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Economics and Human Biology 1 (2003) 161–168

ECONOMICS
AND
HUMAN BIOLOGY

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The secular trend in human physical growth: a biological view

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Received 19 December 2002; received in revised form 19 December 2002; accepted 19 December 2002

Abstract

Nutritionists and anthropometric historians alike are familiar with the secular trend—height and weight in adults, and the rate of physical development in children, increasing since at least the mid 19th century. The social conditions which drive this trend are of interest to anthropometric historians, but the underlying biology is also important. Here the trends for height, weight and menarcheal age are summarised and contrasted. In Northern Europe, adult height has largely stabilised, and the age of menarche has also settled at around 13 years, while weight continues to increase due to obesity. The increase in height from one generation to the next occurs mainly in the first 2 years of life, due to increases in leg length. The height trend has lasted for 150 years or more, i.e. for six generations, because the rate of catch-up from one generation to the next is biologically constrained to avoid the cost of too rapid catch-up.

Keywords: Human physical growth; Human race; Body size; Stature; Development

1. Introduction

Human biologists are well aware that the human race has been increasing in body size over the past one and a half centuries, the rate of increase depending not only on the time and place where it is measured but also on the particular measure of body size used, e.g. stature or weight. Anthropometric historians also know about these temporal changes in body size, particularly stature, but their focus is on the social factors that underlie them and they recognise—perhaps more clearly than human biologists—that the secular "trend" is not always upwards. For this reason they prefer the term *secular change*.

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1570-677X/03/$ – see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S1570-677X(02)00033-3

A principle underlying anthropometric history is that adult stature is a powerful proxy for childhood living conditions, with adverse conditions leading to impaired growth. Nutritionists and human biologists recognise that growth is affected by the interplay of diet and nutrition on the one hand, and morbidity—particularly infection—on the other. Yet the optimal conditions for nutrition and environment, leading to reduced rates of stunting in the developing world, have yet to be identified with any confidence.

The secular trend is of interest for several reasons. It is a marker of the public health of the population as it changes over time (Tanner, 1992), it provides insights into the link between growth and the environment (Cole, 2000b) and it illustrates aspects of the physiology of inter-generational relationships in growth and size (Emanuel et al., 1992).

The aim of this review is to focus on the secular trend as it has manifested itself since about 1850 in Europe. The emphasis here is on biology rather than social history, so that the perturbations upsetting the smooth trend are largely ignored. I summarise the evidence for secular trends in various distinct body measures, to show how they vary with age, time and space, to demonstrate that several different trends operate in tandem and to discuss briefly the factors that contribute to them.

2. Height

2.1. Adults

The most visible expression of the secular trend is the increase in adult height seen in many parts of the world, with grown-up children being taller on average than their same sex parents. This has been happening since at least the mid 19th century, based mainly on male conscript data, for example, from the Netherlands (Van Wieringen, 1986). There mean height has increased from 165 cm in 1860 to 181 cm in 1990 and the Dutch are currently the tallest nation in the world—young men averaged 184 cm and young women 171 cm in the 1997 Dutch reference (Cole, 2000b).

But the trend has not always been to increasing height. There is evidence that in the late 18th century mean height actually fell, due to poor harvests, high grain prices and the resulting poor infant and child nutrition (Floud et al., 1990; Komlos, 1985).

The rate of increase in Dutch conscript height was greater in the 20th century than in the 19th and greater after the Second World War than before. In recent years, the rate has slowed although small increases were still evident up to the 1980s, while conscripts from other European countries, particularly in Southern Europe, have continued to increase in height (Schmidt et al., 1995). Hauspie and Vercauteren (Hauspie et al., 1997) found secular trends in Europe during the latter half of the 20th century ranging from 3 mm/decade in Scandinavia to 30 mm/decade in parts of Southern and Eastern Europe. Height in the Netherlands and Scandinavia appears close to a plateau, while in Southern Europe the increase is likely to continue for some decades to come.

