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Multilevel modeling techniques to study the impact of environmental changes on human face development

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Abstract

Environmental changes leading to different growth patterns of allergenic species, longer pollen seasons, deterioration of indoor and outdoor air quality have reportedly increased allergic rhinitis and viral infections in children which may lead to facial growth problems. The airway has a relevant role in the development of craniofacial structures, thus, in this work, we intended to model the mandibular inclination in growing individuals, considering sagittal pharyngeal characteristics and other craniofacial characteristics as predictors. Angular, linear and area measurements were performed concerning the maxilla, mandible, cranio-cervical posture and upper airway at pre-peak, peak and post-peak cephalograms, in a sample of 157 individuals with no history of orthodontic treatment. Mandibular inclination (ML/NSL) was adjusted as a function of other craniofacial variables using a longitudinal hierarchical linear model (MLH). Two relevant adjustments with random intercepts and slopes were obtained for the time variable. Modelling with MLH allowed for the estimation of fixed and random components at the individual level, the time level for ML/NSL and the influence of certain predictors on the rate of change of ML/NSL throughout growth were explored. The application of MLH is recommended to allow the incorporation of clinical and environmental variables during growth and to better clarify the role of the airway in the development of craniofacial structures.

Keywords: *Linear Hierarchical Model, Longitudinal Data, Cephalometry, Growth, Airway.*

JEL Classification: I19

Τεχνικές πολυεπίπεδης μοντελοποίησης για τη μελέτη των επιπτώσεων των περιβαλλοντικών αλλαγών στην ανάπτυξη του ανθρώπινου προσώπου

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Περίληψη

Οι περιβαλλοντικές αλλαγές που οδηγούν σε διαφορετικά μοτίβα ανάπτυξης αλλεργιογόνων ειδών, μεγαλύτερες εποχές γύρης, επιδείνωση της ποιότητας του αέρα σε εσωτερικούς και εξωτερικούς χώρους έχουν αναφερθεί ότι έχουν αυξήσει την αλλεργική ρινίτιδα και τις ιογενείς λοιμώξεις στα παιδιά που μπορεί να οδηγήσουν σε προβλήματα ανάπτυξης του προσώπου. Ο αεραγωγός έχει σχετικό ρόλο στην ανάπτυξη των κρανιοπροσωπικών δομών, επομένως, σε αυτή την εργασία, σκοπεύαμε να μοντελοποιήσουμε την κλίση της κάτω γνάθου σε αναπτυσσόμενα άτομα, λαμβάνοντας υπόψη τα οβελιαία φαρυγγικά χαρακτηριστικά και άλλα κρανιοπροσωπικά χαρακτηριστικά ως προγνωστικούς παράγοντες. Πραγματοποιήθηκαν μετρήσεις γωνίας, γραμμικής και εμβαδού της άνω γνάθου, της κάτω γνάθου, της κρανιοαυχενικής στάσης και του ανώτερου αεραγωγού σε κεφαλογράμματα προ-αιχμής, κορυφής και μετά-αιχμής, σε δείγμα 157 ατόμων χωρίς ιστορικό ορθοδοντικής θεραπείας. Η κλίση της κάτω γνάθου (ML/NSL) προσαρμόστηκε ως συνάρτηση άλλων κρανιοπροσωπικών μεταβλητών χρησιμοποιώντας ένα διαμήκη ιεραρχικό γραμμικό μοντέλο (MLH). Λήφθηκαν δύο σχετικές προσαρμογές με τυχαίες τομές και κλίσεις για τη μεταβλητή χρόνου. Η μοντελοποίηση με MLH επέτρεψε την εκτίμηση σταθερών και τυχαίων συστατικών σε μεμονωμένο επίπεδο, διερευνήθηκαν το χρονικό επίπεδο για ML/NSL και η επίδραση ορισμένων προγνωστικών παραγόντων στον ρυθμό μεταβολής του ML/NSL σε όλη την ανάπτυξη. Η εφαρμογή της MLH συνιστάται για να επιτραπεί η ενσωμάτωση κλινικών και περιβαλλοντικών μεταβλητών κατά την ανάπτυξη και να διευκρινιστεί καλύτερα ο ρόλος του αεραγωγού στην ανάπτυξη των κρανιοπροσωπικών δομών.

