Does parental similarity degree affect the development of their offspring?

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MÁ PODOBNOST MEZI RODIČI VLIV NA VÝVOJ JEJICH POTOMKŮ?

ABSTRAKT   Podobnost v obličeji a jiných tělesných charakteristikách se považuje za jeden z aspektů při volbě reprodukčního partnera u člověka. Navzdory skutečnosti, že míra rodičovské podobnosti může ovlivnit potomky již v raných fázích jejich prenatálního vývoje, jen velmi málo empirických studií se zatím zaměřilo na důsledky tohoto nenáhodného procesu. Tato studie měla tři cíle: (1) otestovat hypotézu tělesného asortativního párování u lidí, (2) najít vztah mezi fyzickou podobností rodičů a růstovými křivkami jejich potomků a (3) najít konkrétní trendy v růstu potomků související s asortací jejich rodičů. Podobnost rodičů ve fyzických znacích tak byla analyzována ve vztahu k deskriptorům růstových křivek jejich potomků (n = 184 trojic matka-otec-dítě z databáze Brněnské růstové studie). Ve srovnání s náhodně vytvořenými páry si skuteční partneři nebyli podobnější v žádném ze sledovaných znaků. Fyzické znaky však mezi partnery korelovaly (většinou kladně). Nalezené byly i vztahy mezi fyzickou podobností rodičů a deskriptory růstových křivek jejich potomků. Rodičovská podobnost v různých znacích však ovlivňovala růst potomků různým způsobem.

KLÍČOVÁ SLOVA   asortativní párování; nenáhodné párování; výběr partnera; preference; podobnost; lidský obličej; růstová křivka; potomci

ABSTRACT   Similarity in facial and other physical characteristics has been recognized as one aspect of reproductive mate choice in humans. Despite the fact that parental similarity degree may affect offspring already in the early stages of their prenatal development, just a very few empirical studies have focused on the consequences of this non-random process so far. This study included three goals: (1) to test the hypothesis of body assortative mating in humans, (2) to find a relationship between physical similarity of parents and the growth curves of their offspring and (3) to find specific trends in the growth of offspring connected to parental assortative mating. Therefore, the similarities of parents in physical features were analysed in relation to the descriptors of the growth curves of their offspring (n = 184 mother-father-child triads from the Brno Growth Study database). In comparison to randomly generated pairs, real partners were not more similar to each other in any of the observed trait. However, some physical features correlated (mostly positively) between partners. Relationships between physical similarity of parents and the descriptors of the growth curves of their offspring were found. However, parental similarity in various features affected the growth of their offspring differently.

KEY WORDS   assortative mating; non-random mating; mate choice; preferences; similarity; human face; growth curve; offspring

INTRODUCTION

Non-random mating based on physical or cultural (Speakman et al. 2007, 316) similarity of partners is known as positive assortative mating or homogamy (Pearson 1903, 481). Among the first, Pearson (1903, 482) noticed positive correlation in physical traits between partners. Since then, many authors showed correlations in body height, weight, attractivity, health and other physical traits of partners (George et al. 2015, 128–129; Hur 2003, 468–469; Speakman et al. 2007, 317–319; Spuhler 1968, 128; Zietsch et al. 2011, 7). Genetic similarity of partners was also studied (Guo et al. 2014, 2–7;

Rushton 1988, 329–330). In general, correlations in body traits are weak although there are more positive correlations than negative (Rushton et al. 1984, 184).

During the active mate choice, important role is played by human face and previous studies actually showed significantly higher facial similarity between partners compared to random pair formation (Alvarez and Jaffe 2004, 185–188; Thiessen et al. 1997, 160–162; Wong et al. 2018, 5). However, in other studies, the preferences of men (who preferred similar partners) and women (who preferred the most attractive partners) differed (Kocsor et al. 2011, 1266–1267) or there was a difference between matched preference (similar partners) and actual choice (other than similar partners). It appears that several factors play a role in the actual mate choice, often based on evolutionary models like the theory of parental investment (Todd et al. 2007, 15015). The opposite result is the preference for average faces, which are generally considered attractive (Penton-Voak et al. 1999, 110) and sexual resistance to similar faces because of a sign of kinship (DeBruine 2005, 920–921).

Despite that many studies have shown that the human partner choice is not random, just a few of them have focused on consequences resulting from this specific partner choice for offspring. Studies that are illustrating these consequences and possible effect on offspring are often associated with other than physical traits. Many studies showed a strong correlation for demographic characteristics (age), socioeconomical status (education, income) and attitudes (religion or social, family, and political orientation; Buston and Emlen 2003, 8807–8808; George et al. 2015, 128–129; Hur 2003, 468–469; Watson et al. 2004, 1044–1047; Zietsch et al. 2011, 7). Partners often prefer a similar personality which can be also reflected in the face morphology (Little et al. 2006, 975–981). Similarity of partners in personality and attitudes have a positive effect on satisfaction in relationship and also offspring satisfaction (Wu et al. 2019, 8–15). On the other hand, dissimilarity in psychological characteristics leads to conflicts between partners and thus has a negative impact on their offspring. With negative impacts on the relationship and offspring well-being correlations in psychopathologies or addictions are also connected (smoking, alcoholism; Low et al. 2007, 949; Luo 2017, 9). Negative impact of physical parental similarity was also found. Similarity of parents in obesity increases the risk of obesity prevalence in offspring (Jacobson et al. 2006, 104). Moreover, an epidemical consequence in the population may be assumed (Speakman et al. 2007, 321). Nevertheless, there is a question about active preference for obesity and lower fertility of partners.

One of the few studies focusing on social but also physical similarities (age, education, income, body height and smiling frequency) which may enhance offspring prosperity (body height and school attendance) focuses on native Amazonian society in Bolivia. The correlation coefficients between partners were higher than expected by chance. However, no statistically significant relationship between assortative mating and offspring prosperity was found (Godoy et al. 2008, 205–208). On the contrary, Edwards and Roff (2016, 50–53) found an association between parental similarity in education, age, religion and physical characteristics and cognitive tests of offspring based on marital matching models. In this case, similarity also maintained the stability of the marriage.

Adaptive explanations of assortative mating

Based on adaptation theories, it can be assumed that if assortative mating is observed in humans, it may be beneficial for an individual (Godoy et al. 2008, 203; Kościński 2007, 49–50; Roberts and Little 2008, 311–313). According to Thiessen and Gregg (1980) assortative mating increases inclusive fitness (defined by Hamilton 1964) of partners by increasing the proportion of parental (similar) alleles in future generations (Thiessen et al. 1997, 162). By Rushton et al. (1984, 186) and Rushton (1988, 329–330), optimal genetic similarity of parents may have positive consequences by increasing the degree of genetic relationship between parent and offspring, so it may improve stability of marriage, fertility and increase the degree of altruism in the family. Furthermore, Figueredo and Wolf (2009, 326–327) linked assortative mating with Life History Strategy. According to their model, positive assortative mating is associated with a slow life history. It compensates for the disadvantages of sexuality, and through homogeneous offspring it preserves genomes adapted for the stable and predictable environment. On the contrary, negative assortative mating represents a fast life history and through genetic diversity of the offspring it has evolved as an adaptation to an unstable and unpredictable environment (Wolf and Figueredo 2011, 172–173).

