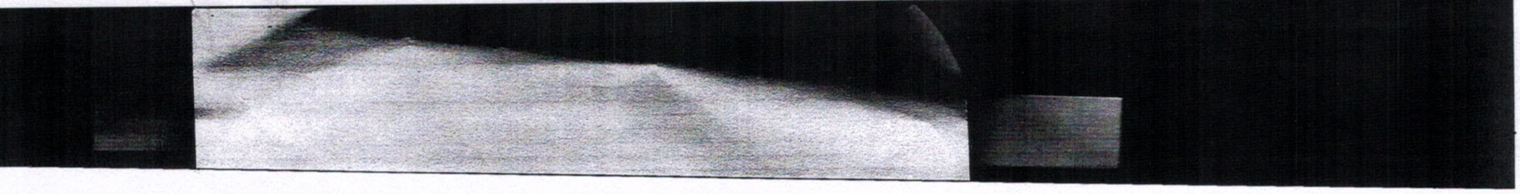


**INTRODUCTION**

# A brief history of the study of human growth

Looking back through the 300-year history of auxology, we can make out three distinct strands of interest, running sometimes separately, sometimes intertwined. We may call them the social, the medical/educational and the intellectual/scientific, after the impulses that gave rise to them: growth study in the service of social reform or social-economic history; growth study in the service of individual children, both in nurturing good development and in treating disorder; and growth study in the service of 'truth', to understand the form, the mechanisms and the evolution of the human growth curve.

The first time we hear the voice of genuine observation of children's growth – and a stentorian voice it is indeed – is in Guarinoni's immense scrap-book (see Appendix 1, 1), inveighing against the harm done to a boy's growth by anxiety at school, and commending the peasant girls of his beloved countryside for their late development (menarche at 17, 18 or even 20 years of age), in contrast to that of the too juicily nourished city girls. A little later we see the word *Anthropometria* for the first time, in a Paduan thesis describing the first known instrument for measuring humans.

Then, in 1729, the story really begins with the first textbook on human growth (see Appendix 1, 3). Comprehensive and detailed, it was dedicated to the irascible and giant-guardsman-collecting Frederick William I of Prussia, with the claim that the usefulness and efficacy of the subject was proved by the fact that the Crown Prince (later Frederick the Great), formerly abhorrently puny and delicate had been cured 'by nothing else than a speedy growth in length'. Stöller confused post-illness catch-up with the normal pubertal growth spurt, a confusion that persisted right through the time of Quetelet (see Appendix 1, 7).

Stöller's work was theoretical-clinical, after the manner of the time: he measured no children. But 25 years later, in 1754, the first thesis derived from a true growth study was presented in Halle (see Appendix 1, 3). Only in hindsight can we fully appreciate Jampert's long-lost work, with its growth tables, its clear comprehension of the difference between longitudinal and cross-sectional methods of study, and its understanding of the problems of variation and sampling. So here we see the first children of whom we have measurements: the first and the smallest.

**Opposite: Goethe's drawing of the measurement of recruits for the Duke of Sachsen-Weimar's army in 1779. Reproduced by courtesy of the Nationale Forschungs- und Gedenkstatten der Klassischen Deutschen Literatur in Weimar, Goethe Nationale-Museum.**

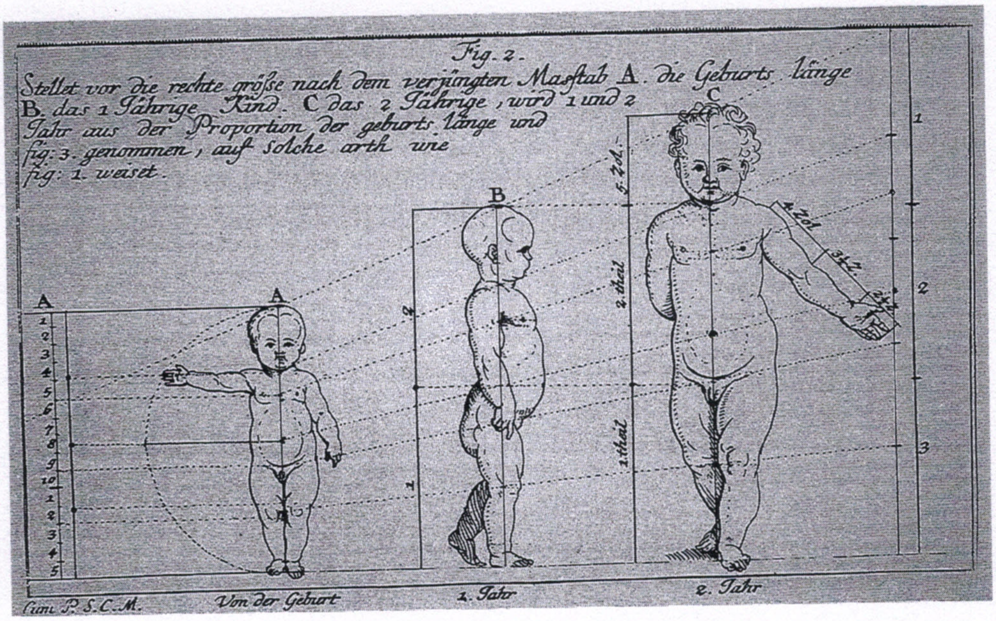
Jampert does not say how he measured height – surprisingly, for he gives details about all the other measurements he took. Probably already the system for measuring army recruits (see p. 2) was in use. The sketch of the measuring was made in 1779 by no less a person than Johann Wolfgang von Goethe who, to his intense disgust, had to include recruiting as part of his duties for the Duke of Sachsen-Weimar. The method of measurement is absolutely modern, and much better than school measurements 200 years later: head correctly aligned with upward pressure upon it, block sliding down the back-board, shoes removed and a recorder recording. The earliest military data retrieved and analysed go back to 1741, in Norway, but evidently measurements were made, if not recorded, somewhat earlier than this. Already, in 1724, the Reverend Joseph Wasse had demonstrated that stature decreased during the day, and he had used that information to help would-be soldiers refused 'for being a little under the standard' persuade recruiting officers they would be acceptable in the morning.

