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# Clinical standards for growth velocity in height of Belgian boys and girls, aged 2 to 18 years

The present paper presents the first clinical standards for growth velocity in height of Belgian boys and girls, based on purely longitudinal data. Growth charts are provided with centiles of height for age, along with the growth velocity curves of the typical early, average and late maturing child in the population.
These new growth velocity standards provide centile lines which allow to judge whether a child's growth velocity over a one-year interval lies within the limits of normal variation for his age, irrespective of his stage of maturation. They also provide information about variability in the individual patterns of growth velocity in the population and can, as such, also be used to evaluate the normality of a child's pattern in growth velocity over a longer period of time. Age at peak velocity occured in 95% of the children within an age range of about 4 years. The average age at peak height velocity at puberty was 14.0 years (S.D. = 1.0) in boys and 11.6 years (S.D. = 0.9) in girls. Peak height velocity was in the average 9.1 cm/year (S.D. = 1.4) in boys and 7.5 cm/year (S.D. = 1.1) in girls.
The representativity of these new standards with respect to the actual Belgian population was tested by comparison with recent cross-sectional data, collected on a large number of subjects. These new charts will find useful applications in longitudinal health screening surveys, and in clinical follow-up studies, where interest lies in the examination of a child's growth retardation in relation to some disease, or catch-up growth, as a response to subsequent medical treatment.

*Key words*: Growth velocity standards, longitudinal growth study, maturation.

## Introduction

An individual child's growth curve of height for age does not perfectly match any of the centile lines in conventional cross-sectional standards. Especially during adolescence, we notice a considerably steeper slope in the growth pattern of an individual child than in the average pattern of height for age as shown by the means in cross-sectional standards. This phenomenon has been thoroughly discussed by Tanner et al. (1966a, b). Recent standards of height for age, allowing for the variability in the shape of individual growth curves, have been published by Tanner and Davies (1987) for the American, by Susanne et al., for the Polish and by Wachholder and Hauspie (1987) for the Belgian population. Such longitudinally-based charts consist of conventional centile lines, but also provide estimates of the growth pattern of the typical early, average and late maturing child in the population.

Although the above mentioned longitudinally-based distance charts already allow a much better evaluation of the individual shape of a child's growth curve, we still need a reference to determine how big or how small a child's change in growth pattern over a particular age interval may be, before we start considering it is abnormal. These sort of questions can only be answered by standards for growth velocity. Such standards are based on longitudinal data and usually provide centiles for whole-year increments in height at each age. They allow to check if a child's increase in height from one year to another lies within the limits of normal variation in the population, irrespective of his maturational status. However, since these standards are generally also unconditional for the variation in tempo or maturation in the population, they suffer from the same phase-difference effect as the distance standards (Wachholder and Hauspie, 1987), and are as such still not apt to evaluate correctly a child's pattern in growth velocity over a longer period.

The present study deals with centiles of whole-year increments for height in Belgian boys and girls, together with curves, showing the variability in the true individual shape of the growth velocity curves of early, average and late maturing children. The methods used in this study are based on techniques recently used by Tanner and Davies (1985). The present growth velocity charts complete the longitudinally-based height for age (distance) standards for the Belgian population (Wachholder and Hauspie, 1987) and are particularly indispensible to judge whether a child's growth rate over time is abnormal. So, for the interpretation of individual patterns in growth velocity, we need reference data about the variability in the shape of the true individual growth velocity patterns in the population. They will find useful applications in longitudinal health screening surveys, where the aim is to verify if the increase in height from one year to another is within acceptable limits for his age, as well as in clinical follow-up studies, where interest lies in the examination of a child's growth retardation as a response to some disease, or catch-up growth, as a response to some intervention or medical treatment. The actual charts are based on the same data as the longitudinally-based distance charts for which the representativity for the Belgian population was shown (Wachholder and Hauspie, 1987).

## Subjects and Methods

The data of the present study comes from the Belgian Growth Study of the Normal Child (Graffar, 1958), which was conducted between 1955 and 1975. Detailed description of the survey, socio-economic background of the subjects, and measuring techniques were given elsewhere (Falkner, 1961; Graffar, 1958; Graffar and Corbier, 1965; Wachholder and Hauspie, 1987).