Λέξεις Κλειδιά: Γραμμικό Ιεραρχικό Μοντέλο, Διαμήκη Δεδομένα, Κεφαλομετρία, Ανάπτυξη, Αεραγωγός.

JEL Κωδικοί: I19

1. Introduction

In orthodontic data analysis it is common for the researcher to be faced with one or more dependent variables measured over several variable time instants. These may be related to other independent variables such as an orthodontic or surgical intervention or pathologies of interest, which in turn may have to be controlled by gender, age and skeletal maturation.

One of the options for longitudinal data analysis is the Analysis of Variance for Repeated Measures (RM-ANOVA). It requires, however, some assumptions that may be limiting, namely verifying sphericity and normality in real data. The use of Generalized Linear Models may overcome such limitations. With Hierarchical Linear Models (HLM) it is possible to include temporal effect on the variability between evaluated instants, as well as effects of independent variables in the various data levels, namely the instant, the individual and/or other characteristics that segregate these individuals into distinct units (Finch *et al.*, 2019).

The purpose of this paper is to outlay theoretical fundamentals for HLM and demonstrate their applicability through computational software on cephalometric data, specifically by modelling mandibular inclination (ML/SNL) over time in regard to craniofacial, pharyngeal and posture variables.



2. Literature Review

2.1 The Biologic Standpoint

Aetiology of orthodontic problems comprises three main factors: genetic, environmental, and specific. An environmental factor is considered to be the set of forces to which the face, jaws and teeth are subjected during physiological activity. These must be considered not only for diagnosis and planning, but also for the stability of orthodontic treatment (Proffit *et al.*, 2013). In this context, the role of the airway in the growth and development of craniofacial structures has been widely debated in scientific literature. Several cross-sectional and longitudinal studies support the existence of a relationship between upper airway patency and the sagittal (anteroposterior) relationship between the maxilla and the mandible (Grauer *et al.*, 2009; Ansar *et al.*, 2015; Uslu-Akcam, 2017; Chan *et al.*, 2020). The terms “adenoid facies” or “long face syndrome” have been used in the orthodontic literature for more than a century to describe patients who, in conjunction with a mouth breathing habit, often present with long, convex faces with lips parted at rest; and, when observed intraorally, they exhibit maxillary constriction and displacement of the anterior teeth (Dunn *et al.*, 1973; Proffit *et al.*, 2013). The peak of adenoid growth occurs between 4-6 years of age, followed by regression until around 10-11 years of age, and interrupted by a brief increase in volume at around 11 years of age, resuming its regression until adulthood (Linder-Aronson & Leighton, 1983). In childhood, hypertrophy of the adenoid gland and palatine tonsil are the second most frequent cause of respiratory obstruction and oral breathing, following allergic rhinitis (Bresolin *et al.*, 1983 apud Valera *et al.*, 2003). On the other hand, environmental changes leading to different growth patterns of allergenic species, longer pollen seasons, deterioration of indoor and outdoor air quality have reportedly increased allergic rhinitis and viral infections in children which may lead to facial growth problems (Wu *et al.*, 2021).

