# GROWTH ANALYSIS OF MARGINAL CASES OF NORMAL VARIATION

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Abstract: *Individual growth curves of 81 boys and 78 girls from Prague, followed-up from birth to 20 years of age, were plotted by hand and using Preece-Baines Model I. Velocity curves were derived from distance curves for each child and 12 of their parameters were computed. From the total number of boys and girls three individuals were selected which represented tall, short, retarded and accelerated individuals of each sex.*

*No chronic diseases were present in the investigated children. Common child- and respiratory diseases showed no relation either to tall or to short children and to early and late maturers. Occupation of the fathers had no distinct positive or negative impact on growth and maturation of the investigated children.*

*Positive impact of midparent height on tall and short stature was observed. Secondary sex characteristics and vital capacity correlated positively with early maturation. Tall and short stature could be predicted already at 4 years of age (H4 and V5). Late maturers often overtook early maturers in their final height. Body characteristics other than heights tend to shift in short as well as in tall boys and girls to normal values. At the age of 12 years, late maturing boys and girls were shorter and more slender than the early maturers.*

*Key words: Prague Longitudinal Growth Study; Variation of growth; Tall and small people; Accelerated and delayed maturation.*

## Introduction

Growth is regulated most probably by polygenic expression rather than by a single gene. A specific genetic losus for growth has not been found yet (Hill and Fiser 1977). Different growth patterns in children would most problably exist even under optimal living conditions of all members in a given humaen population. However, living conditions of children in normal human societies differ somewhat in each community, even in each family. Environmental conditions differ for each child even in the same family.

An attempt was made to elucidate the impact of genetic and environmental factors on the growth, using marginal cases of normal variation from the Prague Longitudinal Growth Study from birth to 20 years (81 boys and 78 girls). This paper is concerned with healthy boys and girls of extreme stature (tall and low) and with extreme early and late maturers of both sexes (Prokopec 1986).

## Material and Method

The original sample of 300 children was selected at random from one Prague district (Žizkov) between 1956 and 1960. Children included in the study were followed-up from birth to the age of 20 years. The health history, social and family background were recorded and 15 measurements were made in each child 5 times in the first year and thereafter twice a year, adhering to the guidelines of the International Childrens' Centre in Paris (Falkner 1960).

Distance and velocity growth curves were drawn first by hand and than by a plotter using Preece-Baines Model I for each individual. Distance curves separately for all boys asnd all girls were drawn on one diagram (Figure 1). This gives a unique picture of the
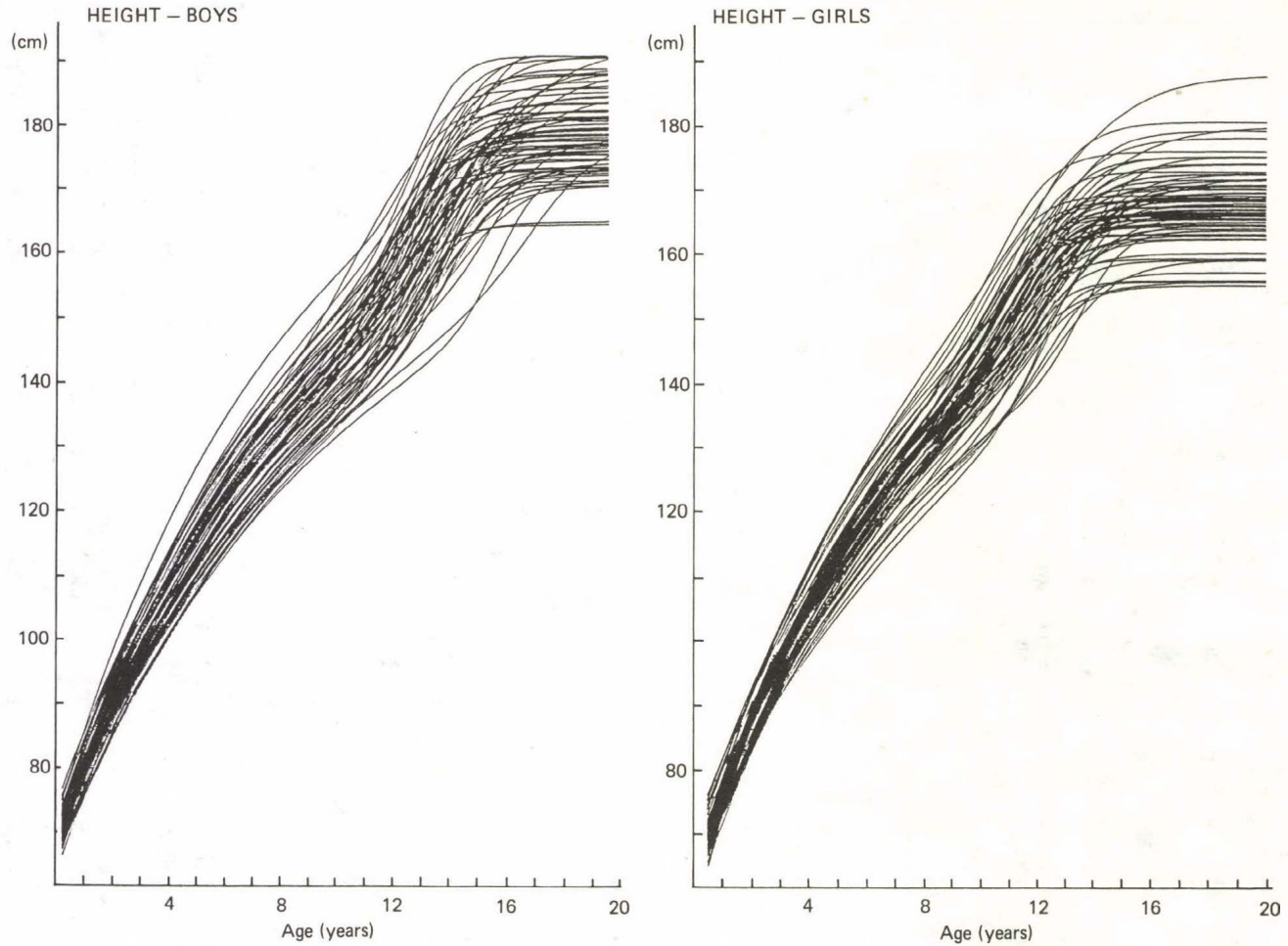
*Figure 1:* Growth curves after Preece–Baines Model I from birth to 20 years of 81 boys and 78 girls from the Prague Longitudinal Growth Study
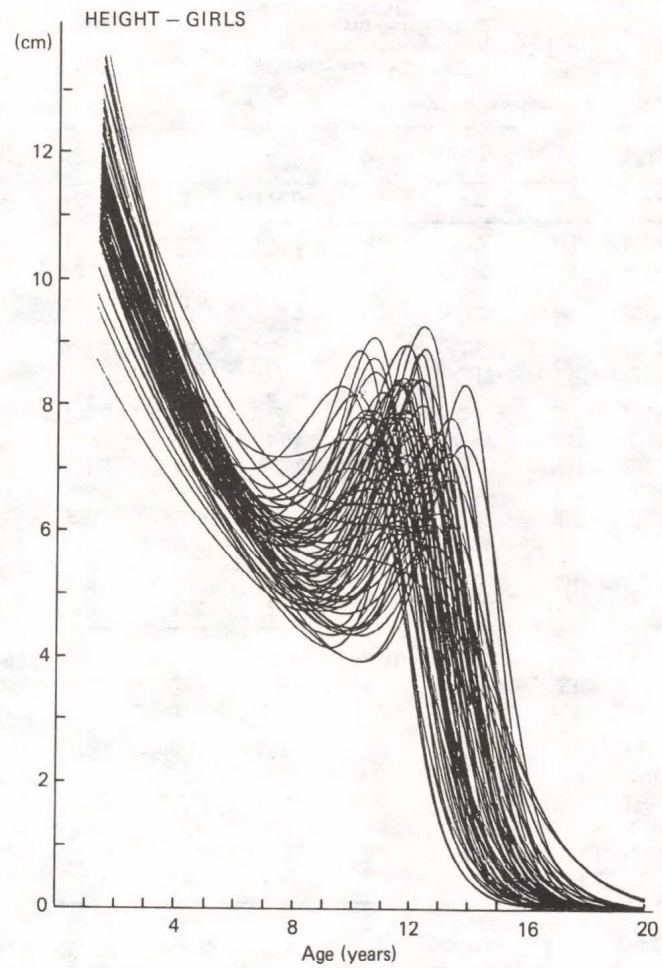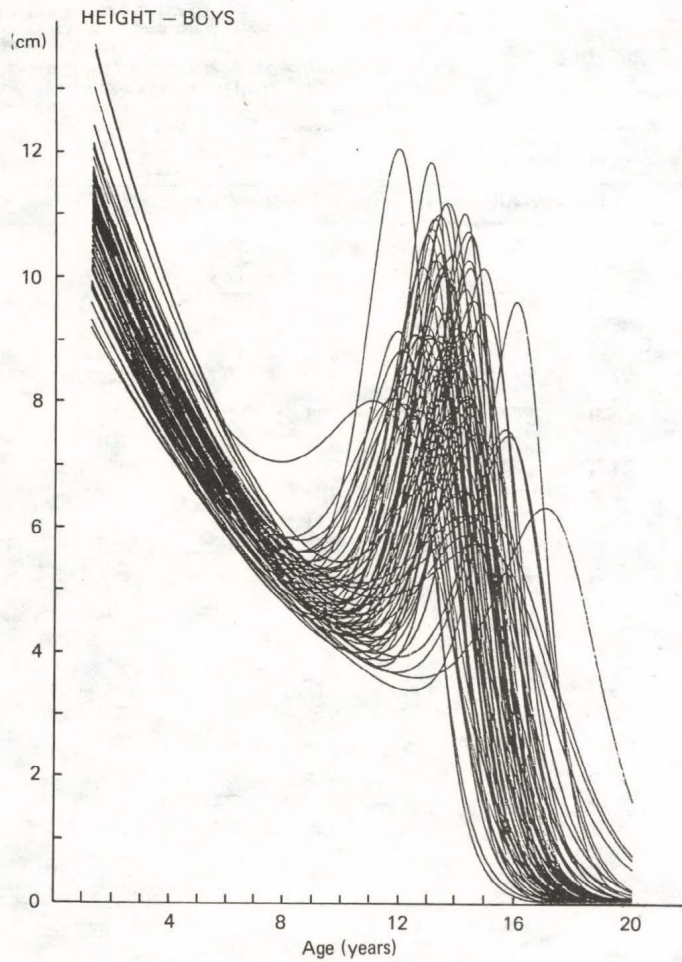
*Figure 2:* Velocity curves of 81 boys and 78 girls from the Prague Longitudinal Growth Study

