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Mathematical models of longitudinal mandibular growth for children with normal and untreated Class II, division 1 malocclusion

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SUMMARY Two-level polynomial models are used to estimate and compare the mandibular growth of French-Canadian children between 6 and 15 years of age with normal occlusion and untreated Class II, division 1, malocclusion. With the exception of annual growth velocity, the curves describing the amount and direction of growth for the cephalometric landmark gnathion are comparable for children with normal and malocclusion. Growth deficiencies for children with malocclusion, approximating 0.4 cm/yr for boys and 0.2 cm/yr for girls, accumulate throughout the age range producing significant differences at the older ages. Peak childhood and pubertal velocities are estimated to occur at 8.7 and 14.1 for boys and 7.7 and 12.9 for girls, respectively. Growth direction changes in a curvilinear manner throughout the age range.

Introduction

The prediction of treatment effects depends largely on our understanding of the growth changes which might be expected without orthodontic intervention. Information on the growth of children with untreated malocclusion is especially important (Mills, 1983); it provides the basis for understanding the aetiology of craniofacial deformities. Moreover, accurate growth descriptions of children with untreated malocclusion are necessary to plan and evaluate the timing, duration, and intensity of anticipated treatment. Due to limited availability of longitudinal cephalometric records for children with untreated malocclusion, more powerful modelling techniques—able to take advantage of the correlated nature of an individual's serial data—must be relied upon to derive precise estimates of the growth parameters.

Polynomial regression models have proven to be effective and efficient for studying longitudinal craniofacial growth (Buschang *et al.*, 1986a and b). However, as traditionally applied, polynomials require a common set of measurement occasions for all individuals, which often reduces the effective sample size and the power of the test statistics.

A new class of statistical models which extends to unadjusted mixed longitudinal data has recently been introduced (Goldstein, 1986a and b; Strenio *et al.*, 1983). The models can easily handle missing data and do not require adjustment of measurement occasions to exact ages. Moreover, the models are multilevel, allowing random variation to be partitioned within and between subjects.

Using these newly developed procedures, this report investigates the mandibular growth of children with normal and untreated Class II, division 1 malocclusion. Two-level polynomial models are used to describe and compare the growth curves.

Subjects and methods

The data are derived from serial lateral cephalograms, collected by the Human Growth Research Centre, Université de Montréal (Demirjian, 1971). The children are French-Canadians, drawn from three school districts in Montreal chosen to represent the different socio-economic sectors of the larger population. A mixed longitudinal subsample of 42 girls (N = 390) and 71 boys (N = 528) followed between 6 and 15 years of age, were selected on the basis of their occlusal status. Only those children with normal and untreated Class II, division 1 malocclusion were included in the study: borderline cases were excluded. Occlusal status was rated by an experienced orthodontist (J.T.) using serial cephalograms and dental casts. A total of 23 boys and 19 girls with malocclusion were included in the analysis.

The analyses pertain to the cephalometric point gnathion, defined as the point on the symphysis formed by bisecting the projections of the mandibular plane and a plane perpendicular to the mandibular plane and tangential to the most anterior point on the mandible. All cephalograms were traced and digitized by the same technician (L.L.). Technical reliability (Buschang *et al.*, 1987) has been estimated at 98.4 and 98.8 per cent for the horizontal and vertical aspects of gnathion, respectively. The measurements were corrected for radiographic enlargement.

The growth of gnathion is evaluated relative to the cephalometric point sella; the sella-nasion reference plane was used for orientation. To better distinguish between the amount and direction of mandibular growth, the digitized, rectangular (x,y) coordinates were transformed into their polar (τ, θ) form.

The basic model partitions variation into two levels: subjects are at the higher level and measurement occasions, nested within subjects, are at the lower level (Goldstein, 1986a and b). The full model can be written as:

$$Y_{it} = \Sigma_j \beta_{ij} x_t^j + \Sigma_k \alpha_k z_i x_t^k + e_{ij};\ t = 1 \ldots n$$

where n is the number of measurement occasions for subject i, x is the age at occasion t, and j(0, . . ., p) indexes the polynomial coefficient.