2.2 The Hierarchical Linear Model

A Hierarchical Linear Model is an extension of the Simple Linear Regression Model, the latter described by the following equation:

$$y = \beta_0 + \beta_1 x + \varepsilon. \quad (1)$$

The application of Simple and Multiple Linear Regression Models is restricted by assumptions of linearity, homoscedasticity, normality, and independence of observations. If the observations are not independent, i.e. individuals can be segregated into separate clusters (school, hospital, residence area), y may take different mean values for $x = 0$ in each group. Likewise, β_1 may also take different values in each group, as well as the remaining regression coefficients (β_i) if more than one independent variable (x_i) is added to the model. As such, modelling datasets with related individuals or repeated measures, calls for the use of other techniques. HLM allows the adjustment of data structures with more than one level, also referred to as clustered data. In the general literature, level 1 of the data structure refers to the individual, while level 2 refers to a larger group of related individuals. However, when applying HLM to longitudinal data analysis, where repeated measures of the same individual are collected over time, the individual is considered a level 2 data structure, whereas the time instant is considered level 1 (Finch *et al.*, 2019).

The addition of group specific intercepts and slopes to the regression equation at the first hierarchical level can be described as follows:

$$y_{ij} = \beta_{0j} + \beta_{1j}x_1 + \beta_{2j}x_{2ij} \dots \beta_{mj}x_m + r_{ij}, \quad (2)$$

where $r_{ij} \sim N(0, \sigma^2)$ and r_{ij} are independent,

and the ij notation generally refers to the i -th individual in the j -th group, considering m predictor x variables that characterize the individual. In the specific case of longitudinal data analysis, the



notation should be interpreted as i -th time instant for the j -th individual. It is possible to model β_{0j} and distinct slopes for each group. The intercept β_{0j} can be modelled as:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}w_1 + \gamma_{02}w_2 \dots \gamma_{0k}w_k + u_{0j}, \tag{3}$$

where $u_{0j} \sim N(0, \tau_{00})$ and u_{0j} are independent; u_{0j} are independent from r_{ij} .

As γ_{00} is common to all groups, it is referred to as a fixed effect, while u_{0j} represents a random effect, such as r_{ij} in equation (2).

As for the slope, β_{1j} can be modelled as:

$$\beta_{1j} = \gamma_{10} + \gamma_{11}w_1 + \gamma_{12}w_2 \dots \gamma_{1k}w_k + u_{1j}, \tag{4}$$

where $u_{1j} \sim N(0, \tau_{11})$ and u_{1j} are independent; u_{1j} are independent from r_{ij} .

Equations (3) and (4) establish the level 2 model, through which individuals may be separated into different groups. In this manner, a linear hierarchical model considers that the effect of x on y may vary on a level higher than the individual.

To assure HLM validity the following assumptions must be verified: (1) the level 1 residuals, r_{ij} , present normal distribution with mean 0 and constant variance σ^2 ($r_{ij} \sim N(0, \sigma_j)$); (2) level 2 residuals, u_{0j} and u_{1j} are independent between clusters, have normal distribution with mean 0 and variances σ^2_{00} and σ^2_{11} respectively ($u_{0j} \sim N(0, \sigma_{00})$, $u_{1j} \sim N(0, \sigma_{11})$); (3) the covariance between level 1 residuals (r_{ij}) and u_{0j} or u_{1j} is null ($Cov(r_{ij}, u_{0j}) = Cov(r_{ij}, u_{1j}) = 0$), that is, level 1 and level 2 residuals must be independent and if otherwise, similarly to multiple linear regression, one should suspect other independent variables or relevant interaction terms better explain the variability of Y ; (4) the covariance between u_{0j} and u_{1j} takes the value of σ_{01} $Cov(u_{0j}, u_{1j}) = \tau_{01}$, a value that can be non-zero (Natis, 2001; Marôco, 2018; Finch *et al.*, 2019).