Height in the USA, the most affluent nation, currently lags behind that in Northern Europe. For example, the US 2000 reference (Kuczmarski et al., 2000) gives median height in young adults as 177 cm for men and 163 cm for women, 7 cm or 4% less than for the Netherlands. These differences are substantial, even if the Dutch reference has a strict inclusion criterion of two Dutch parents for each child, (Roche et al., 1990; Van Wieringen, 1986).

The secular height trend in women was poorly documented in the 19th century, as they were not conscripted. In the 20th century, the women's trend has been less than in men (Kuh et al., 1991; Tanner et al., 1982), so that the sex difference in adult height has increased with time (Cole, 2000a).

2.2. Children

Secular height trends in children mirror those in adults, but in addition they vary with the child's age. Clearly the trends are the same after puberty as the child becomes adult, but at earlier ages, the apparent trend may be smaller or larger than that seen in adults. This is best seen in a graph showing median height by age for a series of successive cohorts (Hauspie et al., 1997; Takaishi, 1994). Height at each age increases steadily with time, but in addition the height curve shifts to the left, as seen particularly clearly in puberty. This is the combined effect of a secular trend to increasing height and a secular trend to a faster developmental tempo. The net effect is that the height trend appears to be larger in puberty than earlier or later. Fig. 1 illustrates this for Japanese data from birth to 17 years, collected over a period of 40 years from 1950 to 1990 (Takaishi, 1994). The secular trend in girls at age 12, the peak of puberty, is 30 mm/decade, whereas at age 17 it is only 10 mm/decade. Boys are similar except that the puberty trend is later (age 14) and greater (35 mm/decade).

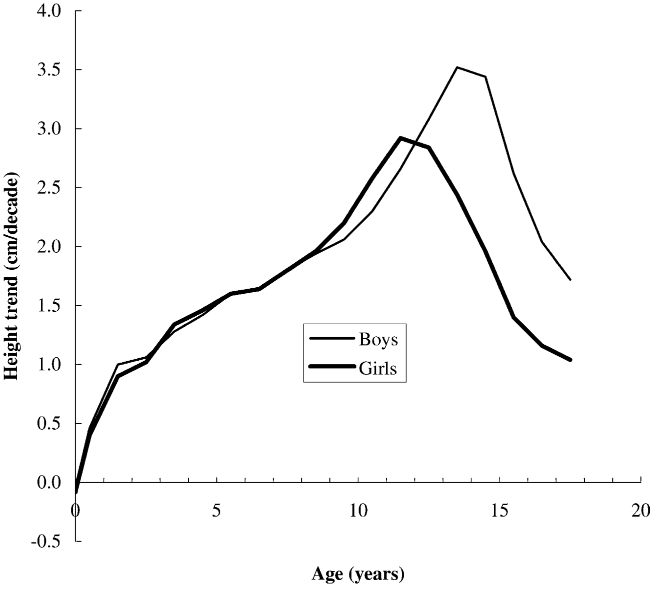

Fig. 1. The mean secular increase in height of Japanese children by age and sex 1950–1990. Note the lack of a trend at birth, the trend of 1 cm/decade at 2 and 17 years (in girls) and the trend of 3–4 cm/decade at 12–14 years.

In addition boys are still growing at age 17 so that their adult trend is likely to be smaller and similar to that for young women.

The most interesting aspect of Fig. 1 is at birth, where mean length has not changed at all in 40 years. In contrast, there has been an appreciable trend of 10 mm/decade at age 2, identical to that seen in adulthood. This means that on average, Japanese children aged 2 were 4 cm taller in 1990 than in 1950 and the same was true for young adults. In other words, the 4 cm secular trend in adult height from 1950 to 1990 was already present at age 2 and the increase in height from 2 years to adult was the same in 1950 as in 1990. In sum, the secular trend in adult height occurs during the first 2 years of life and it is restricted to this period.

