

Vertical facial growth and statural growth in girls: a longitudinal comparison

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SUMMARY Individual and average growth patterns of the facial dimensions Nasion–Gnathion and Sella–Gonion, as related to statural growth were studied. The sample consisted of 134 girls aged 7–14 years. Data were analysed using a multivariate extension of the multilevel model for longitudinal data.

The results confirmed that the mean growth curves of Nasion–Gnathion, Sella–Gonion and body height parallel each other to a large extent. At an individual level it appeared that the pubertal growth spurt of body height and the growth spurts of both facial dimensions are coincident. The major results of the present study pertain to the dynamic (age-dependent) relationship between statural growth and the growth of the face. It appears that there exists a stronger relationship between the growth velocities of standing height, Sella–Gonion and Nasion–Gnathion than between the actual lengths of the three variables themselves. The strongest relation was found between the growth velocity of body height and that of Sella–Gonion. These findings may be a contribution for diagnosis and treatment planning of individual cases.

Introduction

Questions regarding the relationship between growth of the face and growth of standing height can be posed from different perspectives. A first question is whether the form of the growth curve of a particular facial dimension resembles the growth curve of standing height? This question is generally answered by comparing average growth and velocity curves. By comparing average curves, it has been concluded that the mean growth patterns of facial dimensions and of body height are to a large extent similar (Nanda, 1955; Rose, 1960; Bambha, 1961; Hunter, 1966; Pike, 1968; Baughan *et al.*, 1979; Baume *et al.*, 1983).

Most researchers agree, however, that mean curves are not particularly informative and that making comparisons between individual curves is the preferred method of investigation. Such comparisons can take two forms: first, the specific aspects of the growth curves may be compared, such as the time of onset and duration of the pubertal growth spurt. For instance, Nanda (1955) showed that for several facial dimensions the pubertal maximum is reached somewhat later than for body height. This con-

clusion was later confirmed by Bambha (1961) and Baughan *et al.* (1979). In contrast, Hunter (1966), Grave (1973), Thompson *et al.* (1976) and Moore *et al.* (1990) have reported that peak height velocity and the pubertal peaks for facial dimensions are coincident. Secondly, the relationships between individual growth curves can be analysed using correlational techniques. The latter techniques were employed by Pike (1968), Baume *et al.* (1983) and Moore *et al.* (1990). They investigated correlations between changes in facial dimensions and statural growth. Pike (1968) showed that changes in mandibular components (ramus height and mandibular length) are more strongly related to changes in stature ($r=0.64$) than to changes in maxillary components (N–Me, $r=0.41$). The study by Baume *et al.* (1983) revealed that changes in vertical facial dimensions (N–Me) are more closely related to changes in standing height than to changes in total head height. Finally in the study by Moore *et al.* (1990) it was observed that changes in facial dimensions (S–N, S–Ar, Go–Me, N–Me, S–Go) with the exception of changes in S–Go in girls aged 10–11 years, are only weakly related to the changes in statural height.

In summary, there are three options to investigate the relation between facial and statural growth: (i) comparison of mean growth curves; (ii) comparison of characteristics of individual growth curves; and (iii) determination of associations between specific aspects of individual growth curves. In the studies mentioned these options are generally treated separately. That is, separate data analyses are performed with respect to each option. In the present study these options are integrated in one and the same analysis by means of multilevel modelling (Goldstein, 1986; Buschang *et al.*, 1988; Hoeksma and Van der Beek, 1991). The univariate version of the multilevel model has earlier been used in several orthodontic growth studies (Buschang *et al.*, 1986, 1988, 1989; Van der Beek *et al.*, 1991). As Goldstein (1987) showed the multilevel model can be extended to multiple variables, as will be further explained in the methods section.

The present study focuses on the facial dimensions Na-Gn and S-Go. By using the multilevel model, the following questions will be addressed: (i) to what extent do the mean and individual growth curves of the facial dimensions and of standing height parallel each other?; (ii) what are the differences between vertical facial dimensions and stature with respect to the pubertal growth spurt?; and (iii) how does the relation between facial growth and statural growth change with age?