3. Methods and Data

3.1 Data

Convenience sampling was performed using lateral cephalograms available through the AAOF Craniofacial Growth Legacy Collection. Inclusion criteria included patients with pre-growth peak, growth peak and post-growth peak radiographs, according to the stage of skeletal maturation assessed by the cervical vertebrae (Baccetti *et al.*, 2005). Exclusion criteria comprised undergoing orthodontic treatment, open mouth position, low quality of relevant anatomical structures or references for image calibration. A total of 157 individuals met the inclusion and exclusion criteria. Image calibration was performed according to instructions published by the AAOF (AAOF, 2020) and the digital cephalometric analysis (Facad software, version 3.12.1.1653, Ilexis AB, Sweden) was carried out previously described methodology (Solow & Tallgren, 1976; Ansar *et al.*, 2015; Uslu-Akcem, 2017; Baka & Fidanboy, 2021). The working dataset included 28 continuous variables, for which the descriptive statistics are detailed in Table 4 by time instant.

Table 4. Descriptive statistics on the overall sample. Sample mean; sd: sample standard deviation; min: minimum; max: maximum.

	Pre-growth peak		Growth peak		Post-growth peak	
	\bar{x} (sd)	[min; max]	\bar{x} (sd)	\bar{x} (sd)	[min; max]	\bar{x} (sd)
Age (y)	8.0 (0.6)	[7.0, 10.8]	11.6 (1.4)	[8.2, 15.8]	18.9 (2.5)	[16.0, 28.4]
SNA (°)	80.4 (3.3)	[73.3, 90.9]	80.8 (3.3)	[73.2, 91]	81.4 (3.6)	[73.2, 93.9]
SNB (°)	76.2 (2.9)	[69.8, 83.7]	77.2 (3.0)	[70.7, 84.7]	78.9 (3.3)	[70, 87.5]

ANB (°)	4.2 (2.0)	[-0.2, 9.6]	3.6 (2.1)	[-2.6, 8.9]	2.5 (2.5)	[-2.8, 8.8]
PP/NSL (°)	8.0 (3.1)	[0.1, 16.9]	7.6 (3.1)	[0.1, 14.6]	7.3 (3.4)	[0.3, 19.0]
OL/NSL (°)	21.9 (4.4)	[9.7, 34.3]	19.3 (4.4)	[7.4, 34.8]	15.6 (5.1)	[2.0, 26.8]
ML/NS (°)	36.8 (4.6)	[25.2, 46.6]	35.7 (4.6)	[23.7, 45.5]	33.4 (5.3)	[18.4, 46.3]
gonial_angle (°)	130.4 (5.5)	[116.6, 144.9]	128.4 (5.3)	[115.2, 143.1]	125.7 (5.7)	[110.7, 140.9]
body_length (mm)	64.3 (10.4)	[49.4, 96.9]	71.4 (11.6)	[56.6, 105.1]	81.3 (14.6)	[55.4, 125.0]
ramus_height (mm)	37.0 (6.3)	[28.4, 60.1]	41.3 (7.0)	[30.3, 62.0]	50.9 (9.3)	[29.2, 79.9]
ramus_hgt:length	0.58 (0.07)	[0.43, 0.83]	0.58 (0.06)	[0.43, 0.78]	0.63 (0.07)	[0.45, 0.84]
ANS-PNS (mm)	49.0 (8.3)	[39.8, 74.1]	52.9 (8.9)	[40.8, 76.8]	58.5 (10.5)	[40.1, 90.7]
PFH (mm)	63.7 (10.5)	[48.3, 96]	71.3 (12)	[56, 108.3]	84.6 (15.4)	[53, 133.4]
AFH (mm)	105 (17)	[87.5, 157]	114.9 (19.2)	[90.3, 175.6]	130.4 (23.7)	[85.4, 197.2]
LFH (mm)	60.2 (10.7)	[47.7, 98.1]	65.1 (11.8)	[48.9, 106.6]	74.3 (14.6)	[48.3, 123.8]
PFH:AFH	0.61 (0.04)	[0.53, 0.74]	0.62 (0.04)	[0.54, 0.72]	0.65 (0.04)	[0.55, 0.80]
LFH:AFH	0.57 (0.02)	[0.51, 0.63]	0.57 (0.02)	[0.51, 0.63]	0.57 (0.02)	[0.52, 0.63]
NAS (mm)	21.5 (5.6)	[10.8, 39.9]	24.2 (5.5)	[8.5, 42.5]	27.6 (5.6)	[16.1, 46.9]
OAS1 (mm)	10.8 (3.9)	[3.9, 28.8]	11.0 (3.6)	[2.9, 23.7]	12.2 (4.7)	[4.3, 35.3]
OAS2 (mm)	6.8 (3.0)	[2.1, 24.1]	7.0 (3.0)	[1.8, 25.0]	8.2 (3.5)	[1.8, 20.8]
AAA (mm ²)	198.4 (92.1)	[60.0, 589.8]	272.1 (124.2)	[71.4, 792.5]	419.7 (196.3)	[159.1, 1228.1]
NAA (mm ²)	518.1 (218.6)	[264.0, 1356.3]	617.3 (237.5)	[257.8, 1493.8]	790.7 (307.7)	[306.5, 1878.8]
OAA (mm ²)	421.5 (208.1)	[164.0, 1339.0]	488.4 (201.0)	[190.2, 1138.0]	692.3 (316.5)	[227.2, 2199]
AAA/NAA	0.39 (0.12)	[0.1, 0.8]	0.44 (0.12)	[0.14, 0.77]	0.53 (0.13)	[0.28, 0.84]
cHP/TVL (°)	93.4 (7.7)	[80.3, 119.9]	91.1 (7.9)	[74.4, 111.9]	90.8 (6.9)	[78.5, 111.8]
OPT/NSL (°)	98.5 (9.2)	[75.4, 133.3]	97.7 (9.8)	[75.6, 127.6]	99 (8.8)	[80.8, 126.9]
CVT/NSL (°)	101.5 (9.2)	[79.6, 132.8]	101 (9.9)	[80.2, 131.3]	104 (8.3)	[87.1, 125.8]
OPT/CVT (°)	3 (2.9)	[-5.4, 10.6]	3.3 (2.9)	[-5.8, 12]	5 (3.3)	[-2.8, 13.8]