The actual growth velocity charts were constructed on purely longitudinal data on height growth of 48 boys and 50 girls, measured at regular intervals from early childhood until adulthood. Growth velocity was actually calculated as the increase in size over a whole-year interval. Centile values were estimated from the mean yearly increments and standard deviations at each age, while the centile lines were obtained by fitting a mathematical model to the various sets of centile lines at each age.

The growth velocity curves of the typical early, average and late maturing child in the population were obtained as the mathematical first derivative (velocity) of the respective curves in the height for age standards.

Details about methodology and calculations are given in the Appendix section.

## Results

The growth velocity charts are shown in Figure 1 for boys and in Figure 2 for girls. The height velocity centiles (yearly increments in cm/year) are given in Table 1 for boys and in Table 2 for girls. The ages correspond to the midpoints of the one-year intervals. So, the value of 4.7 cm/year for P50 in boys at age 10, for example, relates to the mean increase in height between age 9.5 and 10.5, as calculated over the 48 boys.

The centiles on these charts simply depict the distribution in yearly height increments

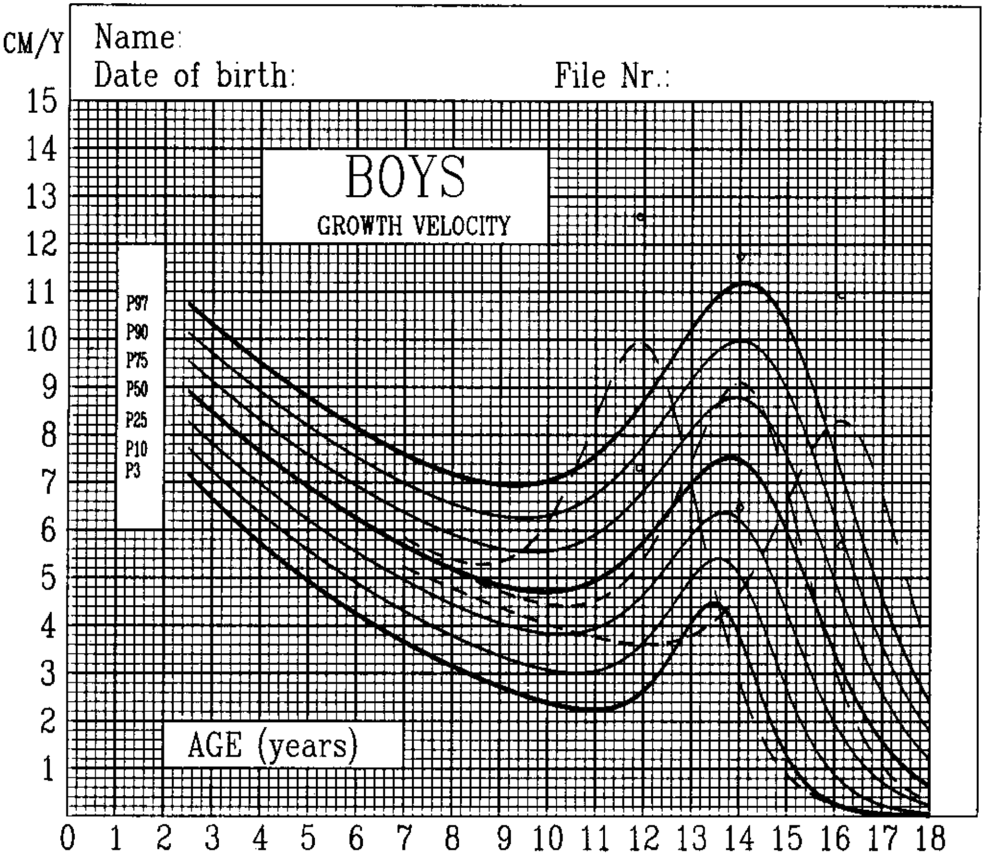


Fig. 1 - Centiles of height velocity (whole-year increments) in Belgian BOYS (solid lines). The dashed lines represent the typical early, average and late maturing child in the population. The 3rd and 97th centiles for peak velocity are shown by the circles.

at each age, but none of the centile lines is truly representative of any single child's pattern in growth velocity, for much the same reasons as distance centiles do not exactly show individual children's patterns of height for age. This is due to the fact that growth velocity centiles were constructed without takng into account that children vary considerably in their maturation rate or tempo of growth. Indeed, although boys for example, reach their maximum pubertal growth velocity at about 14 years of age, there are still some who have not yet started their growth spurt, while others have almost completely stopped growing. Therefore, the average increment in height observed at that age is far below the true average peak velocity. Despite all this, centiles for yearly increments are perfectly suitable to judge if a child's increase in size over a time interval of about one year lies within limits of normal variation, irrespective his tempo of growth or maturational status. In many practical situations, we do indeed miss information about the child's maturational status, or, in other words, about the relative amount of the growth process that he has already completed. Therefore, in all such cases, we can only rely on unconditional centiles. Of course, due to the above mentioned phase-difference effect, this normal variation can be