*Table 1.* **Preece-Baines growth curves parameters in boys from the Prague Longitudinal Growth Study***

| | No. of Children | AMHV y | APHV y | AMHVR y | H4 cm | HMHV cm | TAG y | HPHV cm/y | HMHVR cm/y | HA cm | V5 cm/y | MHV cm/y | PHV cm/y | MPH cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tall | 254 | 0.33 | -0.3 | -0.55 | 2.97 | 2.48 | -0.92 | 2.31 | 2.16 | 1.83 | 3.00 | 0.00 | 1.07 | 1.32 |
| | | 10.2 | 13.2 | 14.5 | 115.7 | 156.5 | 30.5 | 176.4 | 187.1 | 190.5 | 8.3 | 4.7 | 10.4 | 175.0 |
| | 114 | 0.0 | 0.1 | 0.09 | 0.73 | 0.84 | 1.83 | 1.61 | 1.97 | 1.92 | 1.5 | 0.83 | 1.07 | 1.59 |
| | | 9.9 | 13.6 | 15.2 | 107.4 | 145.5 | 40.4 | 172.1 | 185.9 | 191.1 | 7.7 | 5.2 | 10.4 | 176.5 |
| | 223 | 0.66 | 0.8 | 0.82 | 1.46 | 1.58 | 0.97 | 2.11 | 2.29 | 2.21 | 1.00 | 0.17 | 0.21 | -0.02 |
| | | 10.5 | 14.3 | 16.0 | 110.1 | 150.5 | 37.3 | 175.2 | 187.9 | 192.9 | 7.5 | 4.8 | 9.2 | 167.5 |
| Small | 272 | -0.77 | -0.9 | -0.91 | -1.35 | -1.64 | -0.81 | -2.10 | -2.24 | -2.29 | -1.25 | -0.17 | -0.57 | -2.16 |
| | | 9.2 | 12.6 | 14.1 | 99.7 | 128.9 | 30.9 | 149.5 | 159.8 | 164.6 | 6.6 | 4.6 | 8.1 | 155.5 |
| | 210 | 0.56 | 0.6 | 0.55 | -1.08 | -0.87 | -0.39 | -1.15 | -1.16 | -1.40 | -2.00 | -1.17 | -0.07 | 0.25 |
| | | 10.4 | 14.1 | 15.7 | 100.7 | 134.1 | 32.4 | 155.3 | 166.5 | 170.2 | 6.3 | 4.0 | 8.8 | 169.0 |
| | 79 | -1.11 | -1.2 | -1.18 | -1.22 | -1.79 | -0.47 | -2.18 | -2.21 | -2.37 | -1.75 | -0.33 | 0.14 | -2.16 |
| | | 8.9 | 12.3 | 13.8 | 100.2 | 127.9 | 32.1 | 149.0 | 160.0 | 164.1 | 6.4 | 4.5 | 9.1 | 155.5 |
| Early | 122 | -2.11 | -1.9 | -1.82 | -0.62 | -1.72 | 0.58 | -1.54 | -1.50 | -0.94 | 0.00 | 1.83 | -0.57 | -2.07 |
| | | 8.0 | 11.6 | 13.1 | 102.4 | 128.4 | 35.9 | 152.9 | 164.4 | 173.1 | 7.1 | 5.8 | 8.1 | 156.0 |
| | 215 | -1.78 | -1.8 | -1.73 | -0.49 | -1.51 | 2.00 | -0.97 | -0.47 | -0.60 | -0.25 | 1.00 | 2.29 | -1.09 |
| | | 8.3 | 11.7 | 13.2 | 102.9 | 129.8 | 41.0 | 156.4 | 170.8 | 175.2 | 7.0 | 5.3 | 12.1 | 161.5 |
| | 100 | -1.56 | -1.8 | -1.82 | 0.41 | -0.84 | -0.22 | -0.97 | -1.02 | -1.03 | 0.00 | 0.83 | 0.21 | -0.29 |
| | | 8.5 | 11.7 | 13.1 | 106.2 | 134.3 | 33.0 | 156.4 | 167.4 | 172.5 | 7.1 | 5.2 | 9.2 | 166.0 |
| Late | 211 | 2.67 | 2.4 | 2.18 | -1.68 | -0.16 | -0.72 | -0.59 | -0.60 | -1.02 | -2.00 | -2.17 | 0.50 | -2.61 |
| | | 12.3 | 15.9 | 17.5 | 98.5 | 138.8 | 31.2 | 158.7 | 170.0 | 172.6 | 6.3 | 3.4 | 9.6 | 153.0 |
| | 92 | 2.11 | 2.1 | 2.00 | -0.24 | 0.54 | -1.03 | 0.16 | -0.02 | -0.25 | -1.25 | -1.67 | -1.00 | 0.70 |
| | | 11.8 | 15.6 | 17.3 | 103.8 | 143.5 | 30.1 | 163.3 | 173.6 | 177.4 | 6.6 | 3.7 | 7.5 | 171.5 |
| | 13 | 2.89 | 3.4 | 3.36 | -1.38 | 0.27 | -0.83 | -0.02 | -0.19 | -0.30 | -1.75 | -1.83 | -1.86 | -0.64 |
| | | 12.5 | 16.9 | 18.8 | 99.6 | 141.7 | 30.8 | 162.2 | 172.5 | 177.3 | 6.4 | 3.6 | 6.3 | 164.0 |
| Total | M | 9.9 | 13.5 | 15.1 | 104.7 | 139.9 | 33.8 | 162.3 | 173.7 | 179.0 | 7.1 | 4.7 | 8.9 | 167.6 |
| Sample | (SD) | (0.9) | (1.0) | (1.1) | (3.7) | (6.7) | (3.6) | (6.1) | (6.2) | (6.3) | (0.4) | (0.6) | (1.4) | (5.6) |