3.2 Methods

Firstly, a null model was adjusted considering ML/NSL as the dependent variable, using the nlme package and the maximum likelihood method (R x64 4.1.1), expressed by the following equation:

$$ML/NSL_{ij} = \beta_{0j} + r_{ij} \tag{5}$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

To confirm a level 2 effect on the data, the intra-class correlation coefficient (*ICC*) was then estimated considering the within-person variance (σ^2) and the between-person variance (τ_{00}) of mandibular inclination through the null model, given by the following equations:

$$ICC = \frac{\tau_{00}}{\tau_{00} + \sigma^2} \tag{6}$$

$$\hat{\sigma}^2 = \frac{\sum_{j=1}^C (n_j - 1) S_j^2}{N - C} \tag{7}$$

$$S_j^2 = \frac{\sum_{i=1}^{n_j} (y_{ij} - \bar{y}_j)^2}{(n_j - 1)} \tag{8}$$



Then, a random intercept model was adjusted considering time as a level 1 predictor and a fixed slope:

$$\begin{aligned} \text{ML/NSL}_{ij} &= \beta_{0j} + \beta_{1j}\text{time} + r_{ij} \\ \beta_{0j} &= \gamma_{00} + u_{0j} \\ \beta_{1j} &= \gamma_{10} \end{aligned} \quad (9)$$

The previous adjustment was then compared (ANOVA) with a random slope fit on the data:

$$\begin{aligned} \text{ML/NSL}_{ij} &= \beta_{0j} + \beta_{1j}\text{time} + r_{ij} \\ \beta_{0j} &= \gamma_{00} + u_{0j} \\ \beta_{1j} &= \gamma_{10} + u_{1j} \end{aligned} \quad (10)$$

Following graphical error structure inspection of the level 1 fit, predictors, higher order terms and possible interactions were then iteratively searched regarding the level 2 model in a forward manner, considering clinical relevance and 5% level of significance. Adjustments were subsequently compared using ANOVA. Any terms indicating multicollinearity (Variation Inflation Factor, $VIF > 5$) were removed (Gareth *et al.*, 2013).