## The artistic tradition

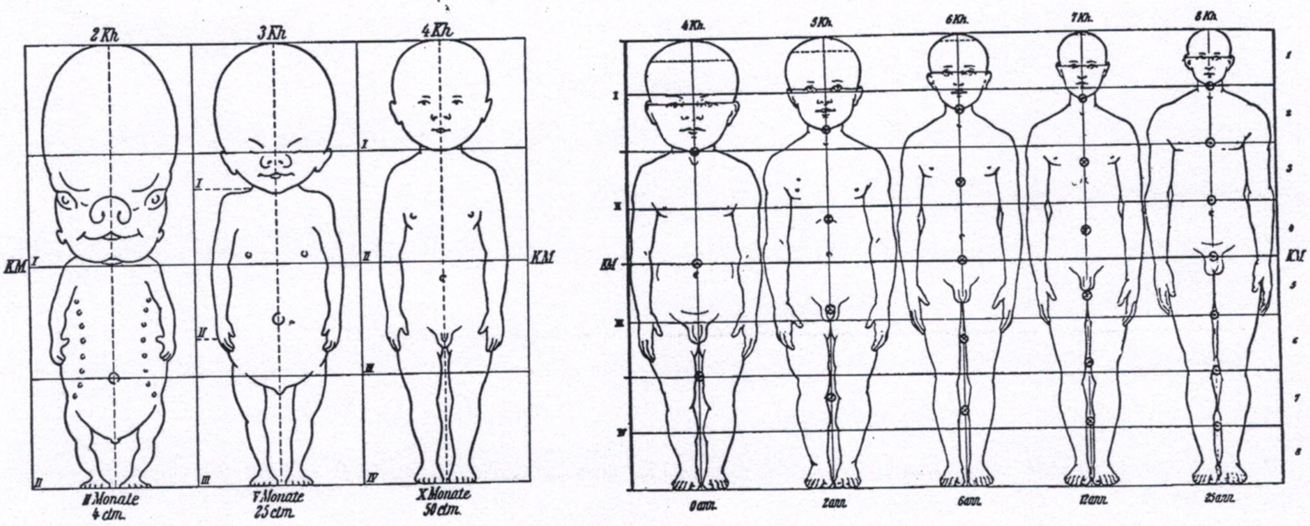
When it came to representing the growth of children, the artistic community was well ahead of the medical one. In ancient times, and again at the Renaissance, canons or rules of proportion were developed for the use of painters and sculptors. The Vitruvius-Leonardo da Vinci canon of man inscribed in a square and circle is universally remembered; later Albrecht Dürer (1528) gave rules for drawing peasants and burghers, and illustrated geometrical methods for transforming faces that became in D'Arcy Thompson's hands (see Appendix 1, 14) the method of transformed co-ordinates.

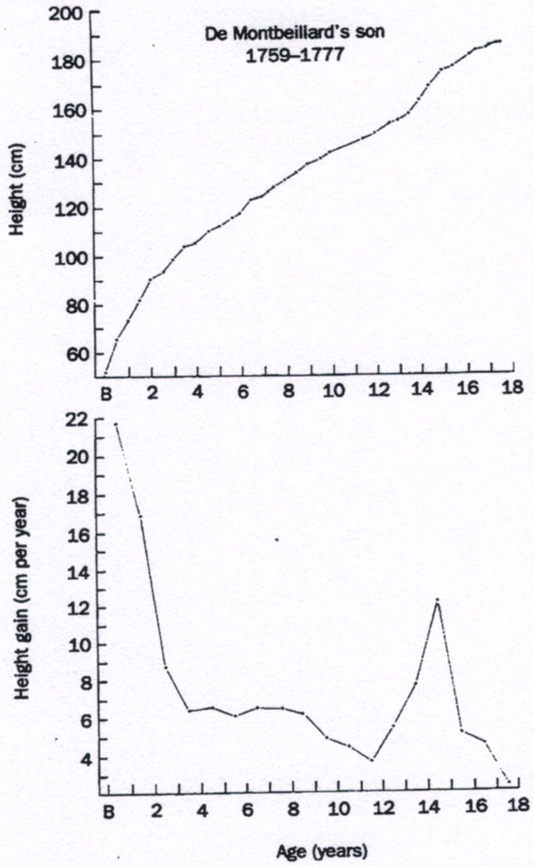
The first book dealing specifically with change of proportions during childhood, published in 1723, was by Bergmüller, Professor of Painting in Augsberg: it was also called *Anthropometria*,

**Right: Bergmüller's (1723) drawings of a child at birth, age 1 and age 2. Courtesy of the Countway Library, Boston.**




**Below: Stratz's (1909) diagram of change in body proportions during (a) fetal (left) and (b) post-natal (right) growth.**






Height (above) and height velocity (below) curves of de Montbeillard's son.

like Elsholtz' thesis. It gave a strict geometrical rule which generated a height curve, though not a very naturalistic one; it omitted any pubertal spurt. Not till 100 years later did more accurate rules for children appear, enabling later artists to escape the criticism of Carl Heinrich Stratz in his Edwardian era textbook on child care that 'the cupids of Boucher, Fragonard and even Rubens and Titian are lusty little men-about-town and certainly no infants' (1903).