* Age at minimal prepubertal height velocity (AMHV)
  Age at peak height velocity (APHV)
  Age at minimal prepubertal height velocity return (AMHVR)
  Height at age 4 (H4)
  Height at minimal prepubertal height velocity (HMHV)
  Total adolescent gain (TAG)
  Height at peak height velocity (HPHV)

Height at minimal prepubertal height velocity return (HMHVR)
Adult height (AH)
Height velocity at age 5 (V5)
Minimal prepubertal height velocity (MHV)
Peak height velocity (PHV)
Midparent height (MPH)

Table 2. **Preece-Baines growth curves parameters in girls from the Prague Longitudinal Growth Study**
(abbreviations idem as in Table 1)

| | No. of Children | AMHV y | APHV y | AMHVR y | H4 cm | HMHV cm | TAG y | HPHV cm/y | HMHVR cm/y | HA cm | V5 cm/y | MHV cm/y | PHV cm/y | MPH cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tall | 136 | -0.33 | 0.1 | 0.18 | 1.64 | 0.97 | 1.73 | 2.04 | 2.32 | 2.25 | 1.0 | 0.86 | 1.75 | 1.02 |
| | | 8.1 | 11.5 | 13.0 | 109.2 | 137.0 | 36.0 | 161.3 | 172.9 | 180.2 | 7.4 | 5.9 | 8.9 | 174.0 |
| | 66 | 0.55 | 0.9 | 1.00 | 1.91 | 1.69 | 0.51 | 2.20 | 2.17 | 2.03 | 0.75 | -0.14 | 0.00 | 1.66 |
| | | 8.9 | 12.3 | 13.7 | 110.1 | 141.5 | 30.5 | 162.2 | 172.0 | 178.5 | 7.3 | 5.2 | 7.5 | 177.0 |
| | 195 | 1.55 | -0.7 | -1.55 | 1.94 | 3.46 | -4.4 | 1.51 | 0.32 | 3.47 | 3.25 | 1.57 | 1.38 | 2.94 |
| | | 9.8 | 10.7 | 11.1 | 110.2 | 152.6 | 8.4 | 158.4 | 161.1 | 187.4 | 8.3 | 6.4 | 6.4 | 183.0 |
| Small | 141 | -1.33 | -1.6 | -1.64 | -1.73 | -2.02 | -1.16 | -2.85 | -3.00 | -1.98 | -1.25 | 0.86 | 1.38 | -0.68 |
| | | 7.2 | 9.8 | 11.8 | 98.1 | 118.5 | 23.0 | 134.4 | 141.5 | 155.2 | 6.5 | 5.9 | 6.4 | 166.0 |
| | 105 | 0.0 | -0.1 | -0.18 | -1.24 | -0.97 | -1.20 | -1.73 | -1.93 | -2.08 | -1.50 | -0.71 | -0.75 | -1.96 |
| | | 8.4 | 11.3 | 12.6 | 99.7 | 125.0 | 22.8 | 140.6 | 147.8 | 154.6 | 6.4 | 4.8 | 6.1 | 160.0 |
| | 221 | 0.78 | 0.6 | 0.45 | -1.45 | -0.79 | -0.47 | -1.27 | -1.20 | -1.98 | -1.75 | -1.71 | 1.63 | -2.06 |
| | | 9.1 | 12.0 | 13.3 | 99.0 | 126.1 | 26.1 | 143.1 | 152.1 | 155.2 | 6.3 | 4.1 | 8.8 | 150.5 |
| Early | 26 | -1.22 | -1.7 | -1.91 | -0.88 | -0.89 | -0.73 | -1.33 | -1.47 | 0.69 | 1.75 | 2.57 | -0.13 | -0.15 |
| | | 7.3 | 9.7 | 10.7 | 100.9 | 125.5 | 24.9 | 142.8 | 150.5 | 171.0 | 7.7 | 7.1 | 7.4 | 168.5 |
| | 36 | -2.44 | -2.1 | -2.00 | 0.03 | -1.74 | 1.11 | -1.29 | -0.28 | -0.22 | 0.50 | 2.29 | 0.88 | 1.98 |
| | | 6.2 | 9.3 | 10.6 | 103.9 | 120.2 | 33.2 | 143.0 | 153.4 | 165.6 | 7.2 | 6.9 | 8.2 | 178.5 |
| | 203 | -1.33 | -1.7 | -1.82 | -1.36 | -1.53 | -0.93 | -2.18 | -2.32 | 1.22 | 0.50 | 1.57 | -0.75 | -0.36 |
| | | 7.2 | 9.7 | 10.8 | 99.3 | 121.5 | 24.0 | 138.1 | 145.5 | 159.7 | 7.2 | 6.4 | 6.9 | 167.5 |
| Late | 61 | 1.67 | 1.8 | 1.64 | 0.45 | 1.29 | -0.42 | 1.20 | 1.02 | 0.58 | 0.00 | -1.29 | -0.88 | 0.38 |
| | | 9.9 | 13.2 | 14.6 | 105.3 | 139.0 | 26.3 | 156.7 | 165.2 | 170.3 | 7.0 | 4.4 | 6.8 | 171.0 |
| | 154 | 1.44 | 1.7 | 1.64 | -0.39 | 0.5 | 0.11 | 0.56 | 0.61 | 0.03 | -1.00 | -1.43 | 0.38 | -1.96 |
| | | 9.7 | 13.1 | 14.6 | 102.5 | 134.1 | 28.7 | 153.2 | 162.8 | 167.1 | 6.6 | 4.3 | 7.8 | 160.0 |
| | 205 | 1.56 | 1.7 | 1.64 | 0.18 | 1.05 | -0.16 | 1.05 | 0.98 | 0.49 | -0.25 | -1.29 | -0.38 | 0.38 |
| | | 9.8 | 13.1 | 14.6 | 104.4 | 137.5 | 27.5 | 155.9 | 165.0 | 169.8 | 6.9 | 4.4 | 7.2 | 171.0 |
| Total Sample | M | 8.4 | 11.4 | 12.8 | 103.8 | 131.0 | 28.2 | 150.1 | 159.2 | 166.9 | 7.0 | 5.3 | 7.5 | 169.2 |
| | (SD) | (0.9) | (1.0) | (1.1) | (3.3) | (6.2) | (4.5) | (5.5) | (5.9) | (5.9) | (0.4) | (0.7) | (0.8) | (4.7) |

increasing variability in height from 1 year to 20 years of age. Some of the curves show clearly that children who were taller than others during puberty do not necessarily retain their position at adult age and that, on the other hand, some extremely short children at the age when most of the children pass their puberty period may reach medium stature at the age of 20.