Table 1 Gnathion length: sella-gnathion (cm). Normal vs untreated Class II, division 1 malocclusion.

	Boys		Girls	
Explanatory variables	Estimates	Standard errors	Estimates	Standard errors
Fixed coefficients:				
Intercept	10.568		10.043	
Age	0.21741	0.011172	0.20136	0.008817
Age^2	−0.013507	0.0047238	−0.0014386	0.0030138
Age^3	0.00060697	0.0020455	0.0040429	0.0012523
Age^4	0.0019792	0.00062328	0.00022084	0.00016917
Age^5	0.00010406	0.000096916	−0.00018114	0.00005200
Age^6	−0.00006163	0.000023762		
Mal	−0.061194	0.087728	−0.037727	0.10552
Mal*Age	−0.040194	0.0098345	−0.018456	0.0081644
Random coefficients:				
σ_0^2	0.00832	0.00062685	0.0077636	0.0006730
$\sigma^2_{\mu,0}$	0.12231	0.021011	0.12906	0.028588
$\sigma^2_{\mu,1}$	0.0010699	0.00025109	0.00058089	0.00015428
$\sigma^2_{\mu,2}$	0.00003041	0.00000995	0.00001927	0.00000819
$\sigma_{\mu,01}$	0.0045347	0.0017382	0.0033945	0.0015778
$\sigma_{\mu,02}$	0.00067948	0.00033655	−0.00061822	0.00036029
$\sigma_{\mu,12}$	0.00013096	0.00003405	−0.00001259	0.00002524
$\rho_{\mu,01}$	0.396		0.392	
$\rho_{\mu,02}$	0.352		−0.392	
$\rho_{\mu,12}$	0.726		−0.119	
Iterations	30		5	
Measurements	528		390	
Subjects	71		42	
Age measured from	10 years		10 years	
Relative accuracy for convergence	10^{-3}		10^{-3}	