## The first longitudinal growth study

Very few growth studies have been made in the spirit of pure inquiry to establish the 'truth' of how things are. But the first ever longitudinal study, instigated by Buffon (see Appendix 1, 5) and made by de Montbeillard on his son in the years 1759–77 was just such a one. It was made in the spirit of the times; the years of the European Enlightenment and the French Encyclopédists. It established the existence of the pubertal growth spurt, and seasonal changes in growth-rate, and confirmed the occurrence of shrinkage during the day. It is a record that has never been surpassed, and seldom equalled, in elegance and presumed accuracy.

## Quetelet's fitted growth curve

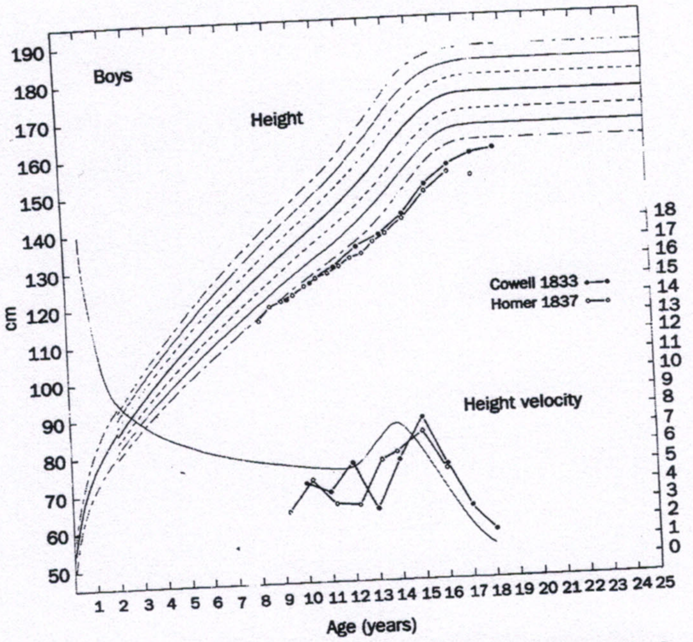
Sixty years and two major Revolutions later science was firmly established and astronomers and mathematicians ruled the roost. Adolphe Quetelet (see Appendix 1, 7), a star of the first magnitude, made two cross-sectional studies of Belgian children, in 1831 and 1832. His interest was in the form of the human growth curve – but as an example of Natural Beauty rather than Natural History. He fitted, for the first time, a mathematical curve to the empirical values, but the elegance of its shape disguised from him its falsity. It showed no pubertal spurt, and such was his authority that it took nearly 50 years for the existence of the spurt to be re-established, by the longitudinal studies of Bowditch (see Appendix 1, 10) in Boston and Pagliani (see Appendix 1, 11) in Turin.

## Growth as a mirror of the conditions of society: the beginning of auxological epidemiology

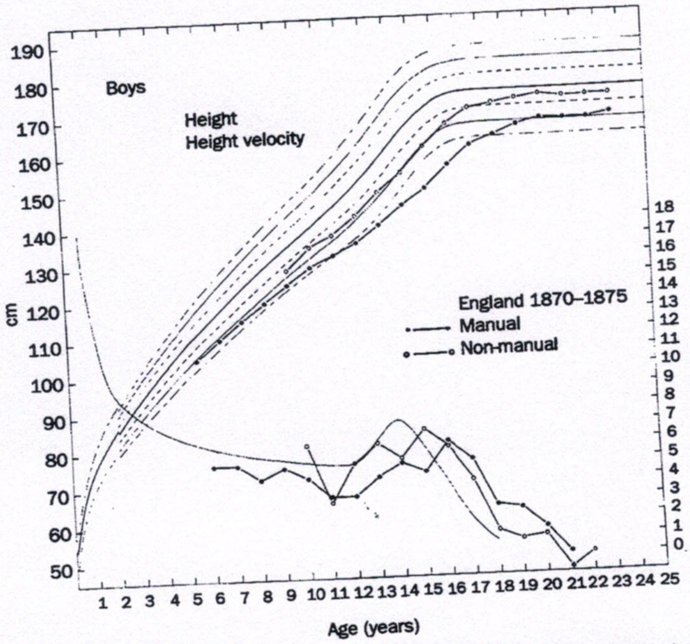
In the early part of the 19th century a new tradition of growth studies appeared, born of the reaction of humanitarians to the appalling conditions of the poor and their children. This activity has been called *auxological epidemiology*, 'the use of growth data to search out, and later to define suboptimal conditions of health' (Tanner, 1981). It monitors *groups* of children rather than individuals, which distinguishes it from the medical/educational tradition. The upshot of the monitoring is not individual treatment but public health measures or even political reforms, targeted at those groups in a population whose diminished growth betrays the signs of neglect: neglect, that is, of education, amenity, housing, work, and money.

