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The role of parental age, family dynamics, and historical adversity in craniofacial variation of pre-World War II cadets

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Abstract

Objective

This study examined how parental age, family context, and historical stressors relate to variation in craniofacial and body dimensions among male cadets from pre-World War II Lviv.

Material and Methods

The sample included 365 male cadets measured in Lviv in 1938. Using Spearman correlations, Mann-Whitney U tests, and Generalized Additive Models with covariate adjustment, we tested whether parental age differences, socioeconomic factors, early-life stress, and family mortality predicted variation in fifteen anthropometric dimensions.

Results

Parental ages were strongly correlated, consistent with age-assortative mating. Larger parental age differences were associated with smaller jaw width, shorter head length, and variation in craniofacial shape, whereas advancing paternal age was associated with smaller jaw width and variation in overall craniofacial size. Maternal age showed only weak, non-significant trends. Higher parental occupational status predicted greater body height and weight. Variation in body height, nasal height, and overall craniofacial size was also related to sibling mortality. Cohorts corresponding to the periods of World War I and the Spanish flu exhibited smaller jaw width and lower body mass. Despite substantial parental mortality, no significant anthropometric differences were observed between individuals with known and unknown parental-age data.

Conclusions

Associations between parental age variables and offspring anthropometry were generally weak and limited to specific craniofacial traits. Future research using larger and more diverse samples is needed to determine whether the observed patterns reflect general biological processes or are specific to this cohort.

Keywords: parental age difference, anthropometry, early-life stress

Original article

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Introduction

Parental age at reproduction is a well-established determinant of offspring development and health, shaped by both biological and social factors (Liu et al., 2011; Zhang et al., 2022). Advanced paternal age is associated with increased germline mutations and epigenetic alterations that may influence offspring growth, cognition, and health (D'Onofrio et al., 2014; Jenkins et al., 2014; Johnson et al., 2015; Kong et al., 2012). Maternal age is linked to declining oocyte quality, altered placental function, and an increased risk of obstetric complications, all of which may constrain fetal growth and affect long-term health (Jolly et al., 2000; Lean et al., 2017; Pinheiro et al., 2019; Tarín et al., 1998). In addition, social factors including age-assortative mating, a common human pattern shaped by socioeconomic and marital norms (Epstein & Guttman, 1984; Luo, 2017; Spuhler, 1968), may affect family resources and early-life environments, thereby indirectly influencing offspring growth and development. Together, these biological and social processes suggest that parental age and reproductive timing may contribute to variation in offspring phenotype. Although parental-age effects have been widely documented in epidemiological and biomedical research, their contribution to normal-range human morphological variation remains poorly understood.

Within biological anthropology, variation in body size and craniofacial morphology has been studied primarily in relation to nutrition, developmental stress, health, and socioeconomic conditions (e.g., Bogin, 2021; Hallgrímsson et al., 2007; Martínez-Abadías et al., 2012). Research on somatic growth has focused largely on outcomes such as birth weight, growth trajectories, and adult stature, with parental influences generally found to be small, context-dependent, and strongly mediated by environmental conditions (Bogin, 2021; Eveleth & Tanner, 1990; Ulijaszek et al., 1998). Similarly, studies of craniofacial morphology have emphasized environmental and developmental influences, while parental age has rarely been examined as a potential determinant of craniofacial variation (Hallgrímsson et al., 2007; Martínez-Abadías et al., 2012). Consequently, despite extensive evidence that craniofacial traits are sensitive to developmental and environmental conditions, the contribution of parental age to craniofacial variation remains largely unexplored.

Using anthropometric data collected from military cadets in pre-World War II Lviv, this study investigates how parental age relates to variation in offspring body size and craniofacial morphology. Craniofacial traits may be particularly informative for detecting subtle developmental influences because they reflect both genetic inheritance and sensitivity to environmental conditions during growth (Hallgrímsson et al., 2007; Martínez-Abadías et al., 2012). Moreover, the historical context, characterized by high-fertility, socioeconomic instability, and major disruptions such as war and pandemic, provides a unique opportunity to examine parental-age effects in a population exposed to substantial environmental stress. By integrating parental, familial, and historical factors, this study contributes to a broader anthropological understanding of how reproductive timing may shape human morphological variation.

Main Aims

First, to examine associations between parental age and the anthropometric traits of their sons in a sample of pre-World

War II cadets from Lviv. Second, to assess additional sources of variation influencing these traits, including socioeconomic status (parental occupation, family size), environmental exposures (place of origin, temporal trends related to World War I (WWI) and the Spanish flu), and family mortality (including parental and sibling deaths). While the study considers multiple sources of variation, its primary focus was on the relationship between parental age and offspring morphology.