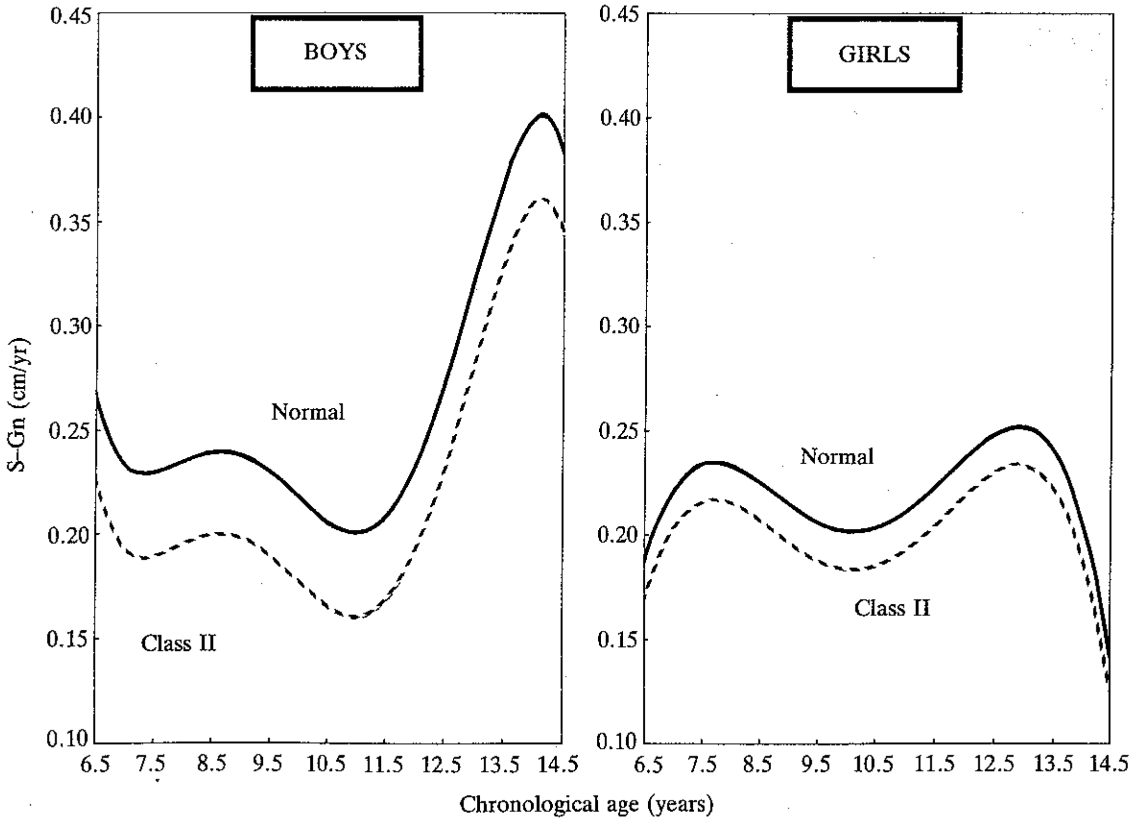

Figure 1 Mixed longitudinal yearly growth increments of sella-gnathion (S-Gn) for children with normal occlusion and untreated Class II, division 1 malocclusion.

The first summation refers to the fitted polynomial; the second summation represents the set of explanatory variables (malocclusion) indexed by k. The α_k remain constant and the β_{ij} are assumed to vary randomly over individuals. Iterative generalized least squares was used to estimate the model's parameters (Goldstein, 1987).

Results

Table 1 presents the growth comparisons for the distance between sella and gnathion, hereafter called gnathion length. The fixed parts of the models describe the mean growth curve. They relate gnathion length to sixth and fifth order polynomials in age for boys and girls, respectively. The intercept estimates gnathion length at 10 years of age. The other coefficients, age through age^j, quantify the shape of the curve between 6 and 15 years. For example, the linear term describes growth velocity, the quadratic terms describe changes in growth velocity (growth acceleration), and so on, through the jth polynomial coefficient. The models indicate that growth velocity over the age range changes direction five times for boys and four times for girls. Boys have four points of zero growth acceleration: two maximum velocities and two minimum velocities. Girls have two points of maximum velocity separated by one point of minimum velocity.

Subjects with normal and Class II malocclusion show small but significant differences in yearly growth velocity (Mal*Age: Table 1). Growth rates for boys and girls with malocclusion are approximately 0.4 mm/yr and 0.2 mm/yr less, respectively, than growth rates for children with normal occlusion (Fig. 1). Peak childhood and pubertal velocities, found

