperity, since as an average parameter it equalizes large differences between the very prosperous and the poor.

Based on the data of male military draftees, Cole calculated that about 150 years (i.e. six generations) of optimal environmental conditions must prevail before the genetic potential for height is reached and no further positive ST can be detected (e9). But what are "optimal life circumstances"? Social class, income, education, and family size have all been seen as associated with the ST without the mechanisms underlying the ST being apparent (8).

A Swedish study also analyzed the relationship between height development and socioeconomic situation. This study dating from the middle of the 20th century found a constant difference in height between children from different social classes. The increase in socioeconomic differences in the 1960s was accompanied by a renewed increase in height differences (e10). Children of Japanese families who had emigrated to the USA were much taller compared to their parents. Their height was similar to that of non-migrant American children (e11). This has been confirmed by further studies; some studies have also shown that an improved economic status is associated with earlier sexual maturation (20).

FIGURE 2



Development of average height in East and West Germany, USA and Japan in dependence on the birth cohort in 1998 (from [11, 12, e3]).
a) Height in women
b) Height in men

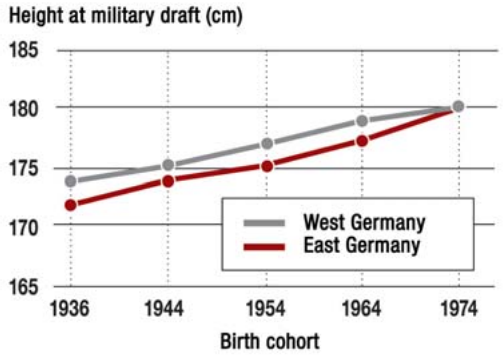
The difficult-to-define "well-being" of an individual (optimal state of health) also influences height development. This is illustrated particularly well by the clinical entity of psychosocially determined shortness of stature. Psychological and emotional stress (e.g. physical or sexual abuse) have negative consequences for childhood growth (21). Such stress situations probably influence the growth not only of individuals but also of populations who as a whole grow up under unfavorable living conditions.

Genetics

Regardless of socioeconomic background, an individual's height development is closely controlled by genetic factors. A prominent role in the mediation of longitudinal growth is played by pituitary growth hormone (GH) and the insulin-like growth factors IGF-I and IGF-II. While IGF-II is particularly important for embryonic growth processes, IGF-I increases proliferation and promotes growth throughout development (22). As regards somatic body growth, GH and IGF-I together are of pre-eminent importance: it was estimated on the basis of animal

Average height of East and West German recruits at military draft in dependence on birth cohort (from [13])

FIGURE 3



TABLE

Average height of German draftees (from [13])

Draft	Year of birth	Height (West Germany)	Height (East Germany)
1989	1970	179.8 cm	177.5 cm
1992	1973	179.8 cm	178.3 cm
1996	1977	180.0 cm	179.5 cm

studies that without GH and IGF-I only about 17% of the normal body dimensions would be reached (e12). Humans also exhibit a high degree of heritability of height (0.8 to 0.9), i.e. the observed variance in adult height has a strong genetic component (e13).

Despite the importance of the GH–IGF-I axis for growth, an ST cannot be explained by differences in the relevant genes. Since changes in the "gene pool" of a population are slow processes, the time interval from one generation to the next is not sufficient to explain the ST of height; there is also no corresponding selection pressure. Moreover, genetic factors alone could not account for why material prosperity is associated with a positive ST both in industrialized and developing countries, whereas poverty rather has a growth attenuating effect. It is therefore not surprising that polymorphisms in height relevant genes (e.g. the IGF-I gene) are significantly associated with the corresponding height but no relationship was found with the generation-to-generation increase in height (e14).

A further consideration regarding ST for longitudinal growth arises from the observation of assortative mating for height. This is the tendency to select a partner with similar phenotypical characteristics (in this case height). However, this would only lead to a long-term change in the gene pool with the consequence of increasing height if there was a reproductive advantage for men and women of tall stature. A previous study has in fact shown that childless men are smaller than fathers (23). Women of below average height, on the other hand, tend rather to have a reproductive advantage (e15) so that the theory of positive assortative mating as a cause of the positive ST for height development is not empirically substantiated.