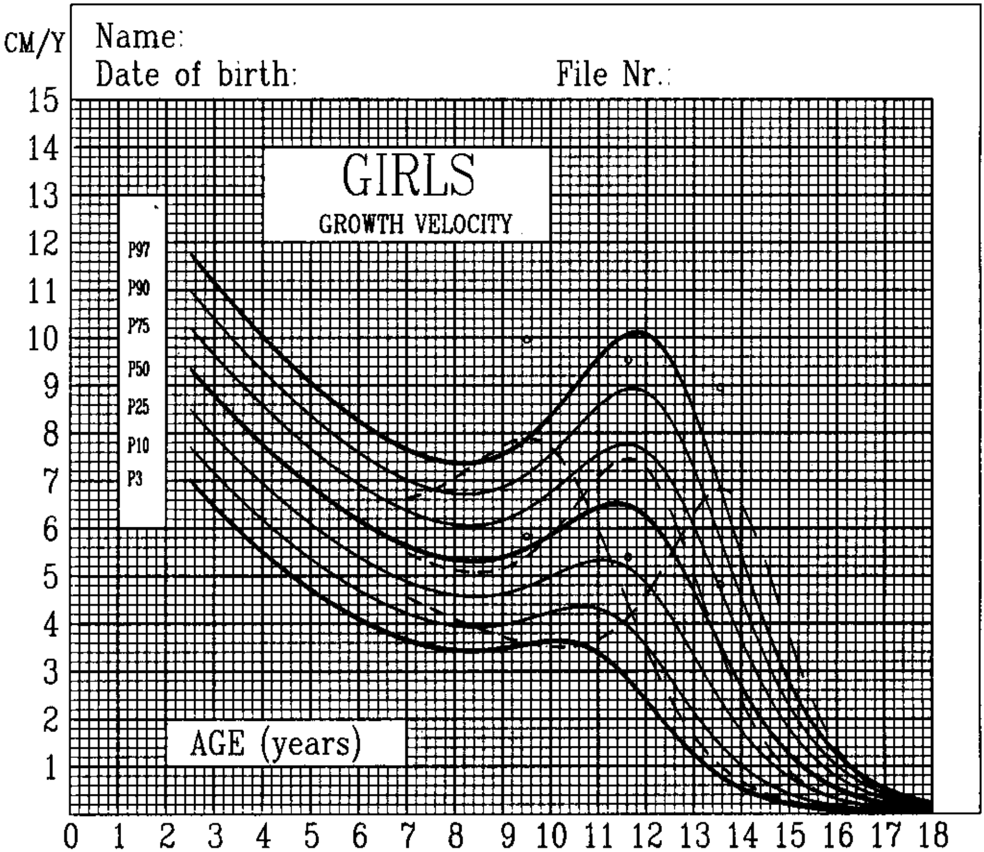


Fig. 2 - Centiles of height velocity (whole-year increments) in Belgian GIRLS (solid lines). The dashed lines represent the typical early, average and late maturing child in the population. The 3rd and 976th centiles for peak velocity are shown by the circles.

particularly large during adolescence, rendering our examination fairly inefficient. In fact, between age 13 and 14, boys can increase in height by as much as 11 cm or as little as 4 cm and still be growing normally. One should at all times be aware that the term «normal» in this context is fairly theoretical and simply means «within arbitrarly defined limits of variation», but not necessarily biologically normal or healthy. Suppose that a boy of age 13.5 has a growth rate of 4.5 cm/year (which is near the 3rd centile) and that we know that he is an average maturer, then his growth velocity growth velocity at age 13.5 years is about 6.5 cm/year (see also next paragraph). Before puberty, the variation in growth velocity due to differential maturation is far less pronounced.