Hypothesis

Parental age differences may influence body and craniofacial dimensions through three mechanisms: (1) paternal age effects, such as mutation accumulation and epigenetic changes; (2) maternal age effects, including reduced oocyte quality and increased obstetric complications; and (3) social mechanisms reflected in age-assortative mating. These mechanisms may operate independently or interactively, and their influence may be pronounced under historical conditions of war, disease, and socioeconomic instability.

Material and Methods

The present study is based on archival anthropometric records collected between 1933 and 1938 as part of routine medical examinations conducted at Cadet Corps No. 1 in Lviv. Measurements were obtained by Franciszek Wokroj at the Department of Anthropology of the Jan Kazimierz University in Lviv and included cadets from all companies of the corps (Wokroj, 1949). The dataset is entirely archival and has been preserved in university collections.

Cadet Corps No. 1 in Lviv was an interwar Polish military-educational institution within a broader system of pre-military training designed to prepare adolescents for military service. Considered one of the leading military schools of the Second Polish Republic, it primarily attracted sons of military officers and members of the intelligentsia. Following major expansion and modernization during the 1920s, the corps became a model institution frequently visited by Polish and foreign military representatives. Admission typically occurred after completion of primary education at approximately 12–14 years of age. The school operated as a boarding institution under the Ministry of Military Affairs and was characterized by a highly structured daily routine and strict discipline (Wyszczelski & Niewęgłowska, 2016).

The sample comprised 365 males and represents a mixed cross-sectional cohort including both active cadets and former students. Participants were born between 1893 and 1920 (mean birth year = 1916.2 ± 3.2) and ranged in age from 18 to 45 years at the time of examination (mean age = 21.8 ± 3.2 years). The relatively broad age range reflects the inclusion of graduates who remained under institutional medical supervision or participated in follow-up examinations.

Anthropometric measurements were collected during routine medical examinations performed by the cadet health service and followed the standardized protocols of the Lviv anthropological school described by Wokroj (1949). All measurements were obtained from living individuals and therefore represent soft-tissue anthropometry. Each record contained demographic and social information, including place and date of birth, parental occupation, and educational affiliation. Anthropometric data included five body measurements and ten craniofacial measurements (Table 1).

Table 1. Summary of anthropometric measurements with landmark definitions, mean values, standard deviations (SD), and measurement units for all traits available in the dataset (n = 365 men)

Measurement	Landmark/Definition	Mean	SD	Unit
Body weight		64.2	7.0	kg
Body height		171.5	6.3	cm
Body mass index	weight / (height ^ 2)	21.8	2.1	kg/m^2
Chest circumference	during inhalation	90.3	4.5	cm
Chest circumference	during exhalation	79.8	4.2	cm
Head length	glabella-opisthocranion	188.3	6.4	mm
Head width	euryon-euryon	157.2	5.6	mm
Mastoid width	mastoid-mastoid	131.9	6.3	mm
Forehead width	frontotemporale-frontotemporale	108.0	4.2	mm
Face width	bizygomatic width	139.5	5.6	mm
Jaw width	bigonial width	107.1	5.6	mm
Face height	nasion-gnathion	119.9	7.2	mm
Upper face height	nasion-prosthion	69.0	4.4	mm
Nasal height	nasion-subnasale	50.3	3.8	mm
Nasal width	alare-alare	34.0	2.4	mm

Paternal age at birth was available for 250 boys (68.5%), ranging from 18 to 54 years (mean = 33.1 ± 6.5 years). Maternal age at birth was available for 286 boys (78.4%), ranging from 13 to 50 years (mean = 26.3 ± 6.3 years). Parental age difference (paternal age minus maternal age) was available for 228 boys (62.5%), ranging from −2 to 27 years (mean = 7.2 ± 5.2 years), indicating fathers were generally older than mothers.

To reduce dimensionality and summarize correlated craniofacial measurements, Principal Component Analysis (PCA) was performed on standardized craniofacial variables. Components with eigenvalues greater than 1 (Kaiser criterion) were retained for further analyses. Two components met this criterion. PC1 explained 36.8% of the variance and reflected overall craniofacial size, with strong loadings from cranial and facial length, width, and height measures. PC2 explained 20.9% of the variance and represented craniofacial shape, being primarily influenced by facial and nasal height dimensions.

Statistical analyses included Spearman's rank correlations (ρ) to assess associations among parental-age variables, family characteristics, and the anthropometric traits of their sons. Subsamples were compared using Mann–Whitney U tests. Non-parametric methods were used because several variables deviated from normality.