Villermé (see Appendix 1, 6) and Chadwick (see Appendix 1, 8) were the pioneers in this field. The illustration of mean height of boys working in factories in the 1830s is that of Chadwick plotted on modern British standards; they were smaller than practically any third-world population nowadays.

In the 1870s Roberts and Galton (see Appendix 1, 9) were able to contrast the growth of working children with those being educated in private schools. Heights of sons of non-manual workers were greater than those of manual workers. A little later Key (1885) in Sweden showed a similar difference between children in elementary schools (mostly working-class) and those in schools providing a longer period of education (mostly upper middle-class).




**Mean height of boys working in factories in the Manchester/Leeds area in 1833 and 1837.**




**Heights of sons of manual workers and non-manual workers, mostly professional class, in about 1870 in England.**

Social class differences have been much investigated since. They are not inevitable, as Lindgren showed in 1976: in Sweden no differences were present in children born in 1955. But worsening conditions later caused the differences to return (see Part 11).

From the 1870s to the present there has been an uninterrupted history of child growth surveys. Bowditch and Pagliani both made large-scale surveys of schoolchildren and soon school committees everywhere demanded surveys to monitor school conditions and especially to investigate the supposed effects of 'over-pressure' of work in the factory-like secondary schools of the day. In 1893 William Porter, later a colleague of Bowditch, showed in St Louis that pupils who achieved above average grades were taller than pupils of identical age who received below average grades. He thus started a series of investigations on social mobility, social class, height and achievement, which still continue.

Comprehensive surveys of a country's whole population of children, however, or even of clearly defined parts of it, are of rather recent origin. Periodical cross-sectional surveys have been made in, for example Holland in 1955, 1965 and 1980; Czechoslovakia in 1951, 1961, 1971 and 1981; Cuba in 1972–4; Hungary in 1981–5, and by the United States National Center for Health Statistics intermittently from the 1960s to the present (HES II and III and NHANES I, II and III). In the United Kingdom, the alternative system of continuous *surveillance* was set up in 1972. Such a permanently operating system has the advantage that it can respond rapidly to social changes by altering its target population: currently schoolchildren aged 5 to 11 are monitored, and changes in sampling were introduced in the 1980s so that the representation of groups believed to be most disadvantaged and at risk of growth failure (inner city and ethnic minorities) was up-weighted. In a few countries, chiefly Scandinavian, the routine measurements taken by school authorities have been used for surveillance purposes; but in most either such measurements were too seldom and/or too badly done to be useful.

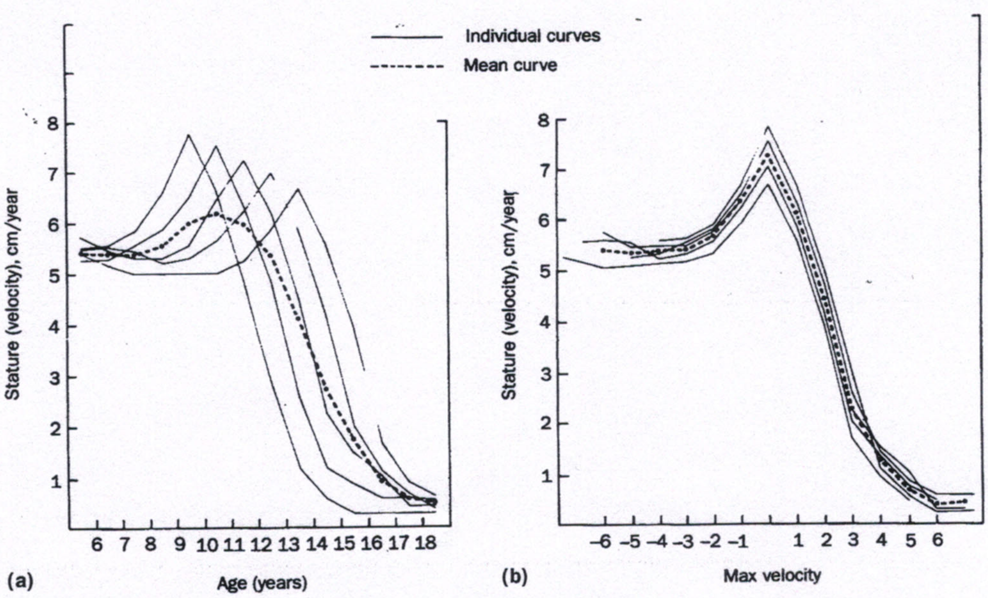
On an international scale, agencies such as the World Bank began in the 1970s to use height of children as a proxy for national well-being, and change of height over time as a criterion of the success of economic aid. As part of the International Biological Programme of 1967–72, statistics on growth and maturation, many unpublished, were collected by Eveleth and Tanner and published as *Worldwide Variation in Human Growth* (1976, second edition 1990). From these surveys, and related data on age at menarche, knowledge of the so-called secular trend (**11.3**) (or shift) towards larger size and faster maturation accumulated and began to receive increasing attention from about the time of the Second World War. War-time measurements, in the First World War in Germany and in the Second World War in Norway under Nazi occupation, showed the trend could be negative under bad conditions and dispelled the idea, once held, that the trend was somehow connected with global climate changes or long-term shifts in world ecology. The largest positive secular shift was seen in the period 1950–80 in Japan, associated with swift and intensive economic development. Here, as also in China and perhaps generally, the trend was associated with increased leg growth rather than growth of trunk (Tanner, Hayashi et al., 1982), reminding one of Dürer's difference between peasants and burghers.