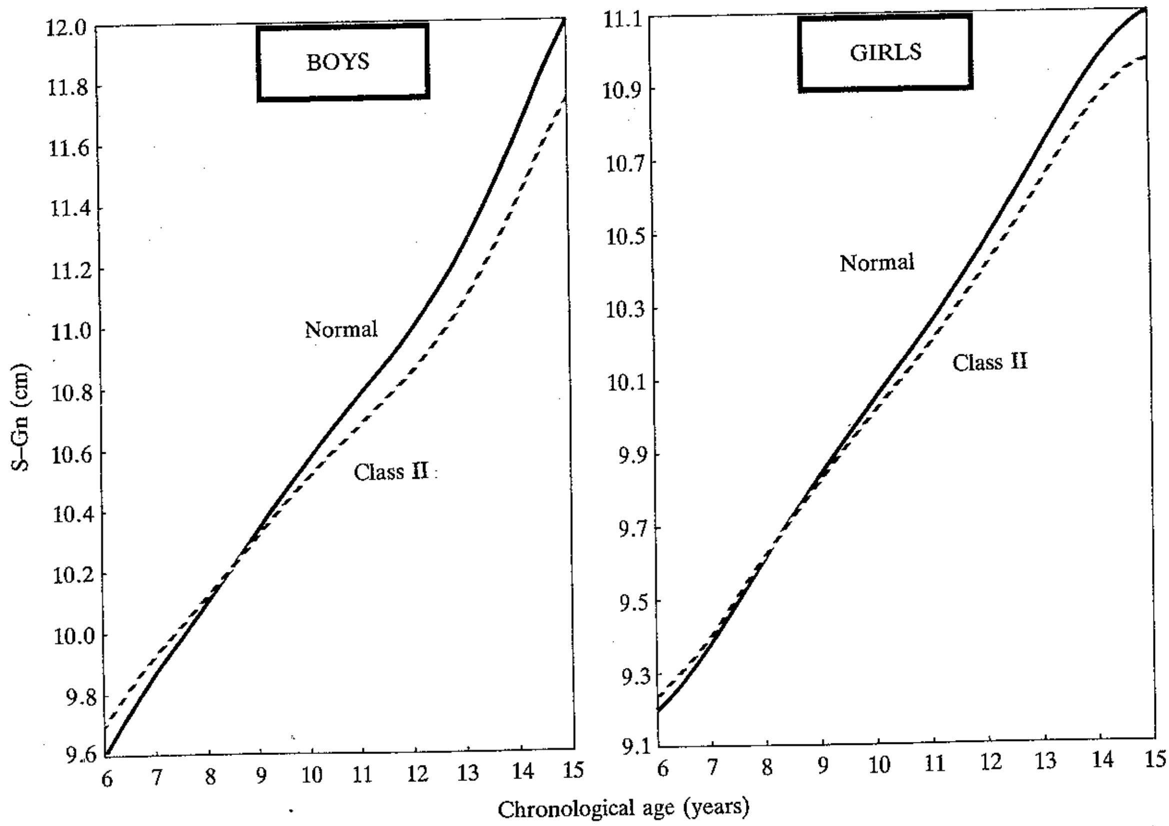

Figure 2 Distance curves for sella-gnathion (S-Gn) for children with normal occlusion and untreated Class II, division 1 malocclusion.

by estimating age of zero acceleration, occur at 8.7 and 14.1 years for boys and 7.7 and 12.9 years for girls, respectively.

Differences in growth velocity accumulate between 6 and 15 years of age (Fig. 2). At 10 years of age (Mal: Table 1), children with normal occlusion are not significantly larger than children with malocclusion. The apparent differences favouring children with malocclusion at the younger ages are also statistically insignificant.

The models' random coefficients (Table 1) pertain to residual variation. Dispersion about the individuals' growth curves is described by a single within-subject variance term. A more detailed modelling of the within-subject variation might have been possible with a larger sample size. The between-subject error terms are fitted for the coefficients up to age squared. In other words, the constant, linear, and quadratic terms were allowed to vary randomly between subjects. The other terms remained fixed. Between subjects, the constant and linear terms are positively correlated (0.40 for boys and 0.39 for girls), indicating that the larger subjects have greater growth velocity. For boys the quadratic term is positively correlated with the intercept (0.35) and linear (0.72) terms. These terms are negatively correlated for girls. The random coefficients describe the average deviation of the individuals' estimates from the fixed model. They indicate that variation about the mean growth curve follows a curvilinear pattern (Fig. 3).

The second set of analyses pertain to growth direction, as described by the angle nasion-sella-gnathion (Table 2). The mean angles at 10 years of age are 292.4 degrees for boys and 291.8 degrees for girls. Girls show little or no change in growth direction during childhood; boys display anterior rotation of the point gnathion (Fig. 4). During adolescence the angle decreases, indicating posterior rotation, for both boys and girls.

Table 2 Gnathion growth direction: nasion-sella-gnathion (degrees). Normal vs untreated Class II, division 1 malocclusion.