Proximate mechanisms of assortative mating

Assumed mechanisms of parental similarity impact on offspring growth include the thrifty phenotype hypothesis (Hales and Barker 1992) and early prenatal programming (Lucas 1991). During the critical period of development, offspring is stimulated by the environment with lasting consequences for its future development, for example body size adaptations (Lucas 1991; Wells 2003). Therefore, the similarity of parents in physical characteristics could through more similar combination of alleles ensure the better conditions for smooth development of offspring. However, the optimal genetic similarity is important. Optimal outbreeding (by Bateson 1983) is balanced by assortative mating similarity maximalization and lethal homozygous selection (Alvarez and Jaffe 2004, 178; Epstein and Guttman 1984, 245; Thiessen and Gregg 1980). Nevertheless, a non-linear trend of assortative mating benefits is expected because the risk of many genetic defects increases with increasing degree of parental similarity (Penton-Voak et al. 1999, 105). On the other hand, the offspring of genetically diverse parents would be forced to combine a several different alleles, which could result in a certain developmental load. However, their prosperity may depend on the environment. As mentioned, negative assortative mating may maximalise
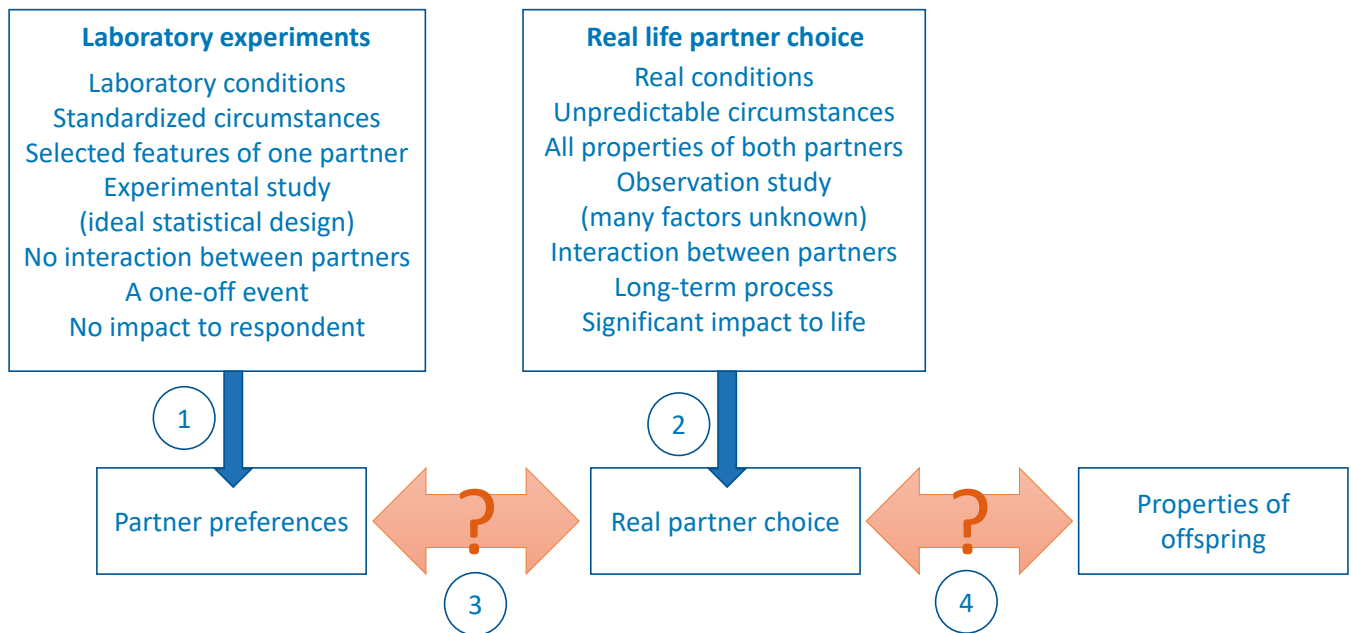
Figure 1: Scheme of the scientific approach to mate choice in humans. Most often, mate preferences are observed in laboratory (cognitive) experiments (1), where stimuli and research groups of volunteers are specified under defined conditions and respondents express their mate preferences. Another type of research is the study of real partner choice (2), the characteristics of partners from real couples based on observations, questionnaires, matrix data, etc. Less research has explored the relationship between pure preferences and their realization in life (3), and the least found in the literature is a focus on how partners' choice of certain traits affects the properties of their offspring (4), i.e., how partner choice affects the next generation. This research focuses on the study of this relationship (4).

the heterozygosity, so this offspring can be better adapted to an unpredictable environment, such as the struggle against pathogens (Godoy et al. 2008, 202; Ochoa and Jaffé 1999, 6; Penton-Voak et al. 1999, 105).

To sum up, it is assumed that the parental similarity degree is one of the factors that can affect offspring already in the early stages of their prenatal development. However, there is an open question if preference of a similar partner comes with potential benefits for the offspring (direct or indirect). Research on partner preferences (Figure 1) often does not follow the consequences of that choice which may represent the actual explanation of observed human mate choice. This study is among the first to focus on the relationship between certain traits of parents and the characteristics of their offspring in detail.

ries, assortative mating benefits can be observed in offspring, if it (in addition to higher fitness), would have a positive effect on offspring prosperity (Godoy et al. 2008, 201–203). We hypothesise that parental similarity could ensure quality conditions for the growth and development of their offspring. Therefore, the more similar the parents are in facial traits, the smoother ontogenesis of their offspring can be assumed. The study included three goals: (1) to test the hypothesis of body assortative mating in humans, (2) to find a relationship between physical similarity of parents and the growth curves of their offspring and (3) to find specific trends in the growth of offspring connected to parental assortative mating. Therefore, the similarities of parents in physical features were analysed in relation to the descriptors of the growth curves of their offspring.

GOALS OF THE STUDY

The goal of the study was to follow up the studies which have showed significantly higher similarity between partners compared to random pair formation (Alvarez and Jaffe 2004, 185–188; Thiessen et al. 1997, 160–162; Wong et al. 2018, 5) and therefore to find a possible explanation of this phenomena. Mainly the facial similarity of partners was studied because the fact that the human face plays an important role during all stages of active partner choice (Miller 1998, 20) and as a genetic contribution of the parents it is also reflected in the faces of the offspring. Furthermore, based on adaptation theo-

MATERIAL AND METHODS

Brno Growth Study

The sample was represented by individuals from the Brno Growth Study (BGS) database. The original longitudinal study, initiated in 1961, focused on growth and development of children from Brno, Czech Republic (Bouchalová 1987, 20–21).

Sample of children

Examinations of children (n = 555, 278 boys) within the Brno Growth Study took place at the Department of Social
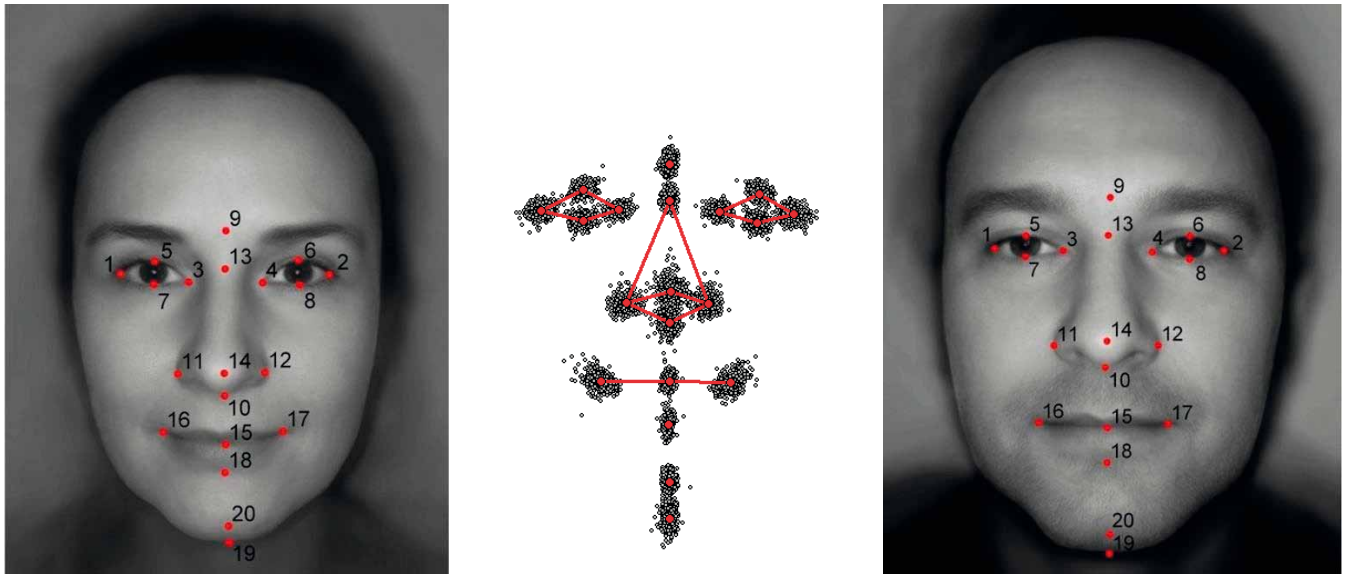
Figure 2: Visualisation of digitalized landmarks (outer average faces) and GPA superposition of landmarks of all individuals (in the centre). The average shape with the lines between the points is marked in red.