Japanese data for height and sitting height for 1957–1977 show that the trend to increasing height is due almost entirely to an increase in leg length, whereas sitting height changed very little (Tanner et al., 1982). This, taken with the previous observations, suggests that the secular height trend arises from increased leg length growth during the first 2 years of life (Cole, 2000b). This association is probably a coincidence in that the period of most rapid growth, when the effect of an adverse environment is strongest, happens to coincide with the period when most growth takes place in the long bones of the legs.

3. Developmental tempo

Developmental tempo is the rate at which children mature, as measured for example by bone age or pubertal stage. The simplest and most accurate pubertal stage measure is menarche in girls, and the mean age when this occurs has been well documented in the 19th and 20th centuries. It has fallen sharply since the 19th century, as shown by data collected, for example, in Norwegian maternity hospitals (Liestøl, 1982). In 1840 menarcheal age was almost 16 years, but by 1940 it had fallen to 13.5 years, a falling trend of 3 months/decade. Several other studies have shown that in the latter half of the 20th century, menarcheal age stopped falling and it has now stabilised at about 13 years and may even have risen slightly in some places (Cole, 2000b). This cessation in trend has also occurred in Dutch boys since 1980, as judged by testicular volume (Mul et al., 2001), but not yet in US boys based on pubertal stage (Karpati et al., 2002).

4. Weight

As with height there have been widely reported secular trends in weight from many parts of the world, both in adults and children. These trends arise from two distinct sources, increases in body size (height) and changes in body shape, which corresponds to adiposity as measured by weight-for-height or indices of regional body composition, e.g. skin-fold thickness or circumferences. So, the secular trend in weight is a combination of the trend in height, as described earlier and the trend in adiposity.

4.1. Body mass index

Adiposity, or more specifically obesity, has been increasing sharply in the last 30 years. The best documented measure of obesity is the body mass index (BMI) calculated as weight/height^2, which is now used almost universally in adults (Garrow and Webster, 1985) and increasingly in children (Dietz and Robinson, 1998). Adult obesity has been rising since the 1960s, most noticeably in the USA (Kuczmarski et al., 1994) but also in Europe, e.g. Poland (Bielicki et al., 2000). In children it only started to rise after 1980 (Chinn and Rona, 1987; Harlan et al., 1988) but has since been increasing as rapidly as in adults. It is now being seen at younger and younger ages (Bundred et al., 2001).

But BMI is actually less than ideal for measuring obesity, as it fails to distinguish between fat mass and muscle mass. When the incidence of obesity first started rising, it is likely that the increase in fat mass was masked by a corresponding reduction in muscle mass. This is particularly true for child obesity, where reduced physical activity, notably time spent watching television, is an important risk factor for obesity (Dietz and Gortmaker, 1993). So, the rise in child obesity probably started earlier than 1980, though BMI did not reflect it until later.

4.2. Birth weight

Length at birth has shown no secular trend and similarly the evidence of a trend in birth weight is not strong (Cole, 2000b). But two factors have operated in recent years to confuse the issue: first, the increase in very premature births due to improved medical management has skewed the birth weight distribution to the left, with babies born as early as 24 weeks gestation now having a reasonable chance of survival. And second, mothers are now fatter than they were and this impacts directly on the birth weight of their babies. The associated increase in gestational diabetes leads even more directly to macrosomia.[1] So, changes in mean birth weight over the past two decades are difficult to relate to earlier trends.

5. Discussion

There is no doubt that secular trends in height, weight, BMI and developmental tempo have been occurring over long periods of time and in many cases continue to occur. Several aspects of these trends are of interest: first, the varied nature of the trends in terms of their timing and intensity; second, the physiological processes underlying them; and third, the environmental factors that have been driving them.

In summary, adult height and weight have been increasing more or less linearly since the mid 19th century. Increases in height have slowed in the late 20th century and approached a plateau in Northern Europe, while weight has continued to increase as part of the worldwide obesity epidemic. Over the same period similar trends have occurred in children, amplified in mid-childhood by increased developmental tempo and earlier maturation, and absent at birth. The secular increase in tempo has largely stopped in Europe since 1950. The increase in adult stature from one generation to the next results from longer legs, the extra leg growth occurring before the age of 2 years.