Similarly the great interindividual variability of peak height velocity and the age at peak height velocity in both sexes are shown in Figure 2.

Three of the tallest and three of the shortest boys and girls at the age of 18 years were selected for the detailed study.

Similarly, three boys and three girls with an early onset of peak height velocity and three boys and three girls with delayed peak height velocity were selected for detailed analysis. Parameters of velocity curves of these 24 children were tabulated and analyzed using z-scores. These were computed as deviations from the means of the total groups (81 boys and 78 girls), (Table 1 and 2). Customary abbreviations of individual characteristics of velocity curves used in the text and tables are explained in the text to Table 1.

## Results

*Tall and small boys:* Tall boys show positive deviation and small boys a negative deviation in AMHV from the mean (except in boy number 210). Already at the age of 4 years the tall boys differ distinctly in height and at the age of 5 years in height velocity (V5) from the small boys (H4, HMHV). HPHV and also TAG (except in boy 254) are greater in the tall boys than in the short ones. The HMHVR, HA and V5 (and to a slightly lesser extent the PHV and MHV) display distinct differences between the two groups in favour of the tall boys.

*Tall and small girls:* Similar results are found in girls. Differences in MHV between short and tall girls are greater and in PHV smaller than between short and tall boys.

*Early and late maturing boys:* Early maturing boys reach MHV at an earlier age than late maturing ones and APHV, AMHVR, HMHV, HPHV, HMHVR and HA are in them smaller. On the other hand, the V5, MHV, TAG, and even PHV are on the whole greater in early maturing boys.

*Early and late maturing girls:* The position in girls is essentially similar to that in boys. As in boys, early maturing girls can be differentiated from late maturing ones already at the age of 4 (H4, MHV) resp. 5 years (V5). Late maturing individuals of both sexes deviate distinctly in their growth characteristics from general mean values.

Growth curves of boys and girls with tall and short stature at 18 years (Figure 3) show a variability in growth patterns. The greatest differences are found during puberty (between 11 and 14 in boys and 9 and 12 in girls). In tall individuals distinct differences from the mean may be present already at the age of 2 years or even before.