Medicine, Faculty of Medicine, University of Jan Evangelista Purkyně and the Pediatric Research Institute in Brno supervised by M. Bouchalová. A total of 334 participants remained until the end of the study and for 18 years they underwent a regular medical, psychological and social examination including body measurement (Bouchalová 1987, 20–25).

The postnatal growth curves of body height of the studied children were analysed by means of Functional Data Analysis (Ramsay et al. 2020) using newly developed R-package *growthfd* (Králík et al. 2021; Klíma et al. 2021) available at website: <https:/ondrej-klima.github.io/growthfd/>. The procedure is based on fitting B-splines into the data, registering all curves in the point of Age at Peak Velocity in adolescence, and decomposing variations in the functions by means of Functional Principal Component Analysis (FPCA), separately for phase and amplitude. As a result, each curve is described by scores on 12 Functional Principal Components, 6 for phase and 6 for amplitude. Curve shape changes for interpretation are available in the R-package *growthfd* and in the supplementary materials of the published method (Králík et al. 2021).

Parental sample

The records of parents from the Brno Growth Study collected from 1970 until 1977 consisted of whole-body photography and basic personal data (date of birth, examination date, sibling number and order) and body measurements (body height, weight, and face measurements). A total of 635 photographs from parental files were scanned with 600 DPI resolution. The images were sorted in order to exclude individuals with a missing partner record (n = 53), individuals without a photograph (at least one of the partners lacked a photograph, n = 98) and individuals for whom it was impossible to record landmarks in the face area due to insufficient image

quality, head rotation and the presence of glasses. The resulting number of images that were further used was 420.

Geometric morphometrics of parental faces

Scanned and edited face images (n = 420 parents, 210 men and 210 women) were added to TPS file in the random order using *tpsUtil 1.78* (Rohlf 2019). Based on the anthropometric points defined for the FIDENTIS 3D face database (Urbanová et al. 2018, 207–208, 210), twenty landmarks which could be used with respect to the image quality and face position were defined (Figure 2). The landmarks were digitalised in *tpsDig2 2.31* (Rohlf 2017). Cartesian coordinates in 3D array (20 x 2 x 420) were calibrated using morphological facial height (the distance between nasion and gnathion). Real measurements of morphological facial height available from parental records were divided by the distance between nasion and gnathion landmarks and obtained fraction represented the scale value by which the raw coordinates were multiplied (n = 416 individuals with possible calibration, 208 men and 208 women). Calibrated coordinates were analysed by Generalized Procrustes Analysis (GPA) method using R-package *geomorph* (Adams et al. 2020, Figure 2). At first, Procrustes shape coordinates were used for the calculation of full Procrustes distances (PD) between configurations of all individuals one by one using routines in the R-package *shapes* (Dryden 2019). From the matrix of full Procrustes distances, it was possible to select values for real pairs (n = 208 real life parents) and randomly generated pairs (n = 43056). In this variant of analysis, the similarity of parents was defined based on the PD between them. The lower Procrustes distances were between partners (the closer their overall configurations were to each other in the shape space), the more similar they were considered. Secondly, differences in centroid sizes (CS) were computed for

all individuals (real and random pairs) calculated as female value subtracted from male value ($D = X_M – X_F$). In this variant of analysis, partners were considered more similar in the overall face size, the closer to zero the differences in CS were between them.

Procrustes shape coordinates were subsequently analysed by Principal Component Analysis (PCA, R-package *geomorph*, Adams et al. 2020) resulting in 36 Principal Components. Principal Components were visualised to show the difference between the reference and target shape (minimum and maximum of the score represented by given component, R-package *geomorph*, Adams et al. 2020). Based on the visualizations, twelve components which represented the real difference in shape between individuals were selected. Selected components included changes in the shape of the head and facial parts as well as changes originated during the photo shoot with a possible interpretation of the similarity in personality between partners (for example head position or facial expression). The distances on the selected components were calculated between partners (males and females) within real (n = 208) and random pairs (n = 43056). The lower the distance on the selected component was between them, the more similar the partners were in the shape expressed by the component.

Additional information about parents

Life-history features and anthropometry of parents from the parental records were also analysed. The similarity of parents was defined as a difference between them in studied characteristics calculated as female value subtracted from male value ($D = X_M – X_F$) for all individuals (real and random pairs).

Life-history features of parents

Parents were born from 1911/04/17 to 1946/01/18 with 1st to 9th birth order and with 1 to 11 siblings. The ages of parents were defined as ages at the time of birth of offspring, calculated from the dates of birth of parents and offspring. The mean age difference (in years) between the real pairs was 3.97 (min = −6.75, max = 20.44). The mean of difference in number of siblings was −0.211 (min = −8, max = 9) and for birth order it was −0.174 (min = −8, max = 5). Differences between partners in number of siblings and birth order were divided into categories −2 and less, −1, 0, 1, 2 and more.

Anthropometry of parents

Differences between parents were calculated based on their anthropometric measurements. The mean of difference in height (in centimetres) was 11.5 (min = −5.5, max = 27.5). The mean of difference in weight (in kilograms) was 14.0 (min = −40.8, max = 59.4). The head measurements (differences between real partners, all in centimetres) were as follows: head circumference (mean = 2.3, min = −2.5, max = 8.0), head width (mean = 0.76, min = −1.1, max = 4.6), head length (mean = 0.98, min = −2.0, max = 3.8), head height (mean = 0.73, min = −1.6, max = 3.6), minimum frontal breadth (mean = 0.47, min = −1.7, max = 2.9), bizygomatic breadth (mean = 1.15, min = −1.3, max = 4.1), bigonial breadth (mean = 0.72, min = −1.2, max = 3.2), physiognomic facial length (mean = 1.15, min = −2.1, max = 4.5), morphological facial length (mean = 0.88, min = −1.7, max = 3.50), nose to chin distance (mean = 0.57, min = −2.0, max = 2.6), nose width (mean = 0.35, min = −1.0, max = 1.8), nose height (mean = 0.39, min = −0.8, max = 1.7), mouth width (mean = 0.3, min = −1.1, max = 1.4), mouth height (mean = −0.23, min = −3.6, max = 1.4).

Data analyses

Relationships between parental variables (distances and differences between partners) and the descriptors of the growth curves of their offspring were analysed. The number of cases where data were available for both children and parents were 184 (96 mother-father-daughter and 88 mother-father-son triads). Data analysis was performed in R (R Core Team 2020). The differences between groups (partners within real and random pairs or between the parents of boys and girls) were compared using Student's t-test or nonparametric Mann-Whitney U test. The correlations between partners were computed using Pearson's correlation coefficient.

All differences between partners (in face centroid size, age, and anthropometric measurements) were edited due to the nature of similarity in the following manner. Mean differences of studied variables between the real partners (parents) represented the optimal values of differences (similarity) between partners ($O = mean(D_{1-n})$). These optimal values were subtracted from each value of difference between partners, so they replaced zero (difference between partners = 0 which means that their difference is identical to the mean value of all differences in the sample) as beginning of coordinates. All obtained differences between partners were then absolutized ($D_1 = |D – O|$). Partners were considered more similar in a certain variable, the closer to zero the absolute differences between them were in that variable.

Relationships between parental variables and descriptors of the growth curves of the offspring were computed in correlation matrices (R-package *Hmisc*, Harrell 2021) using Spearman's correlation coefficient. Correlation matrices were also computed for individual variables of mothers and fathers to control a possible influence of one of the parents. It was thus determined whether the relationship with descriptors of the growth curves of the offspring depend on the characteristics of mother, father, or the absolute difference between them. Relationships were interpreted when the absolute differences between the parents were more significant than the value of each parent. Significant relationships were visualized using scatterplots and regression lines. Categorical data (number of siblings and birth order) were tested by Kruskal-Wallis test and significant relationships were further compared using Dunn's all-pairs test (R-package *PMCMRplus*, Pohlert 2022) and visualized using boxplots.