Model diagnostics included level 1 and level 2 standardized residuals graphical analysis of normality and homoscedasticity. Quality of fit was determined according to Akaike's Information Criterion, AIC (Akaike, 1974); and Schwartz's Bayesian Criterion, BIC (Schwarz, 1978). Influential value analysis included fixed and random effects leverage regarding influence on predicted values; Cooks distance concerning influence on fixed effects estimates; covariance matrix ratio and covariance matrix trace for influence on fixed effects precision; and relative variance change (RVC) for variance influence analysis (Loy, 2013).

4. Empirical Results

Summary statistics for the preliminary level 1 models are detailed in Table 5. The null model \widehat{ICC} suggests that approximately 72.6% of the ML/NSL variability can be explained by the between-person variance (τ_{00}), that is, mandibular inclination tends to be relatively stable over time and there are relevant differences between individuals. On the other hand, only 27.4% of the ML/NSL variability ($1 - \widehat{ICC}$) is explained by the within-person variance. Considering the fixed effects component in the null model (γ_{00}), the overall mean mandibular inclination considering all individuals and all instants was 35.3°.

Table 5. Preliminary models summary for mandibular inclination variation by time.

Parameters	Null model	Fixed slope model	Random slope model
AIC	2597.123	2430.284	2371.135
BIC	2609.587	2446.904	2396.064
logLik	-1295.561	-1211.142	-1179.567
Random effects			
StdDev – Residual (σ)	2.628118	4.391268	4.3600089
StdDev – Intercept ($\sqrt{\tau_{00}}$)	4.280849	2.008558	1.3697296
Fixed effects			
γ_{00} Intercept	35.28089	36.9758	36.65987
Std Error	0.362861	0.3805939	0.3597831
γ_{10} Intercept	-	-1.6949	-0.82739

Std Error	-	0.1135909	0.0665738
ICC	0.7262674	0.8269841	0.9101707

A random slope model was deemed more appropriate after graphical analysis (Figure 10), allowing for ML/NSL rate variation between individuals. Predictive variables were centered prior to adjustment and proportions were multiplied by 100, in favor of their interpretation. A quadratic term for time was initially explored although it ceased to be significant after the introduction of level 2 predictors.

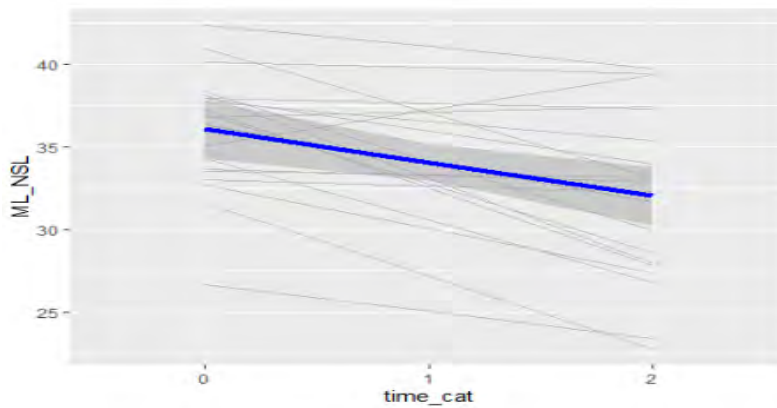


Figure 10. Line graph of observed ML/NSL values per time instant ($n=20$ subset).