Common feature of early maturers, boys as well as girls (Figure 4) is an early start of the growth spurt, and of the late maturers a late start of pubertal growth acceleration. The growth pattern beyond the puberty period and the final height are unpredictable in early as well as in late maturers.
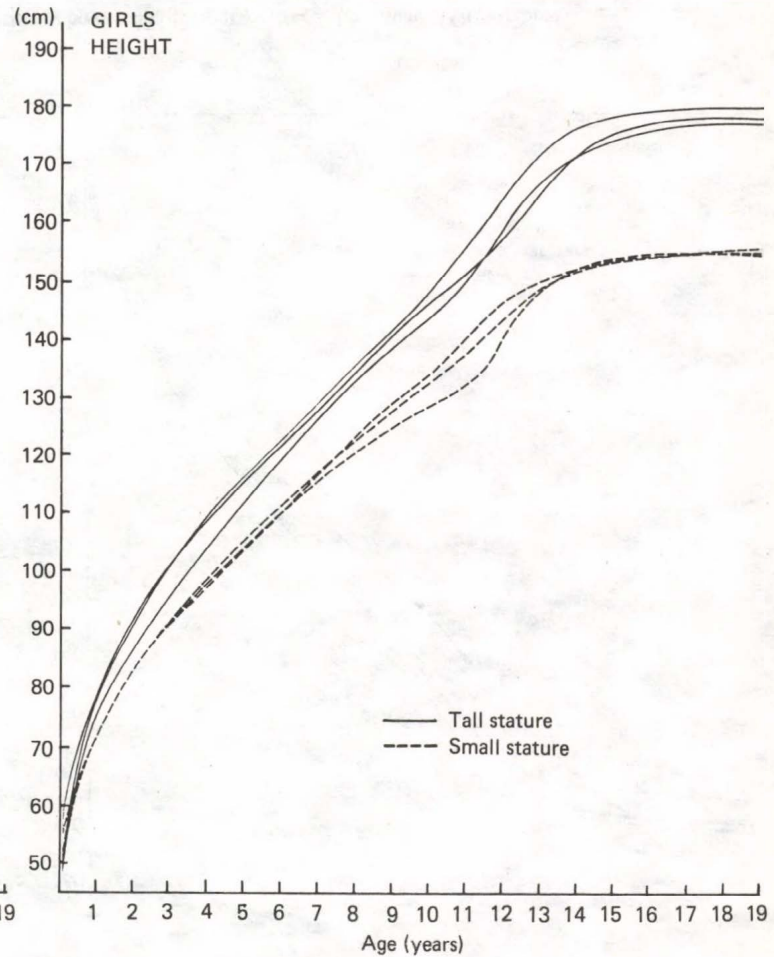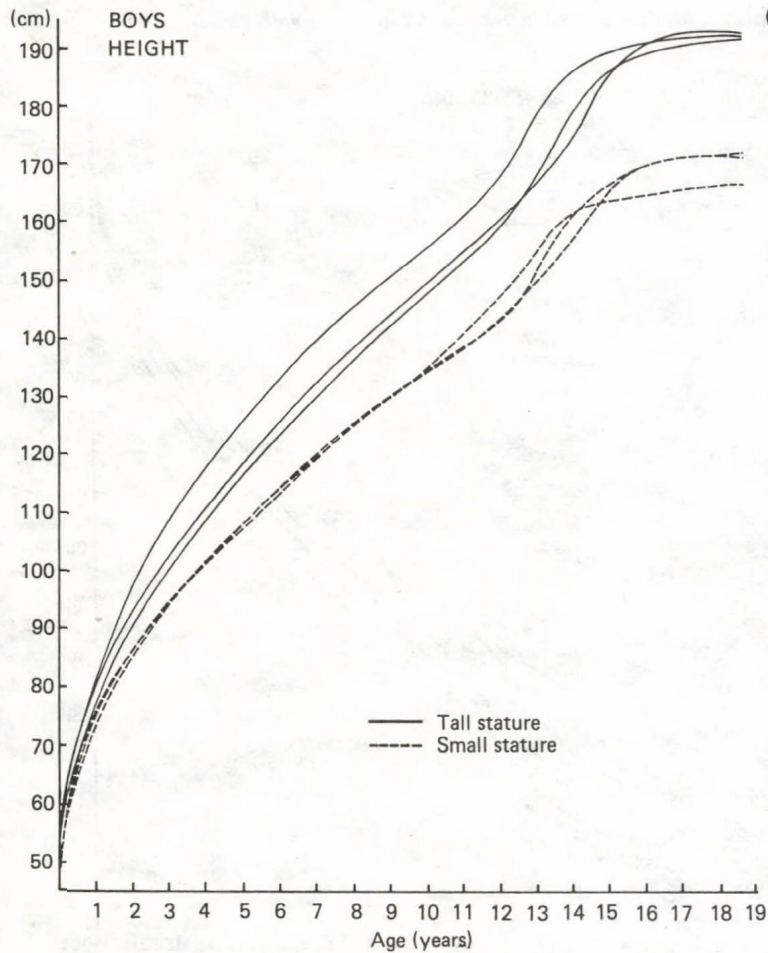
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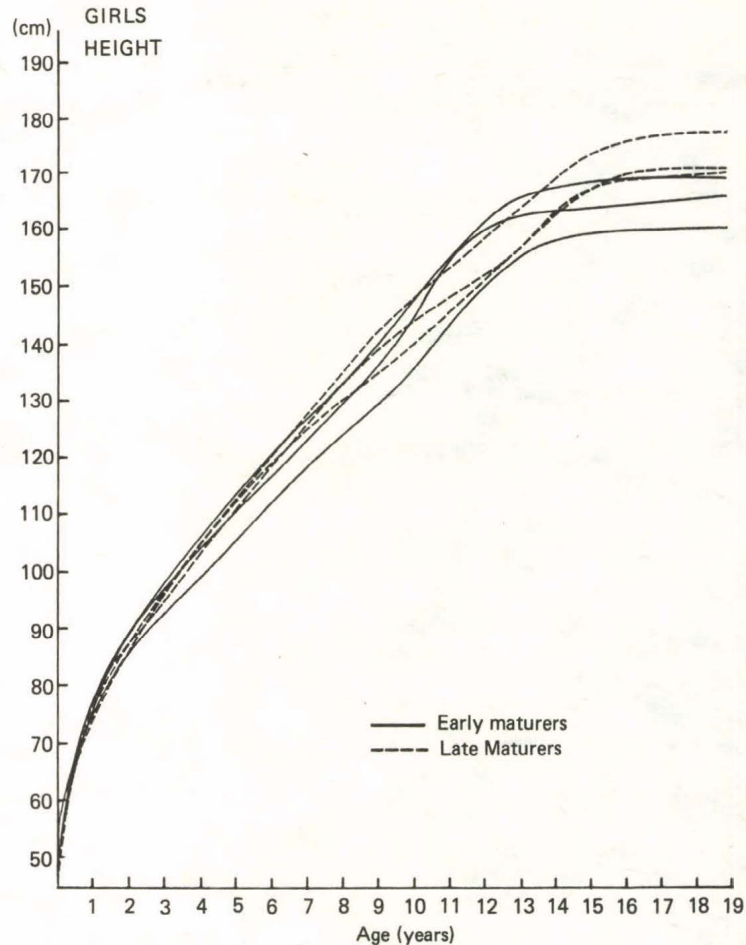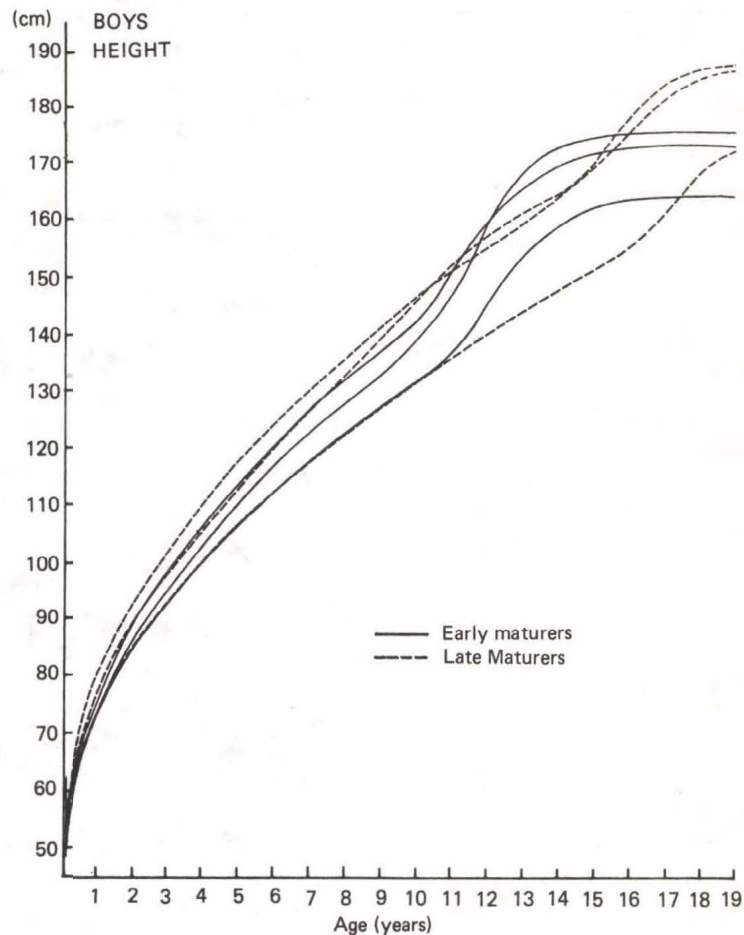*Figure 3:* Growth curves drawn by hand of boys and girls of short and tall stature

*Figure 4:* Growth curves drawn by hand of early and late maturing boys and girls from the Prague Longitudinal Growth Study
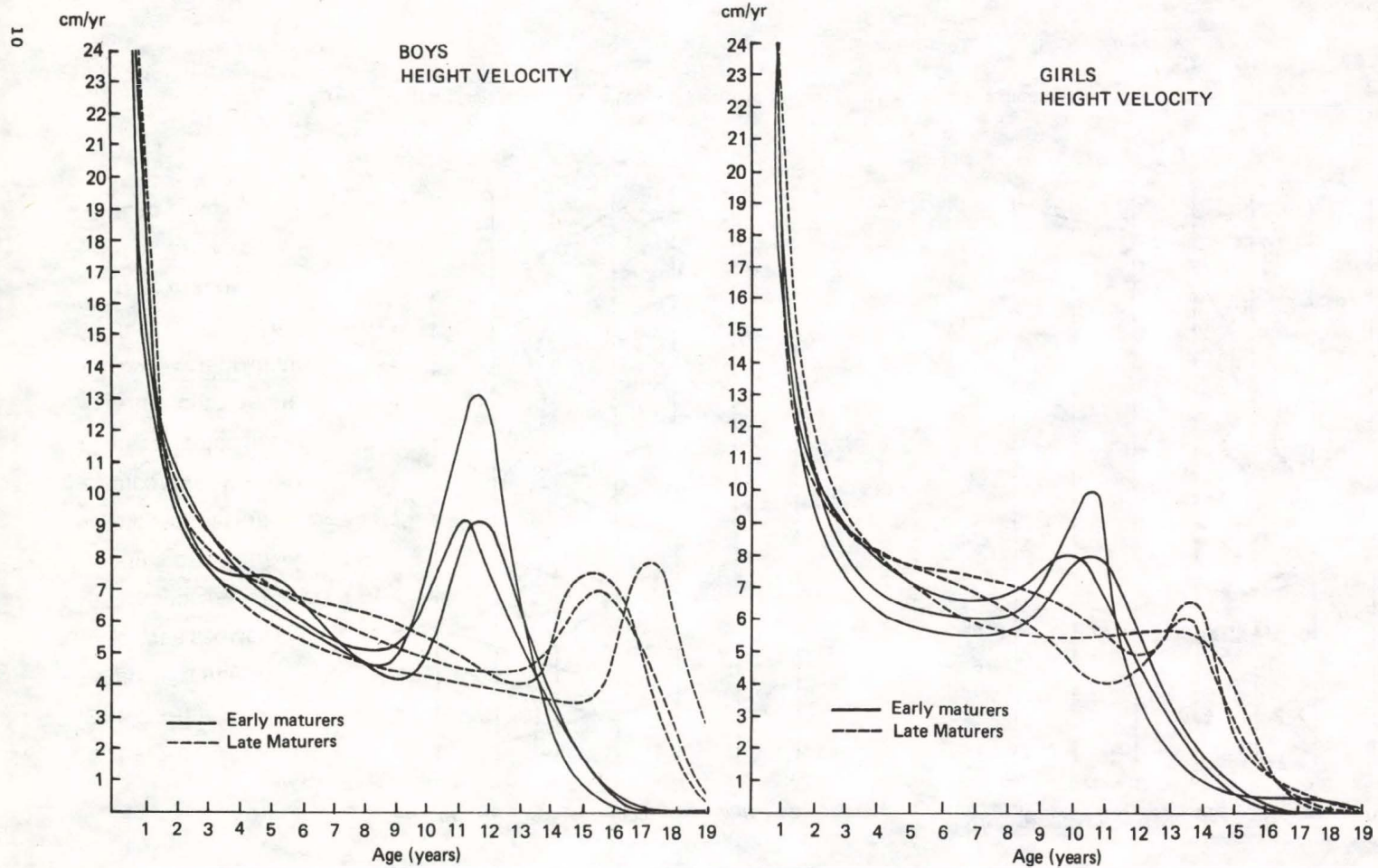
*Figure 5:* Height velocity curves drawn by hand in early and late maturing boys and girls from the Prague Longitudinal Growth Study