RESULTS

Difference between the real and random pairs

There was no statistically significant difference found between the Procrustes distances between partners within real (mean = 0.102, min = 0.059, max = 0.196) and random pairs (mean = 0.103, min = 0.039, max = 0.269) nor between the face centroid size absolute differences between partners within real (mean = 14.054, min = −35.622, max = 54.315) and random pairs (mean = 14.054, min = −70.413, max = 81.636). No statistically significant differences between the groups of real and random pairs were found in the distances between partners on any of the selected components nor in the absolute difference between partners in other characteristics (e.g., age, height, weight or head measurements).

Difference between the parents of boys and girls

Parents of girls had significantly lower Procrustes distances between them compared to parents of boys, so they were more similar in the overall landmark configuration (t = −1.997, p-value = 0.047). Based on the shape expressed by individual components, parents of girls were also more similar in the shape of the head (t = −2.017, p-value = 0.045), and in the chin height (t = −2.391, p-value = 0.018). Parents of boys were more similar in the shape of eyes (t = 2.110, p-value = 0.036). Based on anthropometric measurements parents of girls were more similar in the minimum frontal breadth (t = −2.558, p-value = 0.011). Mothers of boys had significantly higher head width compared to mothers of girls (W = 4110.5, p-value = 0.014) and fathers of boys had significantly higher minimum frontal breadth compared to fathers of girls (W = 4321.5, p-value = 0.051).

Correlations between partners

There was a statistically significant strong positive correlation found in the age of parents (0.734, between parents of girls it was 0.708 and between parents of boys 0.766). Medium strong positive correlation was found in height (0.436, between parents of girls it was 0.514, but between parents of boys the correlation was weak: 0.342). No significant correlations were found in body weight. Weak positive correlation was found in bizygomatic width (0.267, between parents of girls it was insignificant and between parents of boys it was 0.351). Very weak positive correlation was found in chin height (0.138, between parents of girls it was weak: 0.288 and between parents of boys it was insignificant), in nose width (0.142), in bigonial width (0.134) and in the number of siblings (0.142). Between parents of girls was further found a weak positive correlation in the shape of eyes (0.218), in the head position on the photography (0.216) and a very weak positive correlation in the head circumference (0.188). Between the parents of boys was further found a weak negative correlation in the mouth height (−0.223) and in the head position on the photography (−0.203).

Correlations between parents and growth of their offspring

This section contains interpretations of significant correlations between parental variables and descriptors of the growth curves of the offspring, represented by Functional Principal Components (FPC), separately for phase and amplitude, which are introduced at the beginnings of subsequent paragraphs. Tables of Spearman's correlation coefficients and p-values are available in Supplementary Materials (Tables S1–S2 for distances/absolute differences between partners and Tables S3–S6 for individual variables of mothers and fathers). Facial shape changes on Principal Components, of which the distance between parents significantly correlated with descriptors of the growth curves of offspring are visualised in Table S7. Growth curve variations of offspring and respective relationships in parents are available in Figures 3–7 and in Supplementary Materials (Figures S1–S6).

Phase FPC1 represents total age shift in the growth curve meaning the variation between subjects with overall early and late maturation. In other words, it is about the differences between children in how they progress in their biological development at the same age. Phase FPC1 represents 79.7% of variance in boys and 77.6% of variance in girls. In boys, phase FPC1 is related to the head width of fathers (ρ = 0.23, p-value = 0.030), and to the distance on PC8 (which represents chin height/distance between sublabiale and pogonion, ρ = −0.21, p-value = 0.046) and absolute difference in nose to chin distance (ρ = −0.27, p-value = 0.012) between parents. As the distance on PC8 between parents decreases (they are more similar in chin height based on distance between sublabiale and pogonion), the score on phase FPC1 of sons increases (the growth curve shifts from blue to red), therefore according to the height growth curve, sons have a greater tendency to mature earlier compared to other boys. The same relation is true for the absolute difference in nose to chin distance between parents and the score on phase FPC1 of sons. In girls, phase FPC1 is related to the age of fathers (ρ = 0.23, p-value = 0.023), to the minimum frontal breadth of mothers (ρ = 0.27, p-value = 0.008), and to the face centroid size absolute difference between parents (ρ = 0.21, p-value = 0.036). As the absolute difference in face centroid size between parents decreases (they are more similar in overall face size), the score on phase FPC1 of daughters decreases (the growth curve shifts from red to blue), therefore according to the height growth curve, daughters have a greater tendency to mature later compared to other girls.

Amplitude FPC1 represents overall variation in amplitude which reflects absolute height throughout the whole postnatal growth. Amplitude FPC1 represents 78.5% of variance in boys
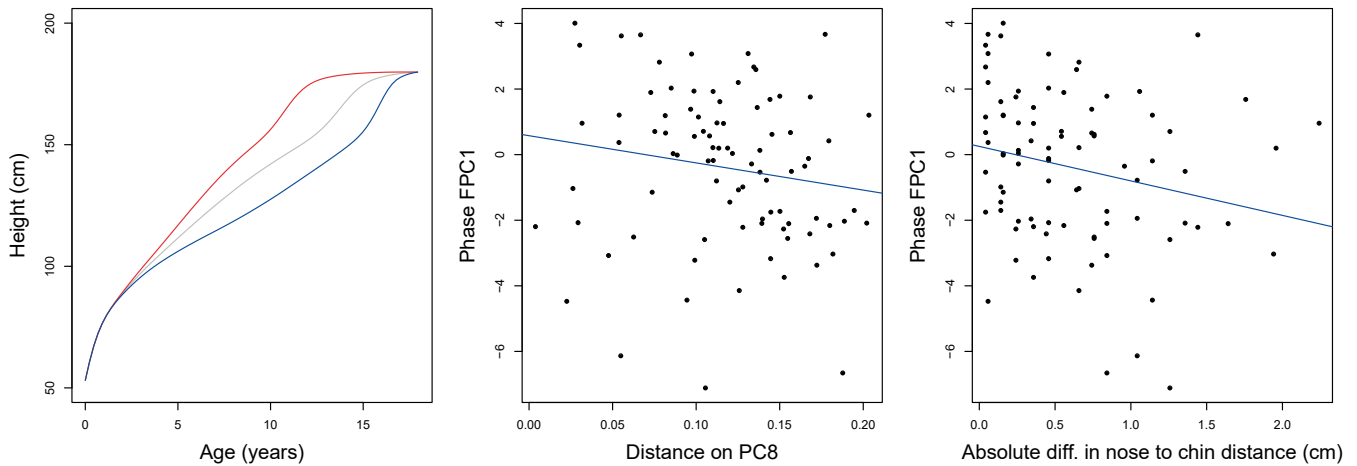
Figure 3: Phase FPC1 growth curve variations in boys and respective relationships in parents. Mean growth curve is marked grey, red curve represents positive values (+ 3SD), and blue curve represents negative values (− 3SD) within the curve change represented by individual Functional Principal Component (FPC).

and 75.5% of variance in girls. In boys, amplitude FPC1 is related to the height of fathers (ρ = 0.46, p-value = 0.000) and mothers (ρ = 0.54, p-value = 0.000), to the weight (ρ = 0.34, p-value = 0.001), head width (ρ = 0.21, p-value = 0.049), head height (ρ = 0.25, p-value = 0.019), nose to chin distance (ρ = 0.21, p-value = 0.047) and score on PC12 (ρ = 0.29, p-value = 0.007, eye shape) of mothers, and to the age (ρ = 0.21, p-value = 0.046), bigonial breadth (ρ = 0.24, p-value = 0.022) and score on PC13 (ρ = 0.24 p-value = 0.025, nose alar position) of fathers, which is why amplitude FPC1 is also related to the distance on PC13 between parents (ρ = 0.26, p-value = 0.015). In boys, amplitude FPC1 is further related to the distance on PC5 (ρ = −0.21, p-value = 0.047, glabella position and nose width), and to the absolute difference in mouth height (ρ = 0.21 p-value = 0.050) between parents. As the distance on PC5 between parents decreases (they are more similar in glabella position and nose width), the score on amplitude FPC1 of sons increases (the growth curve shifts from blue to red), therefore they were overall taller compared to other boys in the same growth phase. At the same time, as the absolute difference in mouth height between parents decreases (they are more similar in mouth height), the score on amplitude FPC1 of sons decreases (the growth curve shifts from red to blue), therefore they were overall shorter compared to other boys in the same growth phase. In girls, amplitude FPC1 is related to the height of fathers (ρ = 0.45, p-value = 0.000) and mothers (ρ = 0.42, p-value = 0.000), to the mouth height (ρ = 0.21, p-value = 0.042) of mothers, and to the score on PC4 (ρ = −0.20, p-value = 0.049, facial expression), score on PC14 (ρ = 0.31, p-value = 0.003, chin shape/distance between pogonion and gnathion), head height (ρ = 0.22, p-value = 0.029), nose height (ρ = 0.20, p-value = 0.047) and weight (ρ = 0.26, p-value = 0.010) of fathers, which is why amplitude FPC1 is also related to the absolute difference in weight (ρ = 0.20, p-value = 0.050) between parents. In girls, amplitude FPC1 is further related to the distance on PC12 (ρ = 0.25, p-value = 0.013, eye shape), absolute difference in centroid size (ρ = −0.32, p-value