## The human growth curve

To define the human growth curve, to study *growth* itself, longitudinal studies are a *sine qua non*; the curves obtained by fitting cross-sectional means are different in shape from individuals' curves, something not universally realized till the time of Boas (see Appendix 1, 13), Baldwin (see Appendix 1, 15) and Shuttleworth (see Appendix 1, 16) in the 1930s. The figure below is from Tanner (1962) but drawn exactly after the manner of Shuttleworth (1937) and Boas (1930). The difference between longitudinal and cross-sectional curves has implications for growth standards, but here we are concerned with the growth curve as a sign of underlying processes and as a characteristic subject to evolution.

As soon as numbers of individual growth curves began to be examined, and particularly *velocity* curves, as advocated by D'Arcy Thompson (see Appendix 1, 14), it was evident some children reached their 'age of maximal growth' (Boas) or 'peak height velocity' (Tanner) earlier than others. Boas coined the expression *tempo of growth*, drawing the analogy with classical music: some children are marked *allegro* (fast), others *lento* (slow), and Boas' empirical finding was that their final adult height did not, on average, differ. Thus there were two independent parameters of growth – size and maturation rate.

There were two great periods of longitudinal studies, the first in America *c.*1930–70, and the second in Europe *c.*1950–80. Before these, however, there were a number of individual enthusiasts for using serially taken measurements to monitor individuals' health and school progress. Chief amongst them was Paul Godin (see Appendix 1, 12) in France, who in 1919 introduced the word *auxology*, which soon came into common usage in the Latin languages and was introduced to the Anglo-Saxon literature by Tanner (see Appendix 1, 22) and others in the 1970s. The International Association of Human Auxologists was founded in 1977 and since then International Congresses of Auxology have been held every 3 years. The proceedings of the Fifth Congress, held in 1988 in Exeter, England, entitled *Auxology 88: perspectives in the*




**(a) Relation between individual velocity curves and mean increment curve (heavy broken line) during the pubertal growth spurt. (b) The same individual curves plotted against years before and after age of maximum growth velocity. Mean again shown by the heavy broken line.**

*science of growth and development* (Tanner, 1989) were deliberately designed, through invited and contributed papers, to give a complete conspectus of the scope and content of auxology at that time. It is thus a valuable historical source.

## The North American longitudinal studies

In the 1920s a powerful child welfare movement in North America spawned a series of studies which shaped the whole pattern of human auxology in the period 1935–55. All were devoted to the 'whole child', though some had educationists as directors (Baldwin, Dearborn), some psychologists (Bayley, McFarlane), some medical men (Todd, Washburn, Stuart, Sontag) and one, in Philadelphia, a physical anthropologist (Krogman, see Appendix 1, 18). Each study had its special characteristics and its own particular triumphs. At Iowa, the first to be established, there was Baldwin and later Meredith (see Appendix 1, 15) concentrating on physical measurements and their analysis. At the Brush Foundation Todd developed the first *Atlas of Skeletal Maturation*, later the *Greulich–Pyle Atlas*. At Boston efforts, still continuing, were made to examine their devoted cohort of subjects into middle- and old age. At Denver two generations of pediatricians were taught growth and development in a hands-on mode, and the mathematical fitting of growth curves was initiated. Of the three California studies, one was oriented towards pubertal physiological change (something almost unique at the time), one to behavioural development, and the third, the Berkeley Growth Study, was a birth-to-maturity cohort study recruited in 1928 by Nancy Bayley (see Appendix 1, 17), which produced landmark analyses both of physical growth and intellectual development.

The largest and longest-lived of the American studies, however, was the Fels Research Institute. The history and results of this study have been admirably described by Roche (1992). Begun in 1929, there were about 600 participants in the first generation, then some 350 who were offspring of a Fels parent, and lastly 90 enrolled 'grandchildren' (in 1991). Privately funded and located on the campus of a Midwestern progressive liberal arts college it boasted in its heyday separate departments of physical growth, biochemistry, social psychology and psychophysiology, all housed in a large 80-room building, an Institute in itself. It was directed first (1929–70) by one of its creators, Lester Sontag, part pediatrician, part psychiatrist, and second (1970–8) by Frank Falkner (see Appendix 1, 21), who before emigrating to the States had set up both the London and Paris teams of the International Children's Centre studies (see below). Falkner brought his experience as a pediatrician and an auxologist, as well as administrator, to the Fels. He was editor, with Tanner, of the massive three-volume *Human Growth: a Comprehensive Treatise* (two editions 1978 and 1986). In 1977 the funding and location changed and the Fels Longitudinal Study became part of Wright State University Department of Community Health. Beside its directors, the Fels was blessed with three successive, outstanding physical anthropologists: Earle Reynolds, Stanley Garn (see Appendix 1, 24) and Alex Roche (see Appendix 1, 23), around whose numerous papers much of American auxology coalesced.