## Small boys

## Tall boys

—— 79  --- 219 ——272    Age: 18.0

—— 114  --- 223 ——254    Age: 18.0

| | |
|---|---|
| HEIGHT | 1 |
| WEIGHT | 2 |
| SITTING HEIGHT | 3 |
| LOWER SEGMENT | 4 |
| BIACROMIAL DIAMETER | 5 |
| BIILIOCRISTAL DIAMETER | 6 |
| BICOND. FEMUR | 7 |
| BICOND. HUMERUS | 8 |
| CHEST CIRCUMFER. | 9 |
| WAIST CIRCUMFER. | 10 |
| U. ARM CIRCUMFER. | 11 |
| CALF CIRCUMFER. | 12 |
| HEAD CIRCUMFER. | 13 |
| HEAD BREADTH | 14 |
| HEAD LENGTH | 15 |

$-3\sigma$  $-2\sigma$  $-\sigma$  $0$  $\sigma$  $2\sigma$  $3\sigma$

*Figure 6:* Morphograms of short and tall boys at the age of 18 years from the Prague Longitudinal Growsth Study

# Small girls

# Tall girls

Small girls:  —— 105   ---- 141   —— 221   Age: 18.0

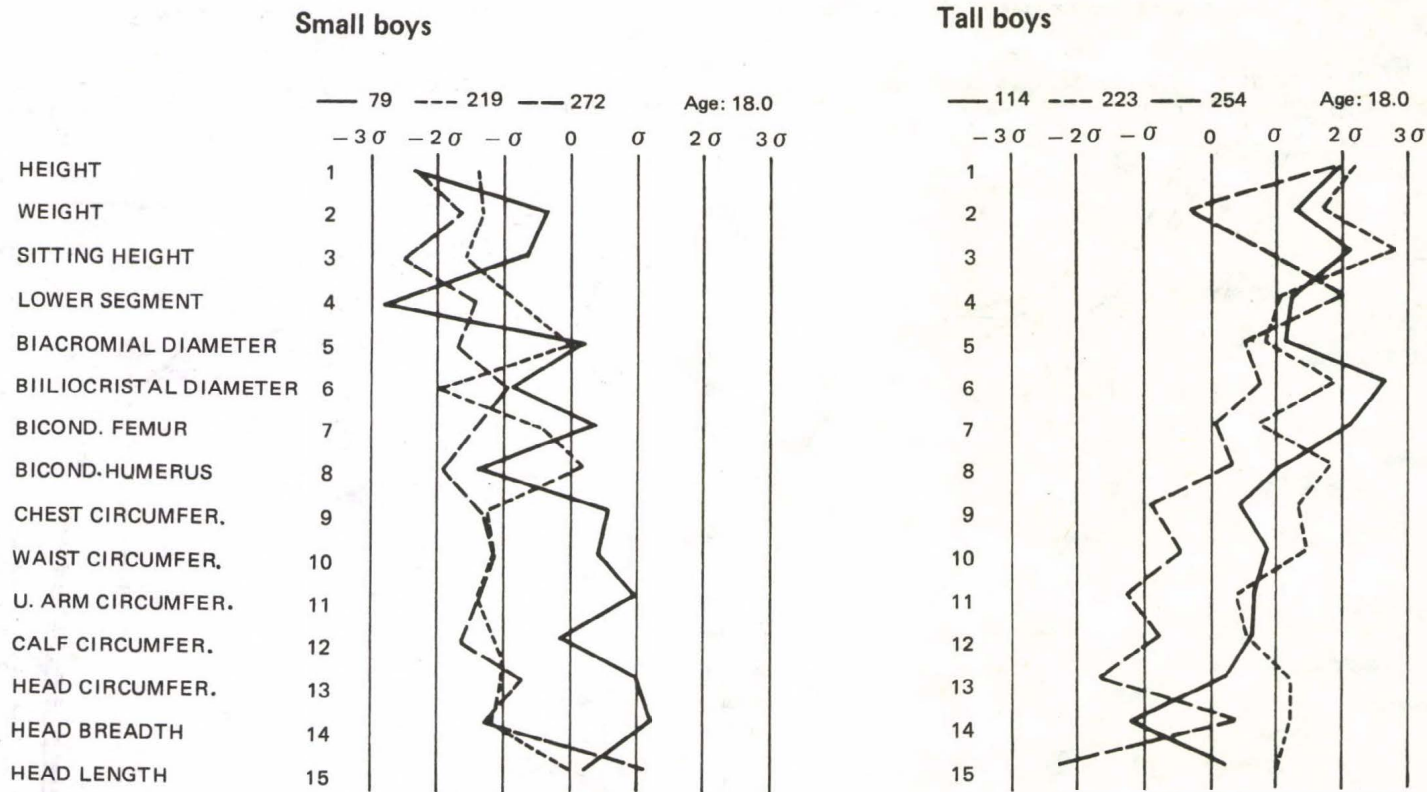Tall girls:  —— 66   ---- 136   —— 195   Age: 18.0

| | | −3σ | −2σ | −σ | 0 | σ | 2σ | 3σ |
|---|---|---|---|---|---|---|---|---|
| HEIGHT | 1 | | | | | | | |
| WEIGHT | 2 | | | | | | | |
| SITTING HEIGHT | 3 | | | | | | | |
| LOWER SEGMENT | 4 | | | | | | | |
| BIACROMIAL DIAMETER | 5 | | | | | | | |
| BIILIOCRISTAL DIAMETER | 6 | | | | | | | |
| BICOND. FEMUR | 7 | | | | | | | |
| BICOND. HUMERUS | 8 | | | | | | | |
| CHEST CIRCUMFER. | 9 | | | | | | | |
| WAIST CIRCUMFER. | 10 | | | | | | | |
| U. ARM CIRCUMFER. | 11 | | | | | | | |
| CALF CIRCUMFER. | 12 | | | | | | | |
| HEAD CIRCUMFER. | 13 | | | | | | | |
| HEAD BREADTH | 14 | | | | | | | |
| HEAD LENGTH | 15 | | | | | | | |