Materials and methods

The material used in this study consisted of the records of 134 orthodontically untreated girls from the Nijmegen Growth Study in The Netherlands (Prahl-Andersen *et al.*, 1979). Cephalometric radiographs and body height measurements were collected on a yearly basis between 7–9 years and on a 6-monthly basis from 9–14 years. The number of measurement occasions varied from five to ten. Landmarks on 1071 radiographs were digitized twice, directly from the cephalogram. The landmarks used in this study were Sella (S), Nasion (Na), Gonion (Go) and Gnathion (Gn). The vertical facial dimensions computed from these landmarks were Na-Gn and S-Go. The accuracy of digitization and the definition of the landmarks is described in Van der Beek *et al.* (1991). Body height was measured twice as described

by Prahl-Andersen *et al.* (1979). For both the facial dimensions and body height, bivariate scatterplots (one for each girl), displaying the measurements against age, were used to check for gross recording errors.

The data were analysed by means of the multivariate multilevel model for longitudinal data (Goldstein, 1987). In the multilevel model polynomial functions are used to describe average and individual growth curves. The average growth curve of dimension Y is written as:

$$Y_t = \beta_{y0} + \beta_{y1} \cdot X_t + \beta_{y2} \cdot X_t^2 + \dots + \beta_{yn} \cdot X_t^n$$

Where Y_t is the mean value of Y at occasion t, and X_t the age at occasion t. The parameters β_{y0} to β_{yn} lay down the form of the curve and are to be estimated from the data. β_{y0} is labelled the intercept, β_{y1} the linear coefficient, β_{y2} the quadratic coefficient, *etc.* The subscript y is added to the parameters to indicate that they refer to dimension Y. The parameters have substantive meanings. The intercept (β_{y0}) corresponds to the mean of Y at the age $X=0$, the origin of the age-scale, the linear coefficient (β_{y1}) corresponds to the rate of change (velocity) of Y at $X=0$, whereas twice the quadratic coefficient (β_{y2}) corresponds to the acceleration of Y at the age $X=0$. The coefficients of the average growth curve are generally referred to as the fixed part of the model.

In the model the parameters of the individual growth curves are expressed as deviations from the parameters of the average growth curve. They are referred to as the random part of the model. The intercept of the growth curve of individual i is written as $\beta_{y0i} = \beta_{y0} + u_{y0i}$, whereas the linear coefficient of the growth curve of individual i is written as $\beta_{y1i} = \beta_{y1} + u_{y1i}$, *etc.* The variances of the individual deviations indicate how the individual growth curves spread around the average growth curve. The individual deviations are considered to be random variables, and as such they can co-vary or be correlated.

The extension of the univariate to the multivariate multilevel model is quite straightforward. All that is required is to add a second set of expressions to the previous ones in which Y is replaced by Z. The resulting model contains the same parameters as the model for a single variable, be it for two variables. The main difference between the single and the multiple variable model pertains to the covariances

between the parameters of the individual growth curves. In the multivariate model the growth parameters co-vary not only within variables but also between variables. This enables correlations to be computed between standing height on the one hand and each of the facial dimensions on the other, both with respect to their growth status, and growth velocity. The method used is more fully described in Hoeksma and Van der Beek (1993). Technical details are given in the Appendix.

Results

The results are presented in two parts: in the first section, the mean and individual growth curves for body height, and the facial dimensions Na-Gn and S-Go are described, including the characteristics related to pubertal growth. The second section deals with the relationship between the three above mentioned variables using the individual growth parameters estimated in the random part of the model.

Growth curves

The multivariate multilevel model was fitted to describe the growth curves for body height and the facial dimensions Na-Gn and S-Go. The parameters of the fixed part of the model (Table 1) describe the average growth curves. For body height, a fourth degree polynomial function was estimated. Higher order polynomial coefficients did not prove to be significant (i.e. did not exceed twice their SE). Also for Na-Gn and S-Go, a fourth degree polynomial proved to be appropriate. The mean growth curves based on the parameter estimates are displayed in Figures 1, 2 and 3.

The random part of the model embodies the parameters of the individual growth curves. For

Table 1 Estimates of fixed parameters, including standard errors (SE)

| | Body height | | N-Gn | | S-Go | |
|-----------|-------------|--------|----------|--------|----------|--------|
| | Estimate | SE | Estimate | SE | Estimate | SE |
| β_0 | 145.30 | (0.58) | 105.70 | (0.46) | 65.74 | (0.32) |
| β_1 | 6.35 | (0.10) | 2.11 | (0.07) | 1.87 | (0.06) |
| β_2 | 0.33 | (0.04) | 0.12 | (0.04) | 0.20 | (0.04) |
| β_3 | -0.07 | (0.01) | -0.01 | (0.01) | -0.01 | (0.01) |
| β_4 | -0.03 | (0.00) | -0.01 | (0.00) | -0.01 | (0.00) |

N=Nasion; Gn=Gnathion; S=Sella; Go=Gonion.