If we are in the less common situation, where we dispose of an extensive series of data on height growth, preferably including the pubertal growth spurt, or if we have precise information about the maturation at each age, then we are in a position to judge about the normality of the pattern of growth velocity. In this situation, conventional centiles of yearly increments are also of little use and information about the variability in the patterns of individual children's growth velocity is indispensable. For that purpose, the charts are

TABLE 1 - *Centiles of height velocity (whole-year increments), BOYS.*

| Age | P3 | P10 | P25 | P50 | P75 | P90 | P97 |
|---|---|---|---|---|---|---|---|
| 2.0 | 7.7 | 8.2 | 8.8 | 9.4 | 10.0 | 10.6 | 11.2 |
| 3.0 | 6.6 | 7.2 | 7.8 | 8.5 | 9.1 | 9.7 | 10.3 |
| 4.0 | 5.7 | 6.3 | 7.0 | 7.6 | 8.3 | 8.9 | 9.5 |
| 5.0 | 4.9 | 5.6 | 6.2 | 6.9 | 7.6 | 8.2 | 8.8 |
| 6.0 | 4.2 | 4.9 | 5.5 | 6.2 | 6.9 | 7.5 | 8.1 |
| 7.0 | 3.7 | 4.3 | 4.9 | 5.7 | 6.4 | 7.0 | 7.6 |
| 8.0 | 3.1 | 3.8 | 4.4 | 5.2 | 5.9 | 6.5 | 7.2 |
| 9.0 | 2.7 | 3.4 | 4.0 | 4.8 | 5.6 | 6.3 | 7.0 |
| 10.0 | 2.4 | 3.1 | 3.8 | 4.7 | 5.6 | 6.3 | 7.0 |
| 11.0 | 2.2 | 3.0 | 3.9 | 4.9 | 5.9 | 6.8 | 7.6 |
| 12.0 | 2.6 | 3.6 | 4.7 | 5.8 | 6.8 | 7.8 | 8.7 |
| 13.0 | 4.1 | 5.0 | 5.9 | 7.0 | 8.1 | 9.2 | 10.2 |
| 14.0 | 3.8 | 5.1 | 6.2 | 7.5 | 8.8 | 10.0 | 11.2 |
| 15.0 | 1.3 | 2.7 | 4.3 | 6.0 | 7.6 | 8.9 | 10.3 |
| 16.0 | 0.3 | 0.9 | 2.0 | 3.4 | 5.0 | 6.3 | 7.6 |
| 17.0 | 0.0 | 0.2 | 0.7 | 1.6 | 2.6 | 3.6 | 4.6 |
| 18.0 | 0.0 | 0.1 | 0.2 | 0.6 | 1.2 | 1.8 | 2.4 |

TABLE 2 - *Centiles of height velocity (whole-year increments), GIRLS.*

| Age | P3 | P10 | P25 | P50 | P75 | P90 | P97 |
|---|---|---|---|---|---|---|---|
| 2.0 | 7.6 | 8.3 | 9.1 | 9.9 | 10.8 | 11.6 | 12.4 |
| 3.0 | 6.5 | 7.2 | 7.9 | 8.8 | 9.6 | 10.4 | 11.1 |
| 4.0 | 5.5 | 6.2 | 6.9 | 7.8 | 8.6 | 9.3 | 10.0 |
| 5.0 | 4.7 | 5.4 | 6.1 | 6.9 | 7.7 | 8.4 | 9.1 |
| 6.0 | 4.1 | 4.7 | 5.4 | 6.2 | 6.9 | 7.6 | 8.2 |
| 7.0 | 3.6 | 4.2 | 4.9 | 5.6 | 6.4 | 7.0 | 7.7 |
| 8.0 | 3.4 | 3.9 | 4.6 | 5.3 | 6.1 | 6.7 | 7.4 |
| 9.0 | 3.5 | 4.0 | 4.6 | 5.4 | 6.2 | 6.9 | 7.6 |
| 10.0 | 3.6 | 4.2 | 5.0 | 5.9 | 6.7 | 7.5 | 8.4 |
| 11.0 | 3.4 | 4.3 | 5.3 | 6.4 | 7.6 | 8.6 | 9.6 |
| 12.0 | 2.4 | 3.5 | 4.8 | 6.2 | 7.6 | 8.8 | 10.1 |
| 13.0 | 1.2 | 2.1 | 3.3 | 4.7 | 6.0 | 7.3 | 8.5 |
| 14.0 | 0.5 | 1.0 | 1.7 | 2.7 | 3.6 | 4.5 | 5.4 |
| 15.0 | 0.2 | 0.4 | 0.8 | 1.2 | 1.8 | 2.3 | 2.8 |
| 16.0 | 0.1 | 0.2 | 0.3 | 0.5 | 0.8 | 1.0 | 1.2 |
| 17.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
| 18.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 |