Generalized Additive Models (GAMs) were fitted for each anthropometric trait to evaluate associations with parental-age variables while adjusting for potential confounders. GAMs were chosen because parental-age effects may not be strictly linear, and these models allow flexible estimation of non-linear relationships using smooth functions while retaining the interpretability of regression models. The models included paternal age, maternal age, and parental age difference as predictors, together with individual age at measurement, birth year, place of origin (town = 35.0%, city = 65.0%; after Scheinkönig & Kowalczewski, 1934), parental occupation (worker/peasant = 25.1%, craftsman = 4.1%, white-collar worker = 50.9%, trader = 9.7%, other = 10.1%; after Szturm de Sztrem, 1931), number of children in family (mean = 3.8, range = 1–13), and number of deceased siblings (none = 78.1%, one sibling = 13.4%, two or more siblings = 8.5%, range = 0–8). The significance of both smooth and parametric terms was assessed using the test statistics and associated p-values reported by the GAM. Significant terms indicated that a predictor explained variation in the anthropometric trait after adjustment for the other variables included in the model.

Results

Family correlations

Maternal and paternal ages were strongly correlated ($\rho = 0.646$, $p < 0.001$), consistent with age-assortative mating. Parental age differences correlated negatively with maternal age ($\rho = -0.269$, $p < 0.001$) and positively with paternal age ($\rho = 0.503$, $p < 0.001$), suggesting that younger women often married older men.

Family size was moderately positively correlated with sibling mortality ($\rho = 0.310$, $p < 0.001$), indicating higher child loss in larger families.

Associations between parental ages and anthropometry

Spearman correlations (Table 2) indicated generally weak associations between parental-age variables and anthropometric traits of their sons, with correlation coefficients not exceeding $|\rho| = 0.16$. Jaw width was the only trait significantly associated with parental age, showing weak negative correlations with parental age difference ($\rho = -0.14$, $p = 0.04$) and paternal age ($\rho = -0.16$, $p = 0.02$), indicating slightly smaller jaw width among sons of older fathers and parents with larger age differences. Additional weak negative trends were observed between maternal age and body height ($\rho = -0.12$) and nasal height ($\rho = -0.12$), as well as between paternal age and overall craniofacial size (PC1; $\rho = -0.13$). However, these relationships did not reach statistical significance ($0.05 \le p < 0.10$).

GAMs (Table S1) identified relatively few significant associations, broadly consistent with the weak correlations observed. Head length decreased significantly with parental age difference ($F = 6.04$, $p = 0.04$), with a weaker contribution from maternal age ($F = 4.77$, $p = 0.08$). Craniofacial size (PC1) was significantly associated with paternal age ($F = 2.16$, $p = 0.05$), whereas craniofacial shape (PC2) varied with parental age difference ($F = 3.15$, $p = 0.02$). Additional weak patterns were observed between paternal age and jaw width ($F = 5.79$, $p = 0.07$) and nasal height ($F = 2.23$, $p = 0.06$), although these associations were not statistically significant.

Table 2. Spearman's rank correlations (ρ) and corresponding p-values between parental age variables (paternal age, maternal age, and parental age difference) and the anthropometric traits of their sons

	Paternal age		Maternal age		Parental age difference	
	ρ	p-value	ρ	p-value	ρ	p-value
Body weight	0.055	0.417	0.077	0.257	0.005	0.946
Body height	-0.004	0.953	**0.122**	**0.071***	**-0.113**	**0.094***
Body mass index	0.059	0.381	-0.002	0.982	0.071	0.296
Chest circumference (inhale)	0.097	0.153	0.102	0.133	0.036	0.600
Chest circumference (exhale)	0.091	0.180	0.059	0.387	0.066	0.333
Head length	-0.047	0.491	0.073	0.280	-0.105	0.119
Head width	-0.082	0.227	-0.022	0.742	-0.029	0.664
Mastoid width	-0.057	0.401	0.034	0.615	-0.054	0.427
Forehead width	-0.078	0.251	-0.060	0.376	0.013	0.846
Face width	-0.096	0.156	-0.023	0.739	-0.069	0.311
Jaw width	**-0.159**	**0.018****	-0.019	0.778	**-0.140**	**0.038****
Face height	-0.060	0.376	0.010	0.883	-0.080	0.236
Upper face height	-0.015	0.826	0.068	0.312	-0.089	0.190
Nasal height	-0.014	0.839	**0.122**	**0.072***	**-0.119**	**0.078***
Nasal width	0.004	0.949	0.007	0.917	-0.026	0.699
PC1 (craniofacial size)	**-0.130**	**0.054***	0.006	0.930	**-0.122**	**0.071***
PC2 (craniofacial shape)	0.076	0.260	0.074	0.273	-0.008	0.908

Note: ρ = Spearman's rank correlation coefficient. Significance codes: **p<0.05, *p<0.1.