= 0.002), minimum frontal breadth (ρ = 0.33, p-value = 0.001) and bizygomatic breadth (ρ = 0.23, p-value = 0.021) between parents. As the distance on PC12 between parents decreases (they are more similar in the shape of eyes), the score on amplitude FPC1 of daughters decreases (the growth curve shifts from red to blue), therefore they were overall shorter compared to other girls in the same growth phase. As the absolute difference in minimum frontal breadth and bizygomatic breadth between parents decreases (they are more similar in these variables), the score on amplitude FPC1 of daughters also decreases, therefore they were overall shorter compared to other girls in the same growth phase. On the contrary, as the absolute difference in face centroid size between parents decreases (they are more similar in overall face size), the score on amplitude FPC1 of daughters increases (the growth curve shifts from blue to red), therefore they were overall taller compared to other girls in the same growth phase.

Phase FPC2 reflects one change in the growth dynamics so the postnatal growth curve is divided into two parts with different growth rates (individuals with higher growth rate in the first period, have lower growth rate in the second postnatal period and vice versa). Phase FPC2 represents 16.0% of variance in boys and 19.3% of variance in girls. In boys, phase FPC2 is related to the age of fathers (ρ = −0.21, p-value = 0.049), and to the score on PC4 (ρ = −0.21, p-value = 0.049, facial expression), score on PC12 (ρ = −0.26, p-value = 0.015, eye shape), score on PC13 (ρ = 0.27, p-value = 0.010, nose alar position), height (ρ = −0.25, p-value = 0.020), weight (ρ = −0.22, p-value = 0.044) and head height (ρ = −0.24, p-value = 0.027) of mothers. In boys, phase FPC2 is further related to the distance on PC5 (ρ = 0.21, p-value = 0.046, glabella position and nose width) and to the absolute difference in bigonial breadth (ρ = −0.30, p-value = 0.005) between parents. As the distance on PC5 between parents decreases (they are more similar in glabella position and nose width), the score on phase FPC2 of sons decreases (the growth curve shifts from red to blue), therefore they have a greater tendency to have a lower growth
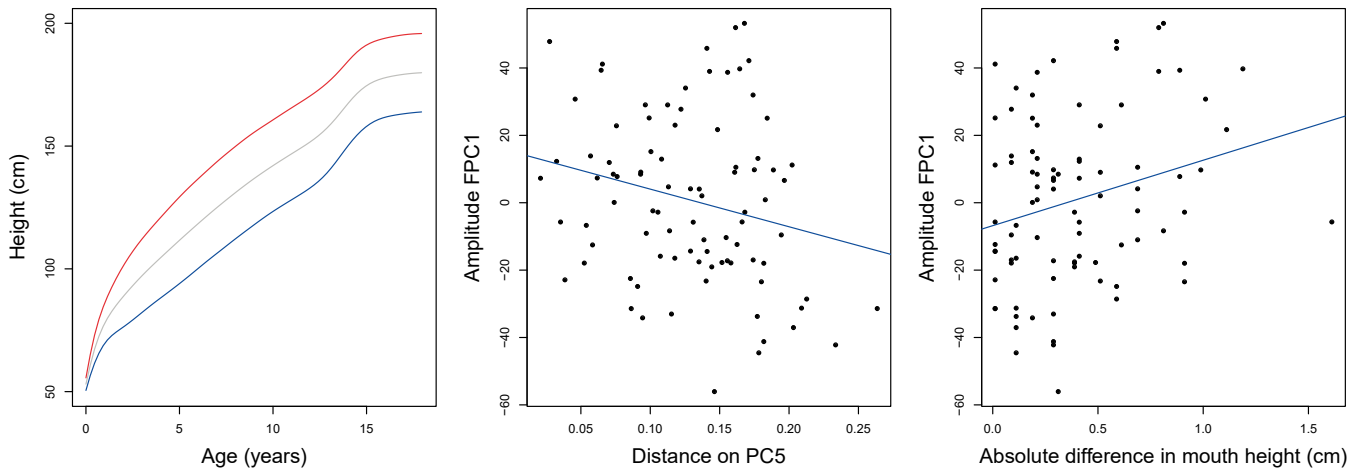
Figure 4: Amplitude FPC1 growth curve variations in boys and respective relationships in parents. Mean growth curve is marked grey, red curve represents positive values (+ 3SD), and blue curve represents negative values (− 3SD) within the curve change represented by individual Functional Principal Component (FPC).
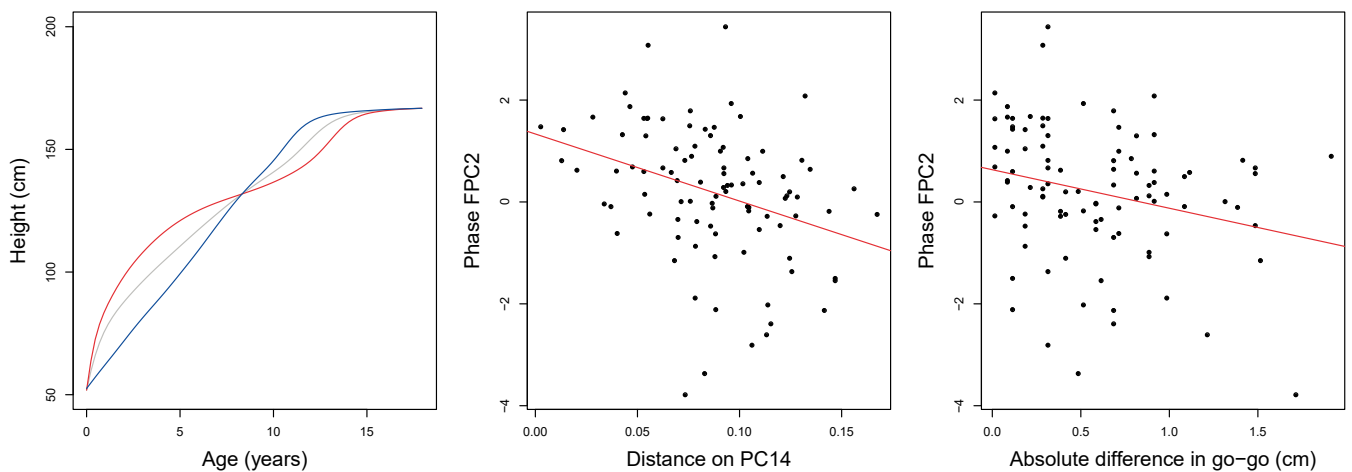

Figure 5: Phase FPC2 growth curve variations in girls and respective relationships in parents. Mean growth curve is marked grey, red curve represents positive values (+ 3SD), and blue curve represents negative values (− 3SD) within the curve change represented by individual Functional Principal Component (FPC).