provided with the growth velocity curves of the typical early, average and late maturing child in the population (dashed lines). The average curve was obtained as the mathematical first derivative of the mean-constant curve of the Preece Baines growth model (Preece and Baines, 1978). This curve represents somehow the growth pattern of the average typical child in the population. The early and late maturer curves were derived by regression techniques from the average curve and correspond to subjects with age at peak velocity respectively 2 S.D. below and above the average age at peak velocity on the population and therefore include somehow 95% of the normal variation (see Appendix-section for details of methodology). The 3rd and 97th centile values for peak velocity are shown by the circles. Peak height velocity is higher in early and lower in late maturing children. The correlation between peak velocity and age at peak velocity is rather small and statistically not significant in our sample ($r = -0.17$ for boys and $r = -0.18$ for girls). The effect of early and late maturation on the growth velocity is far less pronounced during prepubertal ages.

From these typical growth velocity curves, it becomes evident that individual children and particularly early and late maturing children, have a pattern of growth velocity, which shows considerable shifts over time from one centile to another, but with most values of their growth velocity within the range of normal variation of growth rate at each age, as shown by the 3rd and 97th centile lines (except for the very early and very late maturing children). It becomes also clear that growth velocity between age 13 and 14 years in boys for example, is in very early and late maturers only about half the growth velocity of average maturers. The same holds true for girls between age 11 and 12.

The average age at maximum growth velocity in the sample can be estimated in an unbiased, though quite inefficient way, as the age at maximum mean yearly increments. In the present study, these values are 13.8 years in boys and 11.4 years in girls. The maximum value for the mean yearly increments at adolescence (unconditional on tempo) is 7.5 cm/year in boys and 6.5 cm/year in girls. A more precise estimate of mean age at peak velocity is obtained by averaging the respective values observed in the sample of 48 boys and 50 girls. These figures are 14.0 years (S.D. = 1.0) for boys and 11.6 years (S.D. = 0.9) for girls. The true mean values for peak height velocity are 9.1 cm/year (S.D. = 1.4) for boys and 7.5 cm/year (S.D. = 1.1) for girls. The 2SD early maturing boys have an average peak velocity of 10.0 cm/year at age 11.9 years; the respective figures for girls are 7.9 cm/year at 9.5 years. The 2SD late maturing boys have an average peak velocity of 8.3 cm/year at 16.1 years; respective figures for girls are 6.9 cm/year at 13.6 years.

## Discussion

The actual charts are the first growth velocity standards for the Belgian population. As they are based on the same longitudinal growth data which was used to construct longitudinally-based height for age standards (Wachholder and Hauspie, 1987) and for which it was demonstrated that they did not differ significantly from recent cross-sectional growth standards (Vercauteren, 1984), we can consider these new growth velocity standards as representative of the Belgian population. The ages at maximum yearly increments at adolescence in our longitudinal data of 13.8 years in boys and 11.4 years in girls compare very well with the ages at maximum increments of the cross-sectional means in the study of Vercauteren: 13.7 years in boys and 11.3 years in girls. This similarity in age at maximum growth increment between the two groups confirm the validity of the actual data as representative longitudinal growth velocity standards. As stated above, a more precise estimate of the timing of the adolescent growth spurt is given by the group averages of the individual children's age at peak velocity. Such estimates can, as a matter of fact, only be obtained from longitudinal data. The values obtained in the present study were 14.0 years in boys and 11.6 years in girls.

Growth velocity standards are expressed in cm/year. However, in practical situations, it is rather rare that we can measure children at intervals of exactly one year. Nevertheless, Tanner and Davies (1985) advise to estimate yearly increments over time intervals of not less than 0.85 years and not more than 1.15 years, since increments calculated over shorter