### NORTH AMERICAN LONGITUDINAL GROWTH STUDIES

**University of Iowa Child Welfare Research Station**
1917–70 Baldwin, Meredith

**Harvard Growth Study (School of Education)**
1922–34 Dearborn, Shuttleworth

**University of California Institute of Child Welfare**
- Berkley Growth Study 1928–54 — Bayley
- Child Guidance Study 1930–50 — MacFarlane
- Adolescent Growth Study 1932–39 — Stolz, Jones, Shock

**Harvard School of Public Health Study**
1929–54 Stuart, Valadian

**Fels Research Institute. Yellow Springs**
1929– Sontag, Reynolds, Garn, Roche, Falkner

**Child Research Council, University of Colorado**
1930–71 Washburn, Maresh, Deming

**Brush Foundation. Western Reserve University**
1930–71 Todd, Greulich, Broadbent

**Philadelphia Center for Research in Growth**
1948– Krogman, Johnston

*James M. Tanner*

## The European longitudinal studies

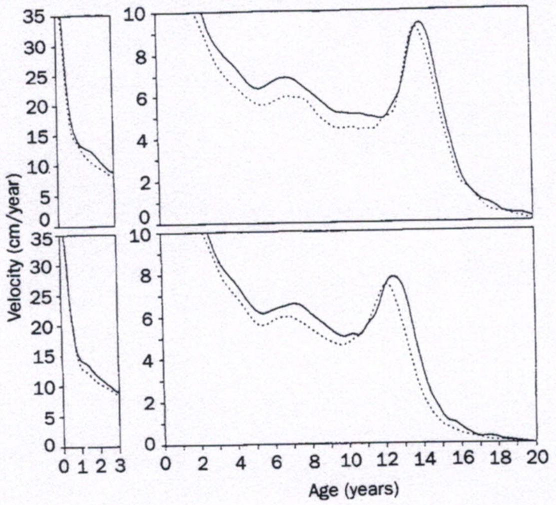
Though most of the European longitudinal studies had an element of psychometry and some study of behaviour, their primary orientation was towards medicine. Effectively the first was the *Harpenden Growth Study*, located in a children's home, directed by Tanner (see Appendix 1, 22), with Whitehouse as anthropometrist. Before setting it up Tanner had visited all the major American studies, and learned the measuring techniques from Meredith. When the International Children's Centre (ICC) Co-ordinated Studies began, first in London under Frank Falkner, initiated by Alan Moncrieff, Professor of Child Health, they all adopted the Harpenden techniques. Thus there was a close historical link between the European studies and the American ones.

Whitehouse designed a new range of anthropometric instruments for Harpenden, and the Harpenden rack-and-pinion wall-mounted stadiometer became the world standard. A new system for assessing skeletal maturity, the so-called Tanner–Whitehouse method (1975, 1983), was introduced. Also at Harpenden the Tanner pubertal stages (**1.10**), now used worldwide, were developed (1955), drawing on the previous work of Earle Reynolds at Fels. During puberty the subjects were seen every 3 months, and this permitted analyses of the pubertal staging data and also rather accurate curve-fitting to anthropometric measurements. This made possible the construction of the first practical longitudinal, or course-of-growth, reference curves and charts. Charts of growth velocity as well as 'distance' were produced and, following Nancy Bayley's (see Appendix 1, 17) (1956) original suggestion, specific curves for early, mid- and late maturers.

The difference between cross-sectional population standards suitable for screening and for surveys, and longitudinal course-of-growth standards suitable for following individuals in school or clinic was a constant theme of Tanner and his colleagues. From 1956 the Harpenden Study and the ICC London Study were part of the Department of Growth and Development of the Institute of Child Health. Set up by the Nuffield Foundation, and self-consciously a mini-Fels, it also had sections of infant ethology, chemical endocrinology, experimental animal auxology, and a Growth Disorder Clinic located at The Hospital for Sick Children. It attracted a steady stream of post-doctoral students from overseas (Hauspie, Lindgren and Falkner, 1995) but, less lucky than Fels, it was dissolved entirely in the early 1990s.

The biometrical expertise necessary for this work was supplied from 1950 onwards by Michael Healy (see Appendix 1, 20) then working under Frank Yates in the famous statistical department of Rothamsted Experimental Station, itself located in Harpenden. Healy's abiding interest in the manipulation of growth data brought about a considerable transformation of human auxology. One of his students, Harvey Goldstein, working in Tanner's department, became the statistical adviser and teacher to the whole group of ICC studies.

Structural average curves of height velocity of the 25% ultimately tallest and 25% ultimately shortest (dashed) subjects of Zürich First Longitudinal Growth Study. Boys above, girls below. From Gasser et al. (1990). The height difference between these two groups arises in the period age 2 years to puberty. This is the generalized version of de Montbeillard's son.




The ICC studies were all of birth-to-maturity cohorts. All were co-ordinated by Natalie Masse, director of the ICC, so that exactly the same techniques were used in every place. They were to serve as replicates, since no single longitudinal study boasted more than 400 children, reducing to about half that number followed to maturity. Every 18 months or so the workers of all studies met to compare techniques and results (Falkner, 1960).

Like the American studies, each had its particular interests and triumphs, and in 1977 an invaluable bibliography of all the teams' publications was published (ICC, 1977). The triumph of the ICC itself was that the meetings increasingly drew researchers from other European countries and stimulated them to embark on similar studies.