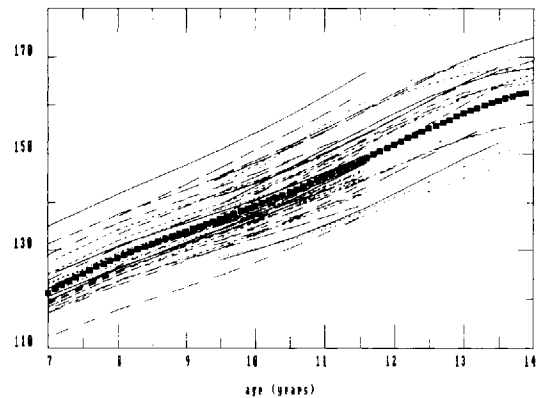


Figure 1 Mean growth curve (bold line) and individual growth curves for body height (cm).

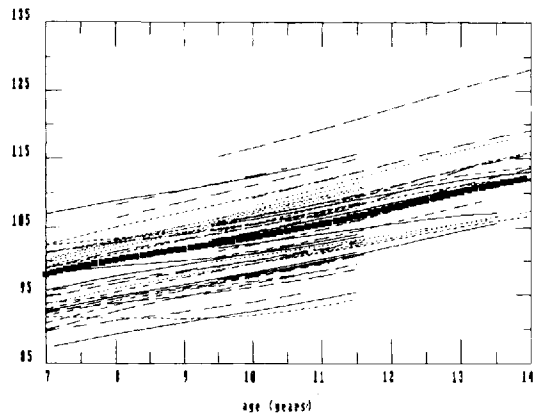


Figure 2 Mean growth curve (bold line) and individual growth curves for Nasion-Gnathion (mm).

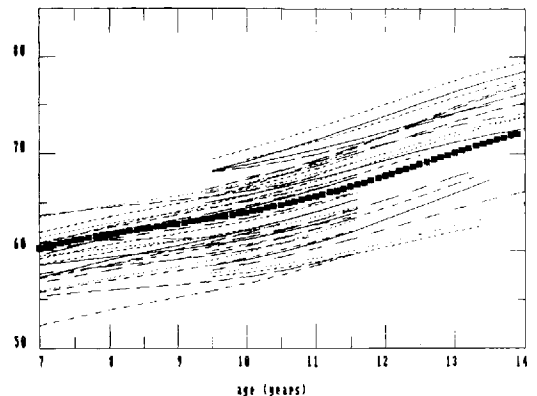


Figure 3 Mean growth curve (bold line) and individual growth curves for Sella-Gonion (cm).

all three dimensions the intercepts, linear and quadratic coefficients varied between individuals. Figures 1, 2, and 3 also display the individual growth curves of body height and facial dimensions. As can be observed from these figures, the deviations of the individual growth curves from the average growth curves increase with age. The individual differences become more pronounced at later ages.

Growth velocity curves were extracted from the individual growth curves by taking the first derivative. The average peak height velocity was found at 12.8 years of age (SD 0.48). In 9 per cent of the cases no peak could be detected. For Na-Gn in 4 per cent of the cases no peak or maximum velocity was found, the mean age was 12.3 years (SD 0.45). With respect to S-Go, the mean age of the maximum growth velocity was 12.8 (SD 0.26); in all cases a peak velocity was found. All growth velocity estimates are instantaneous.

Correlations

The random parts of the bivariate models (Table 2) were used to compute the correlations between body height and facial dimensions, conditional on age. In addition the correlations between the growth velocities were computed.