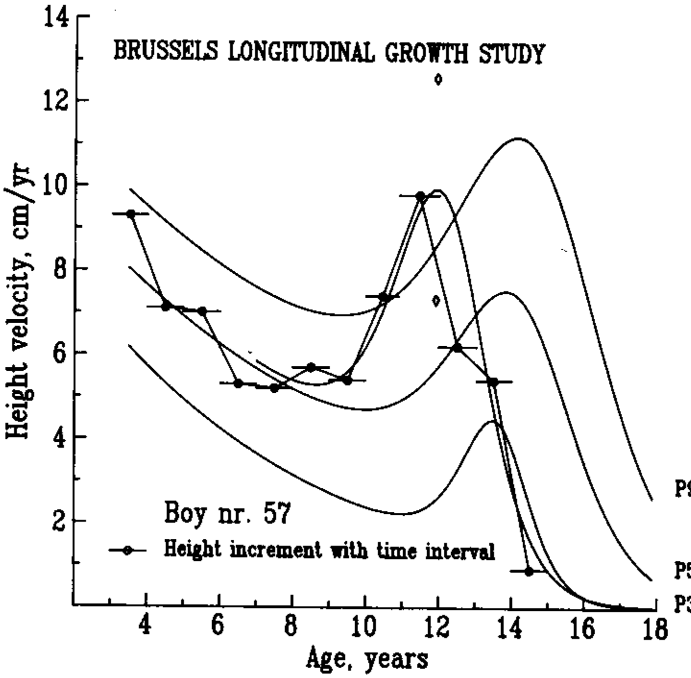


Fig. 3 - Yearly increments of boy Nr. 57 from the present sample, plotted against the 3rd, 50th and 97th centiles and the typical growth velocity curve of early maturers.

periods are more affected by measurements error and will also reflect seasonal variations in growth. Indeed, there is a general tendency for children to grow faster during the spring and slower during the fall (Marshall, 1971; Marshall and Swan, 1971; Tanner, 1962). Individual children's growth increments should be plotted on the charts, after having been adjusted to one-year intervals, by dividing the size increase (in cm) by the length of the actual time interval (in years) between the two respective height measurements.

Yearly increments always represent a child average growth rate during the time interval over which they were calculated. A child may temporarily grow at a slightly higher or slower speed, than what is shown by his yearly increment, particularly during periods of very rapid changes in growth rate, such as the above mentioned seasonal variations in growth rate or by the fact that the instantaneous peak height velocity is not maintained throughout a whole year. Analysis of that sort of short-term changes in growth velocities require more accurate growth-measuring techniques, like those described by Valk and Langhaut Chabloz (1982) and Hermanussen and Sippell (1985) but are generally beyond the scope of clinical examinations.

## Case study

In order to illustrate the use of the present charts, we have plotted in Figure 3 the pattern of growth velocity of a normal and healthy, but early maturing boy, on a simplified version of the velocity charts. The boy is issued from the sample of the present study and has serial measurements of height at annual intervals between age 3 and 18 years. His height for age data are published elsewhere (Wachholder and Hauspie, 1987). Yearly increments are plotted at the midpoint of each yearly interval (circles), and the length of the intervals is indicated by the horizontal bars. For sake of clarity, only the 3rd, 50th and 97th centiles of the velocity charts are shown, together with the typical growth velocity curve for the 2SD early maturing boys.

During pre-adolescent years, the growth velocity of this boy fluctuates around the 50th centile. He starts his pubertal growth spurt quite early, i.e. around 9.5 years of age, while his age at peak height velocity was estimated by the Preece Baines model at 11.8 years, which is 2 SD's earlier than the average age at peak height velocity in the population. His bone age was advanced by slightly more than two years during his growth spurt, so that his characteristic pattern of growth velocity can be entirely explained by his early maturation. He stopped growing almost completely by the age of 15 years. It would have been difficult to interpret the normality of his growth velocity, simply on the basis of the centiles, because his growth rate between age 11-12 years and between 14-15 years falls far beyond the 97th and 3rd centiles respectively. However, compared to the typical curve for the 2SD early maturing children in the sample, we can see that his pattern of growth velocity is perfectly normal.

## References


Falkner F. 1961. *Croissance et développement de l'enfant normal. Une méthode internationale d'étude.* Centre Internationale de l'Enfance, Travaux et Documents, Paris.

Graffar M. 1958. *La nécessité d'études longitudinales de la croissance de l'enfant normal.* Acta Paediatrica Belgica, 4: 171-180.

Graffar M. and Corbier J. 1965. *Comparaison d'enfants belges normaux à des critères adéquates de poids et de taille.* Acta Paediatrica Belgica, 19: 235-274.

Hermanussen M. and Sippell W. G. 1985. *Changes of short term growth velocity (mini-growth-spurts) in 36 healthy children, measured twice weekly by knemometry.* Communication presented at the IV International Congress of Auxology, June 16-20, 1985, Montreal.