The iterative selection of level 2 predictors accompanied by the search for possible interactions produced two relevant adjustments for ML/NSL, which are presented below:

$$\begin{aligned}
 \text{ML/NSL}_{ij} &= \beta_{0j} + \beta_{1j}\text{time} + r_{ij} \\
 \beta_{0j} &= \gamma_{00} + \gamma_{01}\text{ANB}_j + \gamma_{02}\text{PP/NSL}_j + \gamma_{03}\text{OPT/NSL}_j + \gamma_{04}\text{OAS1}_j + \\
 &\quad + \gamma_{05}\text{gonial_angle} + \gamma_{06}\text{PFH:AFH}_j + u_{0ij} \\
 \beta_{1j} &= \gamma_{10} + u_{1ij} \\
 \text{ML/NSL}_{ij} &= \beta_{0j} + \beta_{1j}\text{time} + r_{ij} \\
 \beta_{0j} &= \gamma_{00} + \gamma_{01}\text{SNB}_j + \gamma_{02}\text{PFH:AFH}_j + \gamma_{03}\text{ramus_height:length}_j + u_{0ij} \\
 \beta_{1j} &= \gamma_{10} + \gamma_{11}\text{SNB}_j + \gamma_{12}\text{ramus_height:length}_j + u_{1ij}
 \end{aligned}
 \tag{11}$$

$$\tag{12}$$

Table 6. Summary statistics for mod1 (Equation 11) and mod2 (Equation 12). ¹Wald Test

Coefficient	Parameter	mod1			mod2		
		Estimate	S. Error	P^1	Estimate	S. Error	P^1
β_{0j}	γ_{00}	34.796	0.151	< 0.001	34.860	0.135	< 0.001
	γ_{01}	0.106	0.038	0.005	-0.110	0.035	0.002
	γ_{02}	0.183	0.028	< 0.001	-1.131	0.028	< 0.001
	γ_{03}	0.030	0.008	0.0004	0.190	0.014	< 0.001
	γ_{04}	-0.058	0.020	0.0034	-	-	-
	γ_{05}	0.162	0.019	< 0.001	-	-	-
β_{1j}	γ_{06}	-0.757	0.024	< 0.001	-	-	-
	γ_{10}	0.485	0.082	< 0.001	0.479	0.061	< 0.001
	γ_{11}	-	-	-	-0.037	0.015	0.014
	γ_{12}	-	-	-	-0.014	0.007	0.037



	σ	0.694	-	-	0.595	-	-
	$\sqrt{\tau_{00}}$	1.622	-	-	1.490	-	-
	$\sqrt{\tau_{11}}$	0.546	-	-	0.384	-	-

The comparison between the adjustments (Table 6) favored *mod2* fit (Equation 12), which explains the variability of β_{0j} of the level 1 model through the predictor variables SNB (sagittal position of the mandible relative to the skull base); PFH:AFH (ratio between posterior facial height and anterior facial height); and ramus_height:length, (the proportion between the height of the ramus and the length of the mandibular body). The *mod2* fit also explains the variability of the slope β_{1j} by the presence of significant interaction between two predictor variables and time: SNB and ramus_height:length. It should be noted that the addition of any pharyngeal and postural variables in *mf2*, as well as gender, were not significant to explain the variability of β_{0j} or β_{1j} .

5. Conclusions

Adjustment with MLH distinguishes fixed and random components of the variation in mandibular inclination during growth. Two distinct adjustments were obtained, the first illustrating the relationship between ML/NSL and predictors ANB, PP/NSL, OPT/NSL, OAS1, gonial angle, and posterior/anterior facial height over time; and the second adjustment, with superior quality indicators, demonstrated a relationship with posterior/anterior facial height, SNB and mandibular height/length predictors.

Apart from OAS1/OAS2, no other linear pharyngeal variable was found to be a significant predictor of ML/NSL change during growth. Although it has a reduced effect on the outcome, it may eventually reflect a relationship between the mandibular position and the soft palate, the tissues at the base of the tongue and the hyoid bone. No significant relationship was found between the ratio of free respiratory area/nasopharyngeal area and mandibular inclination.

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