The medical orientation of these studies meant that there was much greater feed-back into pediatric departments than in most of the American ones. The prime figure in this was Andrea Prader (see

## EUROPEAN LONGITUDINAL GROWTH STUDIES

**Oxford Child Health Survey**
1944–64 Ryle, Stewart, Acheson

**Harpenden Growth Study**
1948–71 Tanner, Whitehouse, Marshall, Hughes, Cameron

**International Children's Centre Co-ordinated Studies**
- **London**
  1949–69 Falkner, Tanner
- **Paris**
  1953–75 Masse, Sempé
- **Zürich**
  1954–80 Prader, Gasser
- **Stockholm**
  1955–75 Karlberg, Taranger
- **Brussels**
  1955–75 Graffar
- **Louisville**
  1962– Falkner, Wilson
- **Dakar**
  1954–75 Sénécal, Massé

**Stockholm School of Education Study**
1954–66 Ljung, Lindgren

**Helsinki Growth Study**
1955–75 Backström-Järvinen

**Prague Growth Study**
1956–81 Prokopec

**Brno Growth Study**
1961–81 Bouchalova

**Lublin Growth Study**
1964–80 Chrzastek-Spruch

**Wroclaw Growth Study**
1961–71 Bielicki

**Budapest Growth Study**
1970–88 Eiben

**Edinburgh Growth Study**
1972–95 Ratcliffe

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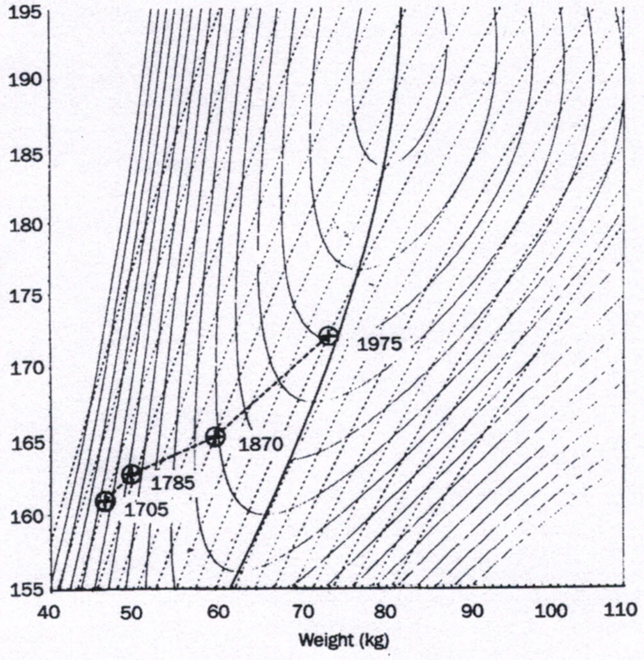
Appendix 1, 19), a greatly respected pediatric endocrinologist, Professor of Pediatrics in Zürich and director of the Zürich longitudinal study, itself perhaps the most successful of the ICC group.

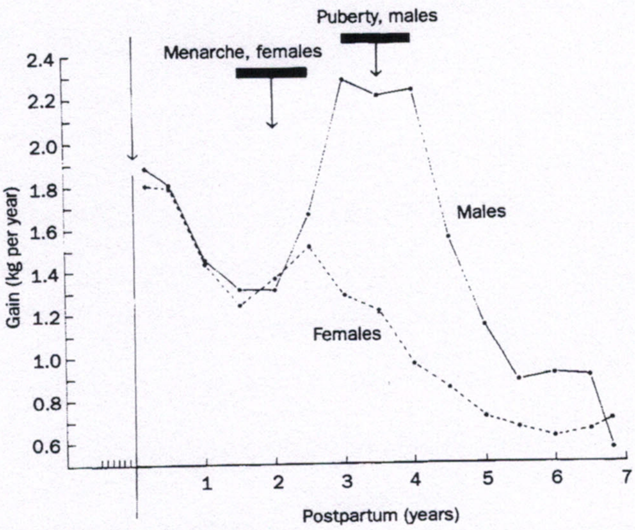
## Economic history

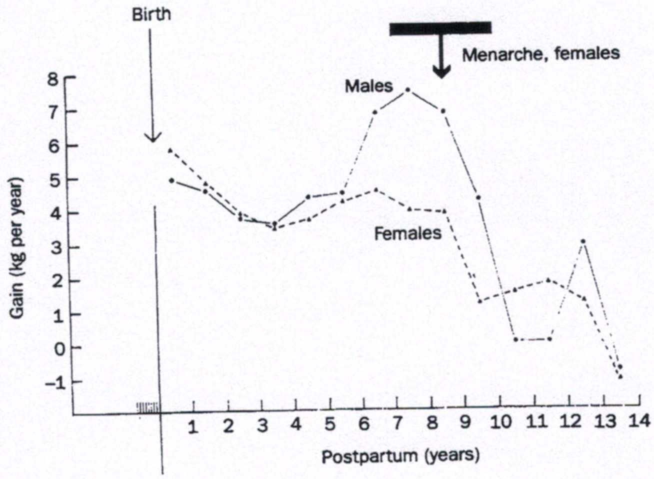
**Iso-mortality curves of relative risks for height and weight among Norwegian men aged 50 to 64 years. Average values of height and weight for the French population at four dates plotted, giving at each date the expected mortality rate of the population. From Fogel (1994).**