Figure 4 shows how the growth status and the growth velocity of body height is correlated with the growth status and velocities of Na-Gn and S-Go. Figure 4 reveals three things. First, after an initial decrease the correlation between body height and facial dimensions are more or

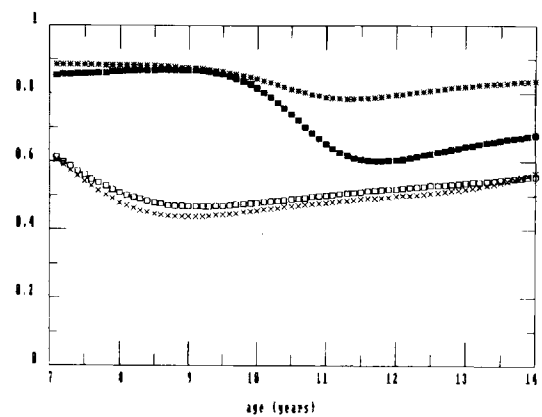


Figure 4 Correlations between body height and Nasion-Gnathion (□ □ □); body height and Sella-Gonion (× × ×); correlations between the growth velocity of body height and Nasion-Gnathion (■ ■ ■); and the growth velocity of body height and Sella-Gonion (* * *) as a function of age.

less constant across the ages. Second it appears that the correlation between the growth velocity is generally larger than between the growth status itself. In other words, the growth velocity of body height and of Na-Gn and S-Go are more closely related to each other than body height and the length of the facial dimensions itself. Finally, Figure 4 reveals that the correlation between the growth velocity of body height and S-Go is stronger and constant with age, while the correlation between the growth velocity of body height and Na-Gn is initially

Table 2 Variance/covariance matrix of random coefficients of two bivariate models. Figures in parentheses are SE.

| | β_{10} | β_{11} | β_{12} | β_{20} | β_{21} | β_{22} |
|------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Nasion-Gnathion | | | | | | |
| β_{10} | 44.48 (5.45) | | | | | |
| β_{11} | 3.83 (0.73) | 1.13 (0.15) | | | | |
| β_{12} | -1.17 (0.26) | -0.11 (0.04) | 0.16 (0.02) | | | |
| β_{20} | 17.21 (3.39) | 1.70 (0.42) | -0.40 (0.15) | 27.55 (3.40) | | |
| β_{21} | 1.48 (0.53) | 0.45 (0.08) | -0.05 (0.02) | 1.46 (0.34) | 0.33 (0.06) | |
| β_{22} | -0.18 (0.19) | -0.07 (0.03) | 0.06 (0.01) | -0.14 (0.11) | -0.02 (0.01) | 0.04 (0.01) |
| Sella-Gonion | | | | | | |
| β_{10} | 44.52 (5.45) | | | | | |
| β_{11} | 3.79 (0.72) | 1.13 (0.15) | | | | |
| β_{12} | -1.17 (0.26) | -0.11 (0.04) | 0.15 (0.02) | | | |
| β_{20} | 11.32 (2.32) | 1.00 (0.37) | -0.34 (0.13) | 12.97 (1.61) | | |
| β_{21} | 0.99 (0.36) | 0.46 (0.07) | -0.03 (0.02) | 0.51 (0.20) | 0.28 (0.05) | |
| β_{22} | -0.31 (0.13) | -0.06 (0.02) | 0.06 (0.01) | -0.14 (0.07) | -0.02 (0.01) | 0.03 (0.01) |

β_{10} , β_{11} , β_{12} = body height coefficients; β_{20} , β_{21} , β_{22} = facial dimension coefficients.

strong but decreases between 10–12 years of age.

Discussion

Different aspects of the relationship between growth of facial dimensions and body height are generally analysed separately and with a small number of cases (Nanda, 1955; Rose, 1960; Bambha, 1961; Hunter, 1966; Pike, 1968; Baughan *et al.*, 1979; Baume *et al.*, 1983). In the present study, the records of 134 girls were analysed. A multivariate multilevel model for longitudinal data was used to perform an integrated analysis with respect to mean growth curves, individual growth curves and correlations between growth parameters. The main advantage of the model used is that the parameter estimates (for instance correlations) are relatively reliable in proportion to the number of cases and the age range studied.

The first result of the analyses pertains to the mean growth curves. The mean growth curves of standing height and of Na–Gn and S–Go parallel each other to a large extent. Nanda (1955), Bambha (1961) and Baughan *et al.* (1979) have made similar observations. The individual growth curves, which largely parallel the average growth curves demonstrate that individual differences become more pronounced at later ages. Moreover the individual growth curves show little crossover patterns. This implies that a girl's relative position in the population with respect to Na–Gn, S–Go and standing height, does not change much with age. In other words small children will be small and tall children will be tall, not only with respect to standing height but also with respect to the facial dimensions considered.