Explanatory variables	Boys Estimates	Boys Standard errors	Girls Estimates	Girls Standard errors
Fixed coefficients:				
Intercept	292.37		291.82	
Age	0.058374	0.037327	−0.039096	0.034385
Age²	−0.025115	0.0047769	−0.014116	0.0049458
Mal	−0.73925	0.82706	−0.35528	0.63776
Random coefficients:				
σ_0^2	0.40573	0.029154	0.45912	0.037096
$\sigma^2_{\mu,0}$	10.612	1.8045	5.2386	1.1551
$\sigma^2_{\mu,1}$	0.069136	0.014091	0.042289	0.010697
$\sigma_{\mu,01}$	0.12996	0.11351	0.23228	0.08617
$\rho_{\mu,01}$	0.152		0.493	
Iterations	30		5	
Measurements	528		390	
Subjects	71		42	
Age measured from	10 years		10 years	
Relative accuracy for convergence	10^{-3}		10^{-3}	

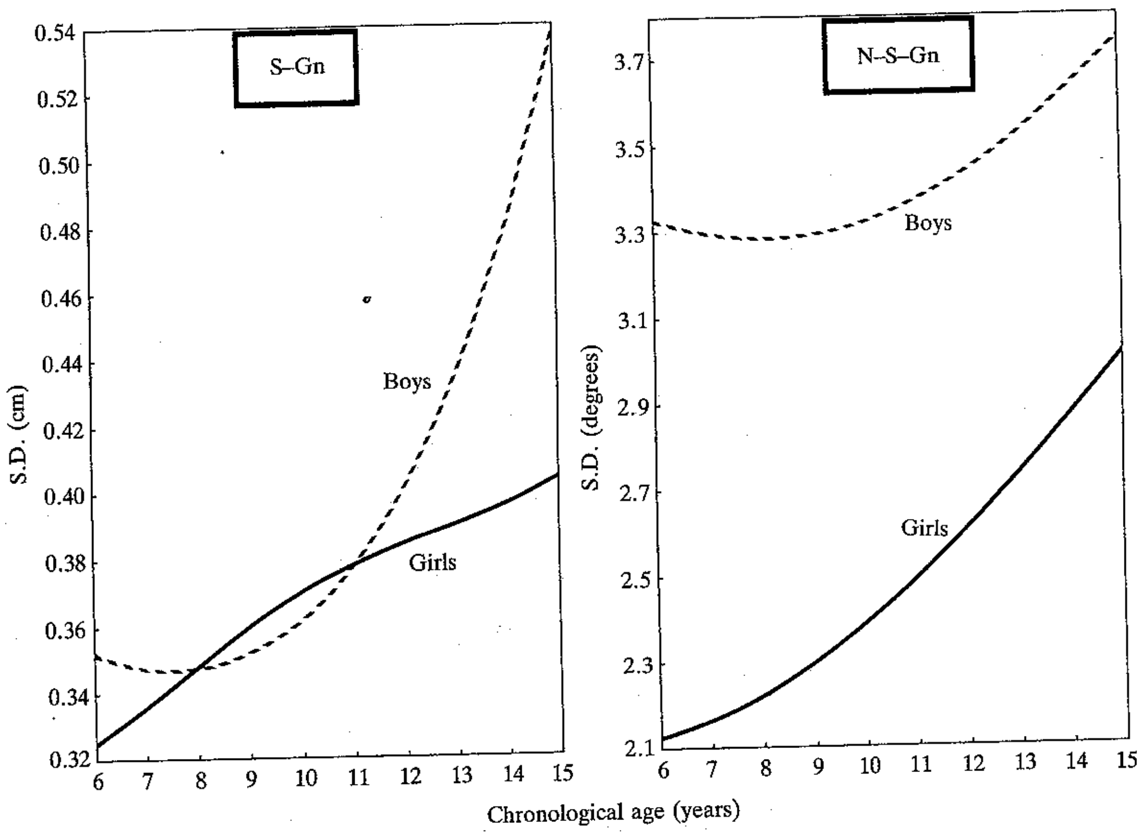

Figure 3 Standard deviations for sella-gnathion (S-Gn) and nasion-sella-gnathion (N-S-Gn) for boys and girls 6 to 15 years of age.