rate in the first postnatal period (approx. until 9 years) and to mature earlier compared to other boys. At the same time, as the absolute difference in bigonial breadth between parents decreases (they are more similar in bigonial breadth), the score on phase FPC1 of sons increases (the growth curve shifts from blue to red), therefore they have a greater tendency to have a higher growth rate in the first postnatal period (approx. until 9 years) and to mature later compared to other boys. In girls, phase FPC2 is related to the head width of mothers (ρ = 0.24, p-value = 0.019), and to the distance on PC14 (ρ = −0.38, p-value = 0.000, chin shape/distance between pogonion and gnathion) and to the absolute difference in bigonial breadth (ρ = −0.27, p-value = 0.007) between parents. As the distance on PC14 between parents decreases (they are more similar in the chin shape based on distance between pogonion and gnathion), the score on phase FPC2 of daughters increases (the growth curve shifts from blue to red), therefore they have a greater tendency to have a higher

growth rate in the first postnatal period (approx. until 8 years) and to mature later compared to other girls. The same relation is true for the absolute difference in bigonial breadth between parents and the score on phase FPC2 of daughters. Based on Kruskal-Wallis test, phase FPC2 in girls is related to the difference in number of siblings between parents (χ^2= 10.63, p-value = 0.031). Pairwise comparisons using Dunn's all-pairs test showed difference between category −1 and −2 (p-value = 0.069). When the difference in number of siblings between parents is −1, which means that mothers have one more sibling than fathers, the score on phase FPC2 of girls is higher, therefore they have a greater tendency to have a higher growth rate in the first postnatal period (approx. until 8 years) and to mature later compared to girls whose mothers have two or more siblings more than fathers (the difference in number of siblings between parents is −2 and less).
Amplitude FPC2 reflects one change in the growth dynamics so the postnatal growth curve is divided into two parts with
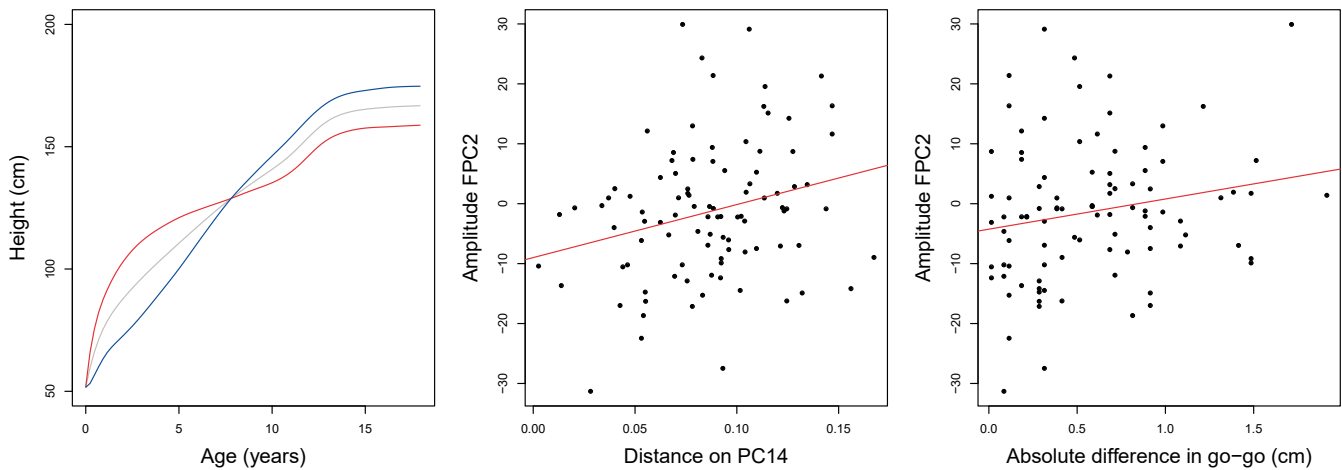
Figure 6: Amplitude FPC2 growth curve variations in girls and respective relationships in parents. Mean growth curve is marked grey, red curve represents positive values (+ 3SD), and blue curve represents negative values (− 3SD) within the curve change represented by individual Functional Principal Component (FPC).

different relative heights (individuals taller in the first period, are shorter compared to the sample in the second postnatal period and vice versa). Amplitude FPC2 represents 13.9% of variance in boys and 19.9% of variance in girls. In boys, amplitude FPC2 is related to the absolute difference in head height (ρ = −0.22, p-value = 0.038) and in bigonial breadth (ρ = 0.23, p-value = 0.032) between parents. As the absolute difference in head height between parents decreases (they are more similar in head height), the score on amplitude FPC2 of sons increases (the growth curve shifts from blue to red), therefore they were overall taller in the first postnatal period (approx. until 7.5 years) and shorter in the second postnatal period compared to other boys in the same growth phase. At the same time, as the absolute difference in bigonial breadth between parents decreases (they are more similar in bigonial breadth), the score on amplitude FPC2 of sons decreases (the growth curve shifts from red to blue), therefore they were overall shorter in the first postnatal period and taller in the second postnatal period compared to other boys in the same growth phase. In girls, amplitude FPC2 is related to the score on PC4 (ρ = 0.22, p-value = 0.033, facial expression) and score on PC5 (ρ = 0.27, p-value = 0.008, glabella position and nose width) of fathers, to the height of fathers (ρ = −0.25, p-value = 0.013) and mothers (ρ = −0.42, p-value = 0.000), and to the centroid size (ρ = −0.25, p-value = 0.013), head width (ρ = −0.22, p-value = 0.030), nose to chin distance (ρ = −0.26, p-value = 0.009) and nose width (ρ = −0.26, p-value = 0.011) of mothers. In girls, amplitude FPC2 is further related to the distance on PC14 (ρ = 0.25, p-value = 0.016, chin shape/distance between pogonion and gnathion) and to the absolute difference in bigonial breadth (ρ = 0.21, p-value = 0.044) between parents. As the distance on PC14 between parents decreases (they are more similar in chin shape based on distance between pogonion and gnathion), the score on amplitude FPC2 of daughters decreases (the growth curve shifts from red to blue), therefore they were overall shorter in the first postna-

tal period (approx. until 7.5 years) and taller in the second postnatal period compared to other girls in the same growth phase. The same relation is true for the absolute difference in bigonial breadth between parents and the score on amplitude FPC2 of daughters. Based on Kruskal-Wallis test, amplitude FPC2 in girls is related to the difference in number of siblings between parents (χ^2= 9.62, p-value = 0.047). Pairwise comparisons using Dunn's all-pairs test showed difference between category −1 and 1 (p-value = 0.061). When the difference in number of siblings between parents is 1, which means that fathers have one more sibling than mothers, the score on amplitude FPC2 of girls is higher, therefore they were overall taller in the first postnatal period (approx. until 7.5 years) and shorter in the second postnatal period compared to girls whose mothers have one more sibling than fathers (the difference in number of siblings between parents is −1).

Phase FPC3 reflects two changes in the growth dynamics so the postnatal growth curve is divided into three parts with different growth rates (individuals with higher growth rate in the first period, have lower growth rate in the second postnatal period, and they mature earlier compared to the sample and vice versa). Phase FPC3 represents 3.8% of variance in boys and 2.8% of variance in girls. In boys, phase FPC3 is related to the score on PC5 (ρ = −0.30, p-value = 0.005, glabella position and nose width) and score on PC10 (ρ = −0.22, p-value = 0.037, nose width) of mothers, to the minimum frontal breadth (ρ = −0.22, p-value = 0.043) of fathers, and to the distance on PC3 between parents (ρ = −0.24, p-value = 0.026, head rotation). As the distance on PC3 between parents decreases (they are more similar in head rotation during photo shooting), the score on phase FPC3 of sons increases (the growth curve shifts from blue to red), therefore they have a greater tendency to have a higher growth rate in the first postnatal period (approx. until 5 years), to have a lower growth rate in the second postnatal period (approx. until 12 years) and to mature earlier compared to other boys (the change in
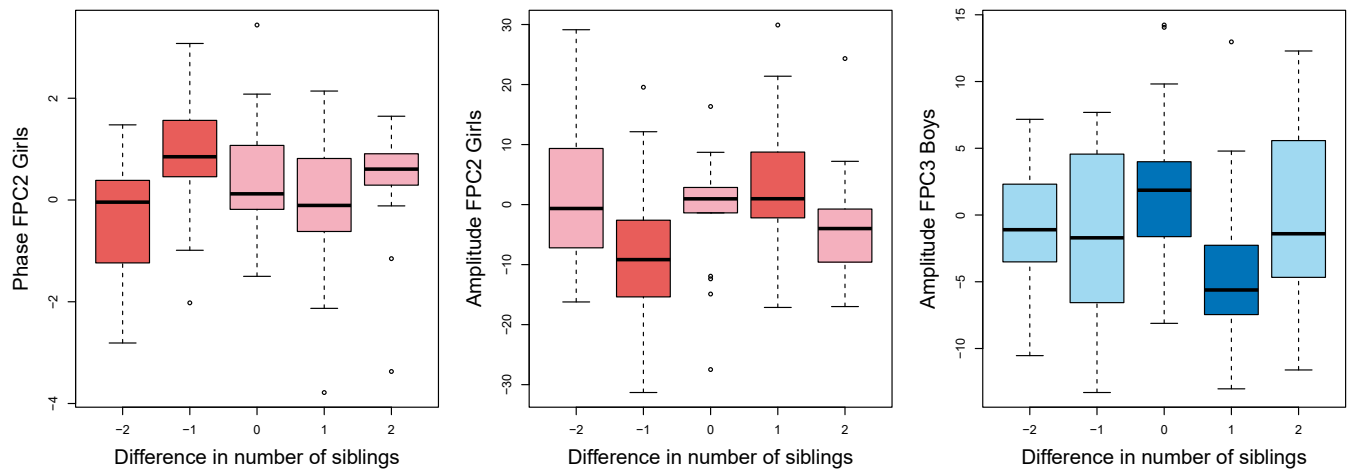
Figure 7: Boxplots of relationship between difference in number of siblings between parents categorized as −2 and less, −1, 0, 1, and 2 and more, and respective descriptors of the growth curves of their offspring. Categories which differ significantly are highlighted in a darker colour.