The results also revealed that the average growth velocity peaks of the facial dimensions are more or less coincident with the peak height velocity. This confirms the results of Hunter (1966), Grave (1973), Thompson *et al.* (1976) and Moore *et al.* (1990). However, pubertal growth spurts could not be consistently demonstrated in all individuals. In these cases a gradual increase in dimension was detected. A lack in pubertal spurt in body height was also demonstrated by Taranger and Hägg (1980). Maj and Luzi (1962) and Lewis *et al.* (1982) reported an absence of spurts in facial dimensions in some children. The absence and presence of

pubertal growth spurts suggests that the growth patterns and sensitivity of different bones to altered levels of circulating hormones may vary among individuals.

The major results of the present study pertain to the dynamic relationship between statural growth and the growth of the face. The age-dependent correlations between statural and facial growth were computed directly from the so-called random part of the model, as proposed by Hoeksma and Van der Beek (1993).

First, it was observed that the correlations between body height and facial dimensions are more or less constant across the ages. Since the growth curves of body height, Na–Gn and S–Go parallel each other to a large extent, this finding would be expected. Second, it was found that stronger relations exist between the growth velocities of standing height, S–Go and Na–Gn, than between the actual lengths of the three variables themselves. In general, hormonal changes are thought to affect changes in growth of the three dimensions considered, and in turn these changes affect the actual distances. In other words assuming a common cause of growth, this cause primarily affects the changes (velocities) and secondarily the result of these changes (the actual distances). If we add to this that primary effects are generally more strongly related than secondary effects it becomes understandable why the growth velocities are also more strongly related to each other than the actual distances.

The final finding pertains to the fact that the relationship between the growth velocity of S–Go and standing height is stronger than that between Na–Gn and standing height. Not only did Lewis *et al.* (1982) find that periods of accelerated growth of ramus height roughly coincided with those in stature, but Pike (1968) and Moore *et al.* (1990) also found the largest correlations for stature and S–Go. In addition, Baughan *et al.* (1979) concluded that ramus height is the one aspect of facial growth which during the pubertal period is closely allied to general skeletal growth. For Na–Gn the initially strong relationship is lost between the ages of 10–12 years. The fact that the peak velocity of Na–Gn (12.3 years) is not coincident with that of body height (12.8 years) but also the lack of growth spurts in both body height and Na–Gn in some individuals can explain the decrease in correlation during this period.

In conclusion, this study indicates that information concerning changes (growth velocity) in body height and facial dimensions are more important than the actual lengths of the distances themselves. In addition it appears that the growth velocity of standing height is a good indicator for the growth velocity of S-Go, and to a lesser extent for Na-Gn. Both facts are worthy of consideration in diagnosis and treatment planning of the individual case.

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Appendix

The data were analysed using the multivariate longitudinal multilevel model (Goldstein, 1987). The model can be described as follows. Let y_{hij} refer to the measurement of variable h ($h=1, 2$) at occasion i of child j . For instance, y_{1ij} refers to standing height and y_{2ij} to facial height. If child j 's age at occasion i is designated by x_{ij} the model can be written as:

$$y_{hij} = \sum_t \beta_{ht} x_{ij}^t + \sum_t u_{hjt} x_{ij}^t + e_{hij} \quad (t=0, \dots, s)$$

where β_{ht} refer to the average growth curves. The u_{hjt} are random variables referring to individual differences with: $E(u_{hjt})=0$, $Var(u_{hjt})=\sigma_{ht}^2$ and $Cov(u_{hjt}, u_{h'jt'})=\sigma_{ht,h't'}$. The level 1 (error) vari-

ance is designated by $Var(e_{hij}) = \sigma_h^2$. The random part of the model contains the information central to our research questions. The correlation between two variables at age x is computed from the covariance between the two measures

$$Cov(\sum_t u_{1jt} x_{ij}^t, \sum_{t'} u_{2jt} x_{ij}^{t'}) = \sum_t \sum_{t'} x_{ij}^t x_{ij}^{t'} \sigma_{1t, 2t'}$$

and their variances

$$Var(\sum_t u_{hjt} x_{ij}^t) = \sum_t x_{ij}^{2t} \cdot \sigma_{ht}^2 + 2 \sum_t x_{ij}^t x_{ij}^{t'} \sigma_{ht, ht'}.$$

The growth velocity is found by taking the first derivative of the growth curve. Thus variances and covariance of the growth-velocity are based on

$$\sum_t t x_{ij}^{t-1} u_{hjt}.$$