Other sources of variation

Body height was higher in sons of white-collar workers (β = 2.58, p = 0.02), while body weight was higher in sons of traders/good owners (β = 3.83, p = 0.03), compared to sons of workers/peasants. A weak association was observed between craniofacial shape (PC2) and urban versus rural origin (β = 0.40, p = 0.06), although this relationship did not reach statistical significance.

Sibling mortality also influenced several traits including body height (β = −2.72, p = 0.05), nasal height (β = 2.11, p = 0.02), and craniofacial size (PC1; β = 1.09, p = 0.02). All GAM results are presented in Table S1.

Family size and birth-year effects were not significant in GAMs, and comparisons between small (1–2 siblings, n = 196) and large families (3 and more siblings, n = 169) revealed no significant differences in any anthropometric trait (all p > 0.05). In contrast, comparisons between birth cohorts corresponding to major historical events revealed several differences. Individuals born in 1914 or later (n = 315) exhibited smaller jaw width than those born before 1914 (n = 50; W = 6247, p = 0.02). Similarly, individuals born in 1918 or later (n = 154) had smaller jaw width (W = 13676, p = 0.01), lower body weight (W = 13180, p = 0.01), and lower

BMI (W = 11590, $p < 0.001$) than those born before 1918 (n = 211).

Comparisons of subsamples with missing data

Parental mortality was relatively common in the sample: 26.6% of boys had lost at least one parent by the time of measurement (20.0% paternal mortality and 11.2% maternal mortality), reflecting the impacts of WWI (particularly the nearly twofold higher mortality of fathers) and the Spanish flu pandemic of 1918–1920. Consequently, parental-age data were unavailable for 37.5% of the sample (137 of 365 boys), reducing the effective sample size and potentially introducing bias.

To evaluate possible selective missingness, individuals with known and unknown parental ages (when at least one parent died) were compared for all anthropometric traits that showed significant associations or weak patterns. No significant differences were found for body height (W = 15243, p = 0.86), weight (W = 15019, p = 0.84), jaw width (W = 13628, p = 0.06), head length (W = 15114, p = 0.69), nasal height (W = 16871, p = 0.17), PC1 (W = 15608, p = 0.99), or PC2 (W = 16828, p = 0.22). These comparisons provide no evidence that missing parental-age data were associated with the anthropometric traits examined, although the possibility of non-random missingness cannot be excluded.

Discussion

The strong positive correlation between maternal and paternal ages reflects pronounced age-assortative mating, a pattern well documented in historical and contemporary societies (Epstein & Guttman, 1984; Luo, 2017; Spuhler, 1968). The observed age-gap asymmetry (older fathers and younger mothers) aligns with demographic and evolutionary expectations (Buss, 1989; Geary et al., 2004): men often delayed marriage until achieving economic stability, whereas women married earlier due to reproductive constraints and prevailing marital norms.

The positive association between larger family and sibling mortality is consistent with established mechanisms. Resource dilution reduces per-child parental investment as family size increases (Blake, 1981). Larger households also facilitate transmission of infectious diseases, historically a major cause of early-life mortality (Preston & Haines, 1991). High-fertility families were additionally more likely to experience crowding or poor sanitary conditions, compounding environmental risks.

Associations between parental age and offspring anthropometric traits were generally weak. Most relationships were small in magnitude and statistically non-significant, with only a limited number of craniofacial traits showing significant associations.

Advancing paternal age was associated with smaller jaw width and variation in overall craniofacial size (PC1), whereas maternal age exhibited only weak, non-significant trends. Although the observed effects were modest, previous research has proposed that advancing parental age may influence offspring development through mechanisms such as germline mutation accumulation and age-related reproductive constraints (Liu et al., 2011; Tarín et al., 1998; Zhang et al., 2022). However, the present findings provide only limited support for individual parental-age effects on anthropometric variation.

Parental age difference was associated with smaller jaw width, shorter head length, and variation in craniofacial shape (PC2). Larger age differences between parents may reflect broader life-history variation, including differences in health, socioeconomic background, reproductive timing, or investment capacity, all of which may influence developmental conditions during early life (Hill & Kaplan, 1999; Myrskylä & Fenelon, 2012). Nevertheless, the observed associations were weak, suggesting that parental age difference contributed only modestly to variation in the anthropometric traits examined.