their growth rate occurs twice). In girls, phase FPC3 is related to the number of siblings ($\rho = -0.22$, p-value = 0.033) and height ($\rho = 0.23$, p-value = 0.027) of fathers, to the birth order ($\rho = -0.22$, p-value = 0.029) and age ($\rho = -0.20$, p-value = 0.049) of mothers, and to the distance on PC3 between parents ($\rho = -0.29$, p-value = 0.005, head rotation). As the distance on PC3 between parents decreases (they are more similar in head rotation during photo shooting), the score on phase FPC3 of daughters increases (the growth curve shifts from blue to red), therefore they have a greater tendency to have a higher growth rate in the first postnatal period (approx. until 5 years), to have a lower growth rate in the second postnatal period (approx. until 12 years) and to mature earlier compared to other girls (the change in their growth rate occurs twice).

Amplitude FPC3 reflects two changes in the growth dynamics so the postnatal growth curve is divided into three parts with different relative heights (individuals taller in the first period, are shorter in the second postnatal period, and they are again taller compared to the sample in the third postnatal period and vice versa). Amplitude FPC3 represents 6.6% of variance in boys and 3.5% of variance in girls. In boys, amplitude FPC3 is related to the score on PC12 ($\rho = -0.25$, p-value = 0.020, eye shape), score on PC14 ($\rho = 0.24$, p-value = 0.027, chin shape/distance between pogonion and gnathion), head width ($\rho = 0.32$, p-value = 0.003), head height ($\rho = 0.22$, p-value = 0.038), minimum frontal breadth ($\rho = 0.24$, p-value = 0.026) and mouth width ($\rho = 0.26$, p-value = 0.013) of fathers and to the height of fathers ($\rho = 0.37$, p-value = 0.000) and mothers ($\rho = 0.25$, p-value = 0.020). There were no statistically significant correlations found between parental variables (distances or absolute differences between them) and amplitude FPC3 in boys. Based on Kruskal-Wallis test, amplitude FPC3 in boys is related to the difference in number of siblings between parents ($\chi^2 = 11.02$, p-value = 0.026). Pairwise comparisons using Dunn's all-pairs test showed difference between category 1 and 0 (p-value = 0.0113). When the difference in number of siblings between parents is 0, which means their numbers

of siblings are same, the score on amplitude FPC3 of boys is higher, therefore they were overall taller in the first postnatal period (approx. until 5 years), shorter in the second postnatal period (approx. until 14 years) and taller in the third postnatal period (the change in the relative height occurs twice) compared to boys whose fathers have one more sibling than mothers (the difference in number of siblings between parents is 1). In girls, amplitude FPC3 is related to the score on PC4 ($\rho = -0.24$, p-value = 0.020, facial expression) of fathers and to the score on PC13 ($\rho = -0.23$, p-value = 0.028, nose alar position), head circumference ($\rho = 0.22$, p-value = 0.031), head length ($\rho = 0.25$, p-value = 0.015), minimum frontal breadth ($\rho = 0.25$, p-value = 0.013), bigonial breadth ($\rho = 0.32$, p-value = 0.002) and mouth width ($\rho = 0.22$, p-value = 0.032) of mothers. There were no statistically significant correlations found between parental variables (distances or absolute differences between them) and amplitude FPC3 in girls.

DISCUSSION

This study focused on parental similarity because of its importance during partner choice, mainly on facial similarity. With the hypothesis that offspring's characteristics may represent the consequences of assortative mating, parental similarity was analysed in relation to the descriptors of the growth curves of their offspring. We assumed that parental similarity could ensure quality conditions for the growth and development of their offspring. Therefore, the more similar the parents are in facial traits, the smoother ontogenesis of their offspring can be expected. It means, in the context of quality conditions (stable environment) that the growth rate of offspring will be lower, and they will be overall taller compared to others.

The first goal aims to test the hypothesis of body assortative mating in humans. Compared to studies which have shown significantly higher similarity between partners than between

random pair formations (Alvarez and Jaffe 2004, 185–188; Thiessen et al. 1997, 160–162; Wong et al. 2018, 5), in our sample the real partners were not more similar to each other in any of the observed traits than randomly generated pairs. However, this result may be affected by the variance of the sample (Wolanski and Siniarska 1984, 250–251). The similarity of partners might be lower than in biologically more diversified samples probably due to origin of the sample prevalently from one small quarter of the town Brno, i.e., partners tend to be relatively less similar compared to samples (e.g., based on wide geographic region) where the variance of observed traits is higher. Nevertheless, strong positive correlation in age was found between the partners, which agrees with the results according to Spuhler (1968, 128) and George et al. (2015, 129). Medium strong positive correlations were found for parental height, compared to a low correlation (0.25) according to George et al. (2015, 129) and low correlation (0.20) according to Zietsch et al. (2011, 16). Weak correlations of other body characteristics and dominance of the positive correlations agreed with previous studies (George et al. 2015, 129; Rushton et al. 1984, 184; Spuhler 1968, 128).

Relationships between physical similarity of parents and the descriptors of the growth curves of their offspring (second goal) were found. In this sample, sons of parents more similar in chin height (based on distance between sublabiale and pogonion) and in nose to chin distance have, according to the height growth curve, a greater tendency to mature earlier. Sons of parents more similar in glabella position and nose width have a greater tendency to have a lower growth rate in the first postnatal period (approx. until 9 years) and to mature earlier compared to other boys and furthermore, they were overall taller compared to other boys in the same growth phase. On the contrary, sons of parents more similar in mouth height were overall shorter compared to other boys in the same growth phase. Sons and daughters of parents more similar in bigonial breadth have a greater tendency to have a higher growth rate in the first postnatal period (approx. until 7–9 years) and to mature later compared to others, and at the same time they were overall shorter in the first postnatal period and taller in the second postnatal period compared to other boys or girls in the same growth phase. The same relations are true for daughters of parents more similar in the shape of chin (based on distance between pogonion and gnathion). On the contrary, sons of parents more similar in head height were overall taller in the first postnatal period, and shorter in the second postnatal period compared to other boys in the same growth phase. Daughters of parents more similar in overall face size (centroid size) have, according to the height growth curve, a greater tendency to mature later and they were overall taller compared to other girls in the same growth phase. On the contrary, daughters of parents more similar in the shape of the eyes, minimum frontal breadth and in bizygomatic breadth were overall shorter compared to other girls in the same growth phase. Sons and daughters of parents more similar in head rotation (during photo shooting) have a greater tendency to have a higher growth rate in the first postnatal

period (approx. until 5 years), to have a lower growth rate in the second postnatal period (approx. until 12 years) and to mature earlier compared to other boys and girls (the change in their growth rate occurs twice).

However, it is difficult to discuss our results due to lack of comparative studies. We have not yet found a study of similar focus and content in the literature. Nevertheless, based on previous summary of results and Table 1, some relationships appear to be coherent therefore we assume that the effects we found correspond to real biological phenomena (Note: by parental variable we always mean the absolute difference between partners in the respective variable, respectively distance between them on certain Principal component which represents the mentioned shape).