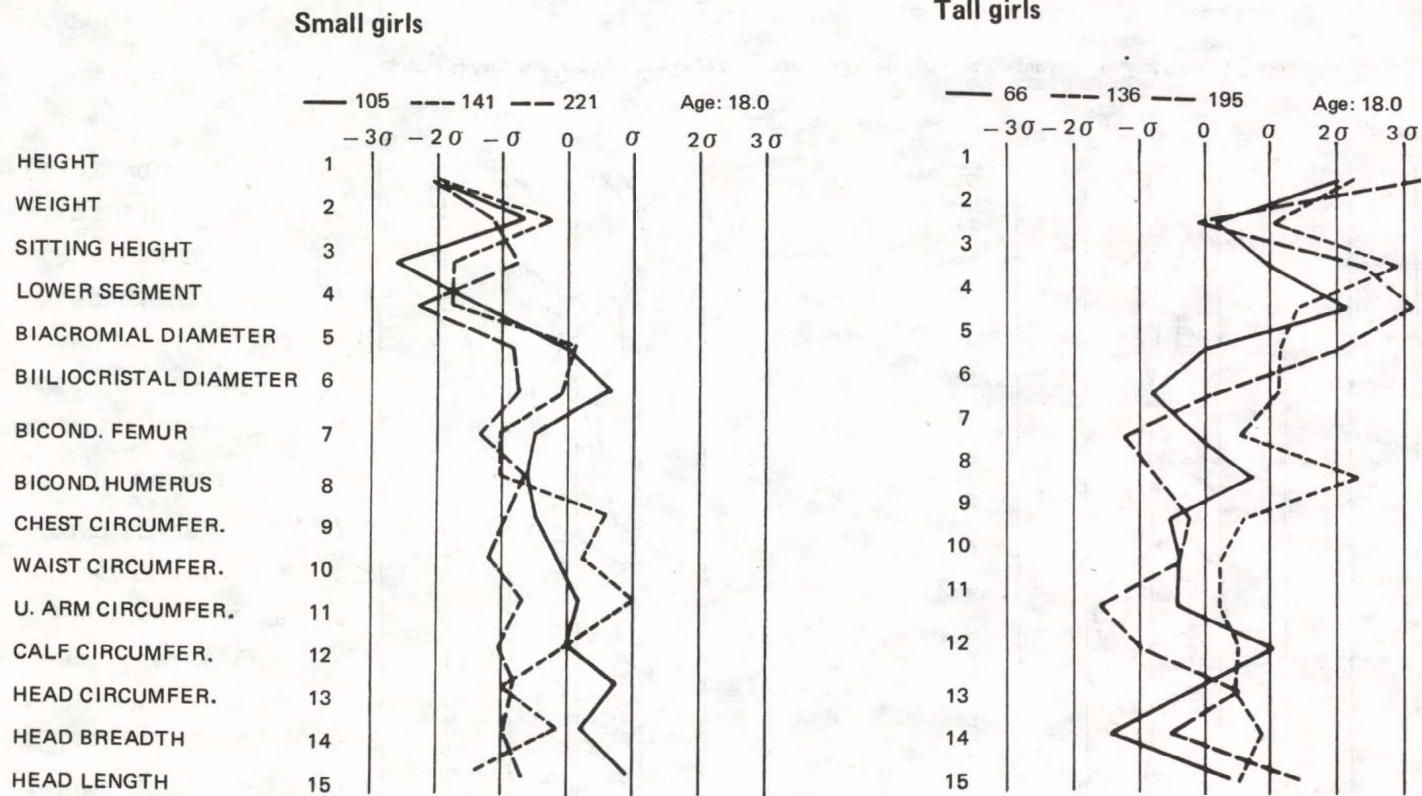*Figure 7:* Morphograms of short and tall girls at the age of 18 years from the Prague Longitudinal Growth Study

## Early maturing boys

— 100  --- 122  —— 215    Age: 12.0

| | | −3 | −2 | −σ | 0 | σ | 2 | 3 |
|---|---|---|---|---|---|---|---|---|
| HEIGHT | 1 |
| WEIGHT | 2 |
| SITTING HEIGHT | 3 |
| LOWER SEGMENT | 4 |
| BIACROMIAL DIAMETER | 5 |
| BIILIOCRISTAL DIAMETER | 6 |
| BICOND. FEMUR | 7 |
| BICOND. HUMERUS | 8 |
| CHEST CIRCUMFER. | 9 |
| WAIST CIRCUMFER. | 10 |
| U. ARM CIRCUMFER. | 11 |
| CALF CIRCUMFER. | 12 |
| HEAD CIRCUMFER. | 13 |
| HEAD BREADTH | 14 |
| HEAD LENGTH | 15 |