Marshall W. A. 1971. *Evaluation of growth rate over periods of less than one year.* Archives of Disease in Childhood, 46: 414-420.

Marshall W. A. and Swan A. V. 1971. *Seasonal variation in growth rates of normal and blind children.* Human Biology, 43: 502-516.

Nie N. N., Hull C. H., Jenkins G., Steinbrenner K. and Bent D. G. 1975. *Statistical Package for the Social Sciences.* McGraw-Hill, New York.

Preece M. A. and Baines J. M. 1978. *A new family of mathematical models describing the human growth curve.* Annals of Human Biology, 5: 1-24.

Susanne C., Chrzastek-Spruch H. and Hauspie R. C. 1987. *Standards for height and height velocity for Polish children.* Journal of Human Ecology. (in press).

Tanner J. M. 1962. *Growth at adolescence.* Blackwell Scientific Publications, Oxford and Edinburgh.

Tanner J. M. and Davies P. S. W. 1985. *Clinical longitudinal standards for height and height velocity for North American children.* The Journal of Pediatrics, 107: 317-329.

Tanner J. M., Whitehouse R. H. and Takaishi M. 1966a. *Standardas from birth to maturity for height, weight, height velocity and weight velocity: British children 1965.* Part I. Archives of Disease in Childhood, 41: 454-471.

Tanner J. M., Whitehouse R. H. and Takaishi M. 1966b. *Standards from birth to maturity for height, weight, height velocity and weight velocity: British children 1965.* Part II. Archives of Disease in Childhood, 41: 613-635.

Valk I. M. and Langhout Chabloz A. M. E. 1982. *Accurate measurement of the lower leg length and its application in growth measurements.* Communication presented at the III International Congress of Auxology, August 26-30, 1982, Brussels.

Vercauteren M. 1984. *Evolution séculaire et normes de croissance chez des enfants belges.* Bulletin de la Société royale belge d'Anthropologie et de Préhistoire, 95: 109-123.

Wachholder A. and Hausoie R. C. 1987. *Clinical standards for growth in height of Belgian boys and girls, aged 2 to 18 years.* International Journal of Anthropology, 1: 327-338.

## Appendix

*Estimation of centiles*

The centiles were estimated by calculating means and standard deviations of whole-year increments in height. Since all subjects were measured within a few days from their birthdays, the adjustements to exact one-year intervals were small and the effect of seasonal variations on the estimated growth rates could be neglected. We calculated the centile values parametrically from the means and standard deviations and assigned the centile values to the midpoints of the respective intervals.

The smooth centile lines on the charts were obtained by fitting the mathematical first derivative of the Preece Baines model I (Preece and Baines, 1978) to the calculated centile values. The function takes the form:

$$y = \frac{2(h_1 - h_\theta)\{s_0 \exp[s_0(t-\theta)] + s_1 \exp[s_1(t-\theta)]\}}{\{\exp[s_0(t-\theta)] + \exp[s_1(t-\theta)]\}^2},$$

where y = height (cm), t = age (years) and $h_1$, $h_\theta$, $s_0$, $s_1$ and $\theta$, are the five function parameters. Curve fitting was done by an efficient non-linear least squares technique (nie et al., 1975). The average residual variance, obtained for the fits to the centile values, was 0.11 in boys and 0.09 in girls. Only the fit of the model to the P3 values in girls produced minor problems due to the rather important fluctuations in the centile values, compared to the weakly pronounced increase of P3 values at adolescence. In order to produce a smooth curve for the P3 centile in girls, we have estimated $s_1$ and $\theta$ by extrapolation on the basis of the values, obtained for these two parameters for the 6 other centile curves. So, the value for $s_1$ obtained by the least squares technique of 0.9698 was modified to 1.07, and the value for $\theta$ of 11.1475 was modified to 11.3. These minor alterations resulted in a graphically more acceptable pattern of the P3 centile line, compared with the other centile lines.

*Typical early, average and late maturer curves*

The typical curves for early, average and late maturers are the mathematical first derivatives of the corresponding distance curves, shown in an earlier paper (Wachholder and Hauspie, 1987). Values of the 97th and 3rd centile for peak velocity around the curves of early, average and late maturers were obtained by adding and substracting respectively $1.88 \times SD$ of the value for peak velocity observed in the population.

All calculations were performed at the University of Brussels Computer Center (C.D.C. - Cyber 170/750).