Nutrition

The variability of ST is an expression of environmental influences on a genetically determined variable (height and physical maturation). Worldwide, malnutrition is the main cause of inadequate growth, but self-induced malnutrition (eating disorders) or chronic diseases can also lead to subnormal growth. A simultaneous reduction in the growth factors IGF-I/IGFBP-3 is frequently observed. In contrast to many third world countries, however, energy supply in the industrialized countries has not been restricted for the majority of the population over the last 50 years. The quality rather than the quantity of nutrition is therefore assumed to be a potential influencing variable for the ST. In this context, discussion has focused particularly on an association between the ST and the supply of proteins and calcium (8, 24).

Apart from the influence of nutrition, there is evidence that altered exposure to so-called endocrine disruptors with estrogen-like and/or antiandrogenic action in drinking water and the environment could be co-responsible for the ST of puberty observed especially in girls over the last century. A recent experts' meeting on this topic, however, failed to produce a consensus interpretation of the currently available data (25).

Epigenetic influences

Recent studies have addressed the possibility of a relationship between height increase and external influences that may possibly be mediated by altered expression of growth relevant genes at the epigenetic level. A Chinese study showed that the longitudinal growth of children of Chinese emigrants was superior to that of young children who remained in their country of origin. Against this background and the observation that despite an improved economic situation up to 150 years are needed until the genetic growth potential of a population is fully utilized, Hui et al. speculated that an epigenetic "restraint," most likely mediated by an only gradual improvement in living conditions, could lead to a reduced expression of growth relevant genes in the population studied (e16). Methylation analyses of genes relevant for growth in entire population groups have not yet been performed. Specific methylation abnormalities have been studied in children with syndromal short stature. 50% of the children with Silver-Russell syndrome (shortness of stature, low birth weight, facial abnormalities, body asymmetry) were found to have epigenetic changes on chromosome 11 which contains the IGF-II gene among others (e17).

Recent studies have shown that maternal care influences the methylation of certain promoters and thus the expression of some genes associated with growth and maturation (e18). The extent and quality of prenatal and early infantile food intake can also influence the degree

of methylation of promoters and thus the expression of growth relevant genes (e19). It has not yet been established, however, whether and in what manner these effects act on the pubertal growth spurt and a later reproductive age. While the stimulation of early childhood growth by pre- or postpartum influences is rather considered as positive, there is mounting evidence that these phenotypic changes induced by fetal/early infantile programming can also have a dark side, especially in terms of increasing the risk of metabolic syndrome in adulthood (e20).

Conclusion

A decline in the ST of height development and stabilization of age at menarche have been observed in Germany over the last few decades. Despite the well proven relationship between ST and socioeconomic situation, nutrition and psychosocial influences, the biological mechanism underlying the ST of height development is not understood. The available data on the influence of early childhood nutrition and the individual psychosocial environment on the epigenetic regulation of specific target genes provide fascinating indicators for possible paradigms of ST; at present, however, a relationship still remains speculative.

Conflict of interest statement
The authors declare that no conflict of interest exists according to the guidelines of the International Committee of Medical Journal Editors.

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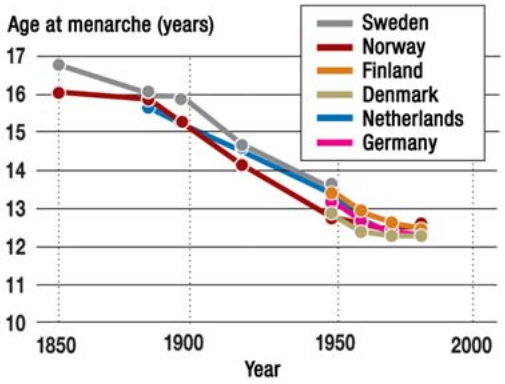
FIGURE 4



ST of physical maturation—a European comparison. The mean age at menarche at the time of the cross-sectional study is stated; (from [5, 17, 18, e7]).

Key messages

- Until the middle of last century there was a marked secular trend for final height of about 2 cm/decade in most Western countries.
- The secular trend for final height has plateaued in the last 30 years and is currently below 1 cm/decade in the majority of Western countries.
- After the German reunification, adult height equalized (measured in draftees in the new and old German federal states).
- Up to the mid 20th century, age at menarche markedly decreased; age at menarche is currently 12.8 years.
- Genetic factors alone cannot sufficiently explain the secular trend of height and maturation from one generation to the next.

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