## Late maturing boys

— 13  --- 92  —— 211    Age: 12.0

| −3 | −2 | − | 0 | σ | 2 | 3 |
|---|---|---|---|---|---|---|

1
2
3
4
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6
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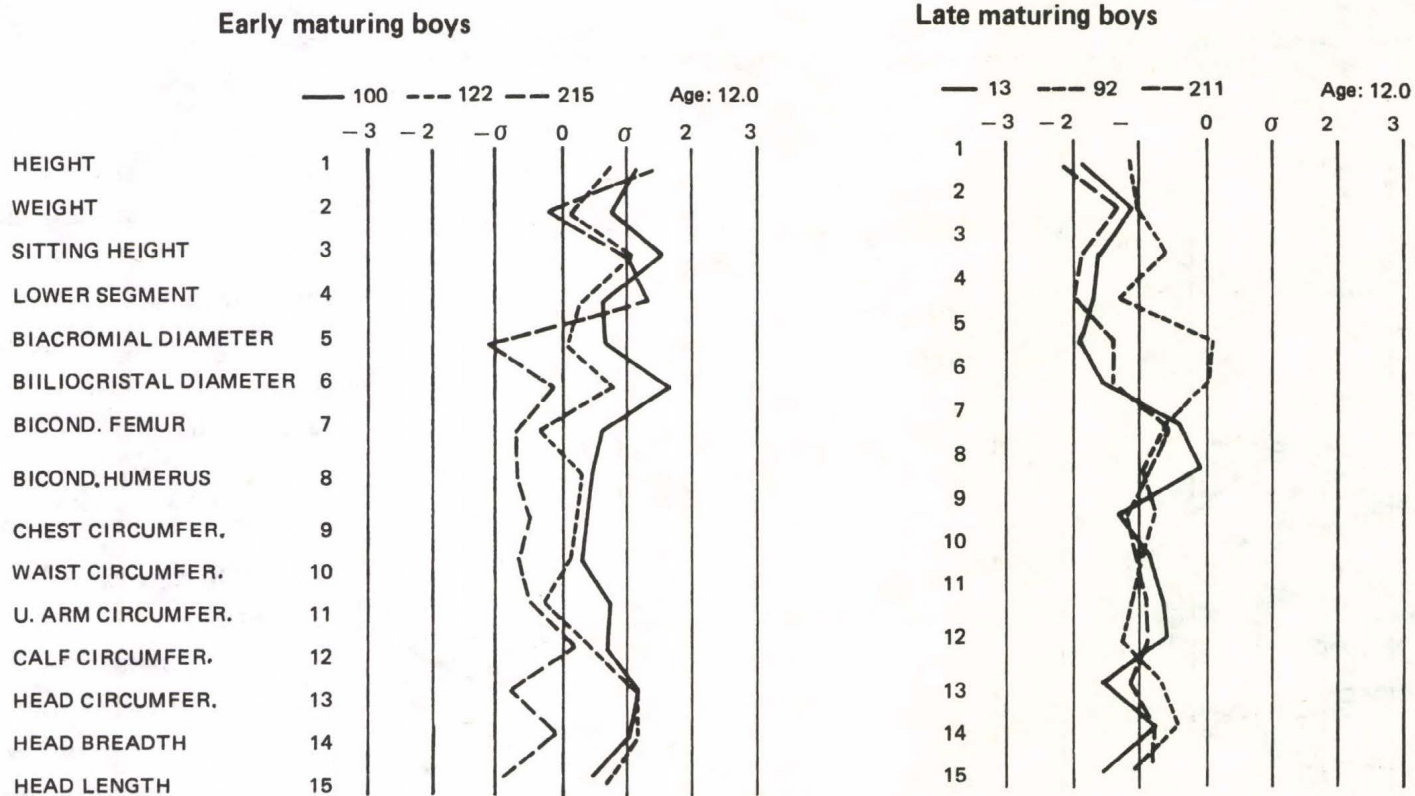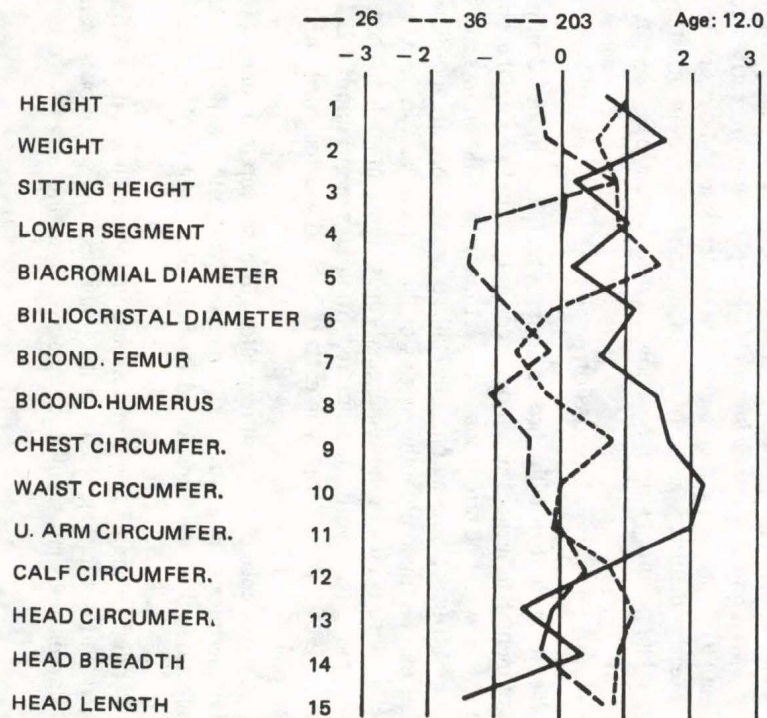*Figure 8:* Morphograms of early and late maturing boys at the age of 12 years from the Prague Longitudinal Growth Study
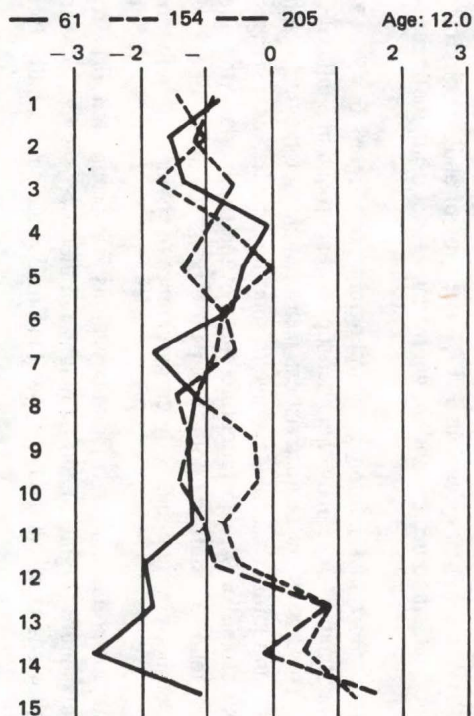
*Figure 9:* Morphograms of early and late maturing girls at the age of 12 years from the Prague Longitudinal Growth Study

Figure 5 shows typical velocity curves of early and late maturers with great differences in APHV and in some cases in PHV. (The growth and velocity curves in Figure 3, 4, 5 have been smoothed out and drawn by hand – not using the Preece-Bains Model I).

*Morphograms of short and tall boys:* Morphograms on Figure 6 show z-score deviations from the standard in 15 body characteristics in 3 short and in 3 tall boys at the age of 18 years. The first eight characteristics: measurements of height, weight and widths of the trunk and joints are below average in short boys and above average in tall boys. Characteristics number 9 to 15 (circumferences of the trunk and extremities and hand dimensions) tend to shift in both groups of boys towards normal values. Correlation between body weight and body circumferences is evident in individuals 79 and 254.

*Morphograms of short and tall girls:* Great deviations in short and tall girls from the mean concern only stature (Figure 7), sitting height and the lower segment. Other body characteristics followed-up in the study do not tend to deviate substantially from the average.

*Morphograms of early and late maturing boys:* Morphograms of early and late maturing boys (Figure 8) show that at the age of 12, early maturing boys are taller than late maturing boys. Their characteristics 5 to 15 are between minus and plus 1 SD from the mean. The late maturing boys are shorter and more slender, with characteristics 7 to 15 close to minus 1 SD.

*Morphogram of early and late maturing girls:* Morphograms of early and late maturing girls (Figure 9) do not show such a clear cut tendency as in boys. There is the same tendency in early maturing girls to overshoot the average in most of the measurements and in late maturing girls to be below average at the age of 12 years.

## Discussion

It may be assumed that children with chronic diseases and those hindered in growth by negative environmental influences are more frequently found among the children with short stature, but it would be erroneous to expect that only children in good health and those living in affluence are among the tallest ones. Normal and abnormal (pathological) cases can be found on both margins of the normal variation next to each other. Therefore clinical screening of these marginal cases is recommended. There were no chronic diseases among the investigated children. Short legs in girl number 221 were noted already at the age of 5 years. Obesity in early childhood was recorded in girl 205, later in life in girls 26, 105 and 141.

Health records give evidence of frequent respiratory diseases (up to 5 times a year in one case) treated sometimes with antibiotics, sometimes with sulfonamides or aspirin only. Common infectious diseases were found in the health records of practically all children.

Fathers of the 24 children from Table 1 and 2 were in 15 cases manual workers, in 5 white collar workers and in 5 instances university graduates. The social background in these individual children does not seem to correlate with stature or with the onset of

puberty, although social status of the family always correlated closely with child growth in cross-sectional studies (Prokopec & Dutková 1985).

Midparent height proved to be highly predictive; this applied in tall boys (average midparent height 173 cm) and girls (173.5 cm), whereas midparent heights of short boys was 160.0 cm and of short girls 161.3 cm. Midparent heights of the early and late maturers showed no clear cut correlation with either early or late onset of puberty of the children.

In all early maturing boys and girls, secondary sex characteristics developed two or more years earlier than in the late maturers. Accelerated morphological development in the early maturers was followed by earlier physiological maturation in comparison with late maturers, as was shown by the values of vital capacity.

## References

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