1. Variables similar in biological meaning significantly correlate with the same descriptor of the growth curve. For example, chin height and nose to chin distance of parents correlate negatively with FPC1 phase in boys, and minimum frontal breadth and bizygomatic breadth of parents correlate positively with FPC1 amplitude in girls.
2. Variables opposite in biological meaning are related to the same descriptor of the growth curve with opposite effects. For example, head height of parents correlates negatively with amplitude FPC2 in boys and conversely bigonial breadth of parents correlates positively with amplitude FPC2 in boys.
3. One parental variable correlates with both phase and amplitude of Functional Principal Component with corresponding effect. For example, parental face centroid size correlates positively with FPC1 phase and negatively with FPC1 amplitude in girls which means that daughters of parents more similar in overall face size have greater tendency to mature later and to be overall taller compared to other girls in the same growth phase. Similarly, this connection is true for correlations between the shape of chin of parents and FPC2 phase and amplitude in girls, and for correlations between bigonial breadth of parents and FPC2 phase and amplitude in boys and also in girls.
4. Same effects on certain Functional Principal Component are present in boys and girls, i.e., in two independent analyses (two separate samples). For example, head rotation of parents correlates negatively with FPC3 phase in boys and girls, and bigonial breadth of parents correlates negatively with FPC2 phase and positively with FPC2 amplitude in boys and girls.

Similar results have been found for the same sample using different methodology in Koníková (2021), where physical similarity of partners (in the same traits) was analysed in relation to the growth parameters of their offspring represented by individual growth milestones during puberty and adolescence (Králík et al. 2021, 5). Based on those results, sons of the parents more similar in glabella position and nose width were taller at the point of peak velocity in puberty compared to other boys, and daughters of the parents more similar in the same

Spearman correlation		Sex	Centroid size absolute difference	Distances between partners					Absolute differences between partners					
				PC3	PC5	PC8	PC12	PC14	Head height	Ft - ft	Zy - zy	Go - go	Nose to chin	Mouth height
FPC1	phase	M				-0,210* 0.046								-0,270* 0.012	
		F	0,210* 0.036												
	amplitude	M			-0,210* 0.047										0,210* 0.050
		F	-0,320** 0.002				0,250* 0.013			0,330** 0.001	0,230* 0.021			
FPC2	phase	M			0,210* 0.046							-0,300** 0.005		
		F						-0,380** 0.000					-0,270** 0.007		
	amplitude	M							-0,220* 0.038				0,230* 0.032		
		F					0,250* 0.016						0,210* 0.044		
FPC3	phase	M		-0,240* 0.026											
		F		-0,290** 0.005											

Table 1: Table of Spearman's correlation coefficients and p-values between parental variables (face centroid size absolute difference, Principal Component distances and absolute differences in anthropometric measurements between partners) which correlate significantly with the descriptors of the growth curves of their offspring (Functional Principal Components 1–3 phase and amplitude).
**. Correlation is significant at the 0.01 level.
*. Correlation is significant at the 0.05 level.

feature were overall shorter at all of the monitored points during growth. For comparison, sons of the parents more similar in glabella position and nose width, were overall taller during the whole growth, but no significant relationship was found in girls in current study. Consistent results were found for the relationship between parental similarity in some features and body height of girls. In Koníková (2021), daughters of parents more similar in minimum frontal breadth were shorter at the point of take-off before spurt in puberty and daughters of parents more similar in the shape of eyes and in bizygomatic breadth were shorter at all of the monitored points during growth compared to other girls. In the current study, daughters of parents more similar in the same mentioned features were overall shorter throughout the whole postnatal growth compared to other girls in the same growth phase. Similarly, the result that daughters of parents more similar in chin shape (based on distance between pogonion and gnathion) had lower velocity at point of take-off before body height spurt agrees with our result that daughters of parents more similar in the same feature have a greater tendency to have a higher growth rate in the first postnatal period (approx. until 8 years) and

to have a lower growth rate in the second postnatal period, so they matured later compared to other girls. On the other hand, this study found no significant relationship between parental similarity in height and descriptors of the growth curve of their offspring compared to Koníková (2021). However, individual parental height (separate body height of mothers and fathers) correlated positively (actually strongest from all correlations) with absolute heights throughout the whole postnatal growth of sons and daughters.

The third goal aims to find specific trends in the growth of offspring connected to parental assortative mating. To simplify the interpretation, the results are divided into three groups according to relation to FPC1–3. In relation to FPC1, we can distinguish two categories. The first category includes parental variables which correlate positively with FPC1 phase (facial centroid size of parents of girls) and negatively with FPC1 amplitude (facial centroid size of parents of girls and glabella position and nose width of parents of boys). These relationships agree with hypothesis of Figueredo and Wolf (2009, 326–327) that positive assortative mating is associated with a slow life history what means that offspring of similar parents

tend to be overall taller during the whole growth and to mature later (have lower growth rate compared to others) which is also consistent with our hypothesis that the more similar the parents are in facial traits, the smoother ontogenesis of their offspring can be expected. On the contrary, the second category includes parental variables which correlate negatively with FPC1 phase (chin height and nose to chin distance of parents of boys) and positively with FPC1 amplitude (mouth height of parents of boys, and shape of the eyes, minimum frontal breadth and bizygomatic breadth of parents of girls). Offspring of parents more similar in these traits conversely tend to be overall shorter during the whole growth and to mature earlier (have higher growth rate compared to others).

In relation to FPC2, the first category includes parental variables which correlate positively with FPC2 phase (glabella position and nose width of parents of boys) and negatively with FPC2 amplitude (head height of parents of boys). Sons of parents more similar in these traits tend to have lower growth rate and to be overall taller in the first postnatal period, and to have higher grow rate and to be overall shorter in the second postnatal period compared to other boys. On the contrary, the second category includes parental variables which correlate negatively with FPC2 phase and positively with FPC2 amplitude (bigonial breadth of parents of boys and girls, and shape of chin of parents of girls). Offspring of parents more similar in these traits conversely tend to have higher growth rate and to be overall shorter in the first postnatal period, and to have lower grow rate and to be overall taller in the second postnatal period compared to others.

In relation to FPC3, we found negative correlation with head rotation of parents of boys and girls. This relationship can be caused by more frequent fluctuations of both parental and offspring variables since FPC3 phase represents two quite subtle changes in the growth rate of offspring, and distance on PC3 between parents represents their head rotation during photo shooting (possible personality aspect).

To sum up, we can list parental variables in which the higher degree of similarity is in final related to:

- delayed maturity of girls: centroid size, chin shape and bigonial breadth,
- overall higher final height of girls: centroid size, chin shape and bigonial breadth,
- early maturity of girls: none,
- overall lower final height of girls: eye shape, minimum frontal breadth and bizygomatic breadth,

- delayed maturity of boys: bigonial breadth,
- overall higher final height of boys: bigonial breadth and glabella position and nose width,
- early maturity of boys: glabella position and nose width, chin height and nose to chin distance,
- overall lower final height of boys: mouth heigh and head heigh.

Overall, it can be stated that parental similarity in various fea-

tures affected the growth of offspring differently in this sample, therefore we have not found a common trend in the growth of offspring in relation to a parental assortative mating. In other words, the effect of parental assortative mating will be probably different for assortative mating in different traits.

One of the limitations of parental similarity study is the question of active choice, i.e., whether the observed similar features are actually preferred among partners. However, this study focused mainly on facial similarity because the human face is clearly visible and considered important during all stages of partner choice. Furthermore, the effect of convergence (increasing similarity with time, Watson et al. 2004, 1033) is eliminated by relatively low facial plasticity and in addition, the parents were photographed after a relatively short period of cohabitation, after birth of their offspring. However, the influence of social homogamy is possible (similarity due to common geographic and social area, the town Brno in this case). The important factor influencing adaptive explanation of parental similarity is the environment. Firstly, benefits of adaptation may be connected with the environment of evolutionary adaptedness, in which these adaptations have evolved (Buss 2016, 37). And secondly, benefits of parental similarity for offspring depend on actual environment (i.e., if it is stable and predictable or unstable and unpredictable; Ochoa and Jaffé 1999, 6; Penton-Voak et al. 1999, 105; Wolf and Figueredo 2011, 172–173) and on the extent to which it affects the human at all.

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