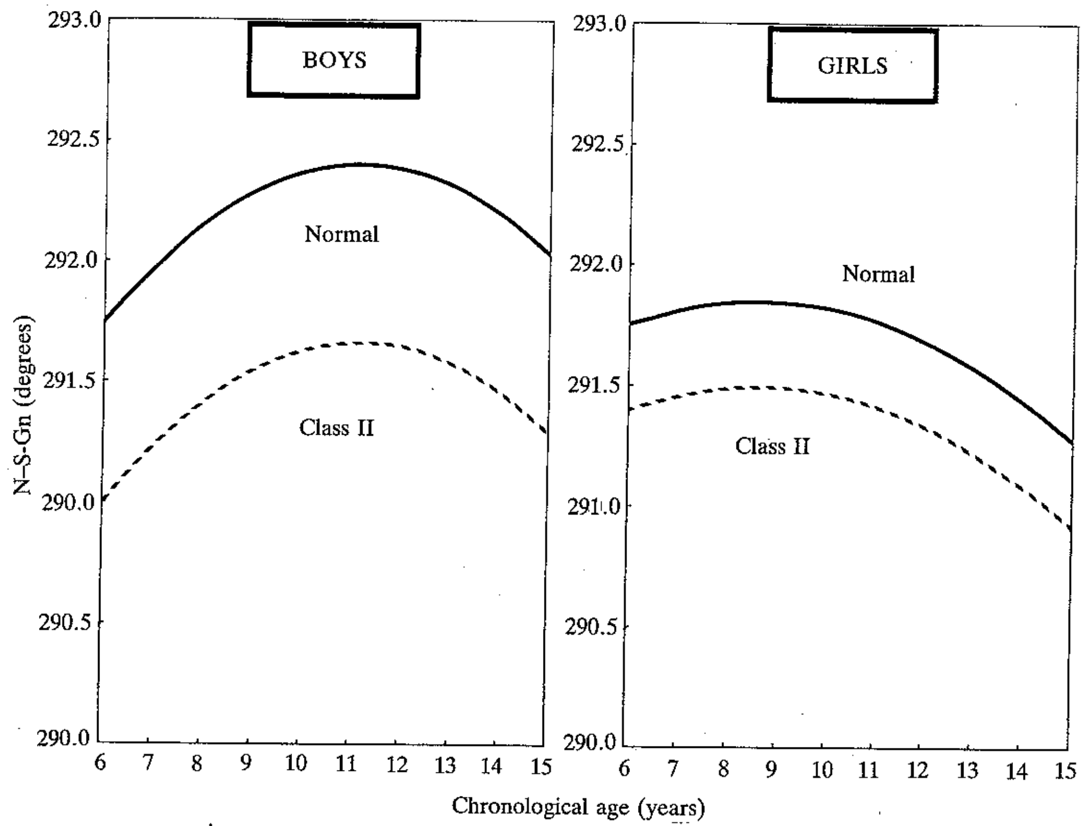

Figure 4 Growth direction (nasion-sella-gnathion) for children with normal occlusion and untreated Class II, division 1 malocclusion.

There is a consistent tendency for children with malocclusion to have a more vertically oriented growth direction than children with normal occlusion. However, the differences are smaller than their corresponding standard errors and, therefore, are not statistically significant.

The random coefficients (Table 2) for growth direction indicate that variation within-subjects is comparable for boys and girls. Between-subjects variance displays dimorphism; boys appear to be more variable in growth direction than girls. Correlations between the intercept and linear terms are negligible for boys (0.15) and moderate for girls (0.49). Variation increases as a curvilinear function of age (Fig. 3).

Discussion

The results provide, for the first time, longitudinal models contrasting the mandibular growth of children 6 to 15 years of age with normal and untreated malocclusion. The models take full advantage of the correlated nature of the individuals serial data and summarily describe growth tendencies and inter-group differences. The parameters derived therefrom might be expected to be more precise than those that would have been obtained using conventional procedures (Goldstein, 1979).