[1] Overgrowth, particularly in the context of the birthweight of babies of diabetic or obese mothers.

What has been driving the secular height trend over this period and why has the period been so extended? It appears to be an inter-generational phenomenon, with the offspring of each generation becoming taller than the preceding generation, but with the increase in height per generation being tightly controlled. Over the course of many generations the cumulative increase in height eases the drive to grow. This presupposes three different processes operating in tandem: a propensity for the young child to grow rapidly, so far as the environment allows it; an upper limit to this growth rate, as too rapid growth is deleterious in the long term; and the propensity to grow being linked inversely to the child's size. These elements are similar to those of Tanner's target-seeking growth model (Tanner, 1986).

But the rapid growth starts after birth, not before. This requires a further process whereby the mother constrains the growth of the foetus in utero, so that growth only increases after delivery. This is thought to be due to imprinting in pregnancy, whereby the father's genes, which in evolutionary terms want a large baby, are rendered temporarily inactive, while the mother's genes, which want to protect both the mother and her whole family, retain control over the foetus's size. It is known from Walton and Hammond's 1930's experiments with shire horse—Shetland pony crosses that it is the mother not the father that controls the size of the infant at birth, while the father's influence emerges only later (Walton and Hammond, 1938). The key issue is foetal-cephalic disproportion—the mother must not produce a baby that is too large to be delivered safely. So, if the foetus is programmed to grow rapidly, it is in the interests of both foetus and mother that the extra growth takes place after birth and not before.

The most striking aspect of the secular trend is not its existence, but that it is spread over so many generations. If environmental conditions are good enough to allow optimal growth, why does the child not grow sufficiently rapidly to compensate entirely for the height deficits of previous generations, as summarised by the parents' heights?

It is because the secular trend is constrained physiologically by the amount of extra growth permitted (primarily by biological circumstances) in early post-natal life. It is becoming clear that catch-up growth, i.e. rapid growth in early infancy, has a cost in terms of later health. Rats malnourished in infancy are known to live longer than well-nourished controls and in many species the presence of catch-up growth immediately postnatally has long-term adverse consequences (Metcalfe and Monaghan, 2001). The net effect is that for children to reach their genetic potential in height, they require some 150 years (judging from the Dutch conscripts), i.e. *six generations* of optimal growth conditions. So, in practice the concept of genetic potential is unhelpful, as it must be conditioned on the height of the parents.

The trend in developmental tempo is probably linked to the trend in size. Menarche in girls occurs at an age when their skeleton, particularly their pelvis, is close to adult size, so that earlier maturation and increased height gain go hand in hand (Bogin, 2001). On average menarche occurs 1 year after the age of peak height velocity, so if mean velocity is increased then adult size is reached at an earlier age. However, clearly there is an upper limit to mean height velocity through childhood and this in turn delays menarche until 13 years or so.

Thus, in the optimal environment there is a physiological upper limit to the rate of early growth. What is the optimal environment and what are the environmental factors that affect the secular trend? Clearly the factors are linked to poverty, as poor growth and short stature are trade marks of deprivation (Tanner, 1992). Factors such as social class, income, education, family size, urban or rural location, housing and overcrowding have all been implicated in the secular trend in height or developmental tempo (Cole, 2000b).

The worldwide epidemic of obesity, linked to fat mass, started in adults in the 1960's, and in adolescents and children in the 1980's. It arises from an imbalance between energy intake and energy expenditure, so that both diet and exercise are implicated. Physiologically it seems that once energy expenditure falls below a certain level, the body's natural ability to regulate energy intake breaks down and fat stores accumulate. The way to avoid or cure obesity is to increase activity and to control energy intake. Television watching is likely to have played an important role in the origins of obesity and the western emphasis on a labour-saving lifestyle almost guarantees increasing levels of obesity.

In conclusion, the secular trend in human physical growth is a natural experiment which highlights the complex interplay between genes, physiology and environment in determining the size and shape of individuals from one generation to the next.

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