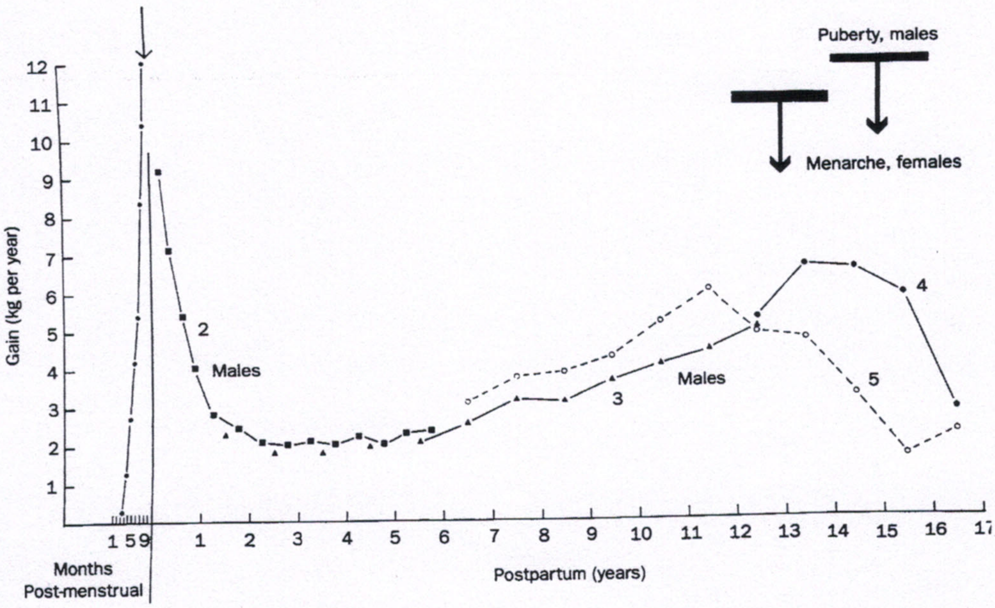

One of the most striking recent developments in auxology has been its impact on economic history and even economic theory. The chief impacting instrument, the Chicago economist Robert Fogel, has recounted the history of the collision. He and his colleagues found thousands of records of heights of children of Black slaves in American archives, and in 1976, in collaboration with Tanner, used the height curve to estimate average age of menarche, a statistic they needed for economic and demographic reasons. Once started, these diggers in government archives unearthed more data on growth in the 19th and even 18th centuries than auxologists dreamed existed. Here was hard data throwing light on the old politico-historical debate as to whether the Industrial Revolution first lowered the conditions of life of the working class, or whether, to the contrary, it provided a rescue by urban immigration from the Malthusian imperative in the countryside, over-population producing starvation.

This is one of the fastest growing areas linked to auxology at present. In 1984 Waaler published data on Norwegians showing that at all ages up to 80 years short men and women had a higher overall mortality rate than tall men and women. Height was a proxy for living conditions, especially in the infant years, and evidently poor conditions had long-lasting effects. Those with high, or very low weight-for-height also had a higher rate of mortality. Fogel (1994) developed these data into so-called Waaler surfaces, in which contours representing the mortality rate for each combination of height and weight were plotted. The combination of height and weight giving the lowest rate at ages 50 to 64 is shown by the continuous solid line. Fogel has used such surfaces in historical stud-




Weight-velocity curves for rhesus (above left), chimpanzee (above right) and humans (right). From Tanner (1962).




ies: the change in mortality rate in France, for example, until the very recent era, can be closely associated with the increase in height and weight. Further work in this field can be accessed through the collection of papers edited by Komlos (1994, 1995).

## The evolution of the human growth curve

Lastly, we return to the intellectual/scientific strand of growth study. On the mechanistic side, this means the physiology of growth, but this would take us beyond the space allocated to this brief history. Suffice to say that the discovery that growth hormone was species-specific and that growth hormone deficiency could be successfully treated (in 1958) gave an enormous, if temporary, boost to the study of auxology, as clinicians vied with each other to demonstrate successful diagnoses and outcomes. Methods for height prediction burgeoned, the assessment of skeletal maturity was briefly automated, course-of-growth standards became *de rigeur*. By 1990 the effect had largely worn off however, and most clinicians were back to assessing individuals' velocities by looking at cross-sectional, height-attained charts.

But since Darwin, the scientific impulse has centred on the light that growth studies of humankind can shed on the mechanism and history of evolution (**2.3**). The figures on the previous page show the growth curves of weight of Rhesus, Chimpanzee and Humans. They are all similar, but the interval between infancy and puberty has progressively lengthened. The physiology was determined in the 1980s: neurones of the gonadotrophin-releasing hormone (GnRH) nucleus, secreting at birth, are turned off soon after, and stay turned off for a short time in Rhesus, longer in Chimpanzee, longest in Man. Evolution proceeds by alterations in timing and intensity of growth and development. Changes in adult form are produced by increased growth at particular sites (the Gibbon's limbs come to mind) and the cellular physiology of this is in process of becoming clear. Change in timing, or heterochronic development, is crucial: one part, such as the GnRH nucleus, slowing up so that another, the cognitive part of the brain, has the possibility of developing more than before. These are the ways of evolution, and it is along this path that the history of auxology will perhaps proceed furthest.

*James M. Tanner*