The findings are consistent for boys and girls. Both sexes display childhood and pubertal growth spurts. Although more detailed analyses are necessary to estimate accurately the timing and variation of the spurts, sexual dimorphism in mandibular growth is clearly indicated. Analyses of craniofacial growth based on annual increments indicate that maximum pubescent growth velocity is greater and occurs one to two years later for boys than for girls (Nanda, 1955; Tracy and Savara, 1966; Savara and Tracy, 1967; Hunter, 1966; Lewis *et al.*, 1982). The childhood growth spurt for girls has been reported as occurring simultaneously (Nanda, 1955; Bambha, 1961; Ekström, 1982) or earlier (Krieg, 1987; Harris, 1962; Woodside *et al.*, 1975) than for boys. Since girls are always skeletally more mature than boys from birth onwards (Tanner, 1962), dimorphism in the timing of the childhood and pubertal spurts might be expected.

Annual velocities for boys and girls with normal occlusion are 0.4 and 0.2 mm greater, respectively, than children with untreated malocclusion. Although small, the growth discrepancies accumulate and the growth curves diverge between 6 and 15 years of age. Our previous analyses (Buschang *et al.*, 1986b) indicate that French-Canadian boys 12.5 years of age with normal and untreated malocclusion display significant differences (2.5 mm) in mandibular length (Ar–Po). Variation in growth velocity between 11 and 14 years was not substantiated by the previous analyses, suggesting that the differences occurred at an earlier age. In the present analysis, size differences for boys attain probability levels below 0.05 at approximately 12.6 years of age. The significant differences in growth velocity found may be attributed to sample sizes and age range used, which combine to produce more accurate estimates of growth changes.

Surprisingly, no significant differences in growth direction were found in children with normal and Class II malocclusion. Since subjects with vertical growth at the chin have comprehensive orthodontic treatment more often than subjects with horizontal growth (Lundström and Woodside, 1981), variation in growth direction might have been expected, along with growth deficits, to produce Class II deformities. There is, however, a consistent tendency for boys and girls with Class II malocclusion towards a more vertical growth direction, which serves to further increase anteroposterior discrepancies. Variation is simply too great to allow discrimination with any degree of certainty.

Although it may not be possible to distinguish between normal and malocclusion on the basis of growth direction, the positive correlation found between the intercept and linear terms holds important clinical implications. A positive association indicates that growth directions of vertical and horizontal growers will tend to become more vertical and horizontal, respectively, with time. As such, individuals with Class II malocclusions *and* who are vertical growers, will tend to increase anteroposterior discrepancies to the greater extent than other children with malocclusion. They provide the 'worst-case' scenario. Horizontal growers with malocclusion provide the greatest opportunity for successful treatment effects.

The results also hold important implications for clinical evaluation and prediction of mandibular growth. Most importantly, they imply that normative standards for children with Class II malocclusion will over estimate growth velocity at gnathion. Since the growth curves for children with normal and malocclusion are similar and growth differences are not complex, reference standards could be easily adjusted to remove the observed velocity differences. Similarly, control samples for functional appliance studies, which are often problematic (Mills, 1983), might thus be composed of randomly selected normal subjects.

Assuming that functional appliances stimulate mandibular growth (McNamara, 1973; Petrovic, 1974) treatment of children during the late mixed and early permanent dentition stages of development might be expected to increase mandibular height considerably more than mandibular length. Based on the mean growth direction for boys at 10 years of age, a unit increase in sella-gnathion results in an increase of 0.93 units vertically and 0.36 units horizontally. Moreover, the relative amount of vertical, over horizontal, growth increases as gnathion rotates posteriorly during adolescence. As such, increases in lower facial height and little or no change in the forward growth of the mandible reported by clinical studies (Baumrind *et al.*, 1981; Creekmore and Radney, 1983; Harvold and Vargervik, 1971) might be expected.

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