A plausible explanation for the weak parental-age effects is early-life selection. With nearly one-quarter of families experiencing sibling deaths, high infant and child mortality likely removed the most vulnerable individuals. Consequently, surviving children represent a genetically and physiologically hardier subset, reducing variation in observed traits and masking stronger underlying associations between parental characteristics and anthropometry.

Sample homogeneity likely further constrained detectable variation. Military cadets represented a selective group due to competitive admission procedures and health requirements, which may have reduced variation in physical and developmental characteristics, including body size. In contrast, specific craniofacial traits, including jaw width, head length, and overall craniofacial size and shape, being less directly influenced by general growth and nutrition, showed relatively greater sensitivity to subtle parental-age, family-structure, and environmental effects.

Socioeconomic differences were also associated with anthropometric variation. Sons of higher-status parents exhibited greater height and weight, consistent with better access to nutrition, household stability, and caregiving quality (Bradley & Corwyn, 2002). Occupation, however, captures only part of socioeconomic variation; correlated factors such as parental education, parenting practices, and social capital may further contribute to offspring outcomes.

Sibling mortality was associated with body height, nasal height, and overall craniofacial size among surviving offspring, potentially reflecting two complementary mechanisms. First, surviving children may represent genetically hardier individuals with better immune function and growth potential (selection effect). Second, the loss of siblings may concentrate household resources (food, parental attention, financial investment) on survivors, enhancing growth through reduced competition (resource reallocation effect).

Finally, birth cohorts corresponding to the periods of WWI and the Spanish flu exhibited smaller jaw width, while individuals born during or after the Spanish flu period also showed lower body weight and BMI. These patterns are consistent with studies demonstrating long-term growth deficits following wartime stress and early nutritional deprivation (Mazumder et al., 2010; Palloni et al., 2020).

Research Limitations

Several limitations should be considered when interpreting the findings. First, the dataset comprises a relatively homogeneous cohort of male military cadets, with 94.8% born in the 1910s, introducing potential selection bias. The sample was socially and educationally selective, reflecting competitive selection process and general health requirements. Consequently, the findings may not be representative of the broader population, and associations with parental age or socioeconomic factors may differ in more diverse populations or among females. At the same time, this homogeneity may have reduced confounding from broader social and historical influences, thereby increasing internal consistency. Nevertheless, the findings should be generalized with caution.

A second limitation concerns missing parental-age data, which were unavailable for 37.5% of the sample, partly due to parental mortality associated with WWI and the Spanish flu pandemic. Comparisons between individuals with known and unknown parental ages revealed no significant differences in the anthropometric traits examined, suggesting no obvious pattern of selective missingness in the measured outcomes. However, the missingness was unlikely to be completely random, as parental mortality may have been associated with unmeasured factors such as socioeconomic conditions, parental health, or wartime experiences. Therefore, the possibility of residual bias cannot be excluded.

An additional limitation is the lack of information on intra- and inter-observer measurement error. Because the study relies on archival records collected in the 1930s, measurement reliability cannot be assessed retrospectively. Although measurements were obtained according to the standardized protocols of the Lviv anthropological school (Wokroj, 1949), it remains possible that measurement error influenced the observed associations.

Finally, given the number of statistical tests performed, some significant findings may reflect Type I error. The results should therefore be interpreted cautiously and regarded as exploratory until replicated in independent datasets. Future studies based on larger, more diverse, or longitudinal samples are needed to determine whether the weak associations observed here reflect broader biological processes or are specific to this historical cohort.

Additional information

Supplementary materials [online version].

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Author contributions

LK: Formal analysis; methodology; writing – original draft preparation; writing – review & editing (lead). GL: Conceptualization; data curation; supervision; writing – review & editing (supporting).

Ethics statement

The data were obtained from the archives of the Institute of Human Biology and Evolution at Adam Mickiewicz University, Poznań. The 1938 study of cadets from Corps No. 1 in Lviv was conducted by Professor Franciszek Wokroj (1949) under the ethical and professional norms of his time. Formal bioethics review did not exist in Poland until the 1990s. Nevertheless, all procedures followed institutional and national ethical and methodological standards. Personal data in this study were processed in accordance with Recitals 27, 158, and 150 and Article 89 of Regulation 2016/679 (GDPR), with appropriate measures taken to respect the rights of the participants.

Data availability statement

The data that support the findings of this study are available from the authors upon reasonable request.

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Conflict of interest

The authors declare that there are no conflicts of interest related to this manuscript.

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