

Secular changes in body height, body mass, and BMI among rural boys in Eastern Poland (1986–2021)

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Abstract

INTRODUCTION

Body height, body mass, and BMI are key indicators of physical development, reflecting the combined effects of genetic potential and environmental conditions. Secular changes in these traits are particularly pronounced in populations undergoing socio-economic transformation, including rural regions. Eastern Poland remains one of the economically weakest regions of the European Union, which may influence the somatic development of children and adolescents.

STUDY AIM

This study examined long-term secular changes in body height, body mass, and BMI among rural boys aged 7–15 years from eastern Poland between 1986 and 2021.

MATERIAL AND METHODS

The sample comprised 14,685 boys from five cross-sectional surveys conducted in 1986, 1996, 2006, 2016, and 2021, with sample size increasing from 1,259 to 5,599. Measurements were performed using standardized anthropometric procedures, and BMI categories were defined using Cole's international cut-off points. Statistical analyses included one-way ANOVA with Games–Howell post hoc tests, linear regression, and chi-square tests for BMI categories.

RESULTS

Significant increases were observed in all traits. Between 1986 and 2021, mean body height increased by 7.85 cm, with the largest gains among 13-, 9-, and 14-year-olds. Mean body mass rose by 5.83 kg, particularly in 14- and 15-year-olds. BMI increased by 1.21 kg/m², with the greatest changes occurring in older boys. The prevalence of overweight and obesity increased consistently across all age groups, with a marked acceleration between 2016 and 2021, while the prevalence of underweight declined slightly over the long term. Regression models confirmed systematic upward trends in all somatic traits.



Original article

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CONCLUSIONS

These findings indicate that although linear growth continues, the pattern of development is increasingly characterized by rising body mass and BMI, reflecting a shift toward a higher prevalence of overweight and obesity. This trend highlights the need for targeted public health monitoring and early preventive strategies in rural populations.

KEYWORDS: somatic development, rural population, adolescents, nutritional status, overweight, obesity, growth patterns

Introduction

Body height and body mass are fundamental indicators of somatic development, as they reflect the integrated influence of genetic predisposition and a wide range of environmental factors, including nutrition, living conditions, and access to healthcare (Lui et al., 2024). Changes in the mean values of these parameters observed across successive cohorts are referred to as secular trends and are considered important indicators of the biological status of populations and their adaptation to shifting socio-economic conditions (Fudvoye & Parent, 2017; Pop et al., 2021). In European populations, after a period of rapid increases in body height during the second half of the twentieth century, a marked deceleration of secular trends has been observed in recent decades. This pattern has been documented in Hungarian (Bodzsár et al., 2016), Portuguese (Costa et al., 2017), Lithuanian (Venckunas et al., 2017), Romanian (Pop et al., 2021), and Swiss populations (Eichelberger et al., 2024). At the same time, numerous studies indicate that the rate of body mass increase exceeds that of height, resulting in a systematic rise in BMI values (Ates & Kaki, 2025; Negasheva et al., 2024; Topçu et al., 2017; Zhang et al., 2019). This phenomenon highlights the increasingly complex nature of contemporary secular trends and the rising importance of environmental factors associated with excessive weight gain.

In addition to biological and nutritional determinants, increasing attention has been given to the role of broader socioeconomic, environmental, and sociological factors in shaping human growth (GBD 2023 Child Growth Failure Collaborators 2026; Mekonnen et al., 2021; Tang et al., 2024). Body height is now widely recognized not only as a marker of individual health status but also as a sensitive indicator of social conditions, including family resources, social inequality, access to healthcare, and environmental quality (Mekonnen et al., 2021; Tang et al., 2024). This perspective is consistent with the concept of socio-endocrine regulation of growth, which suggests that growth processes may be influenced by social interactions and hierarchical structures within populations (Hermanussen et al., 2022).

Secular processes in Poland have been systematically documented since the 1960s. Classic studies demonstrated considerable socio-economic variation in the tempo of somatic development (Bielicki et al., 1997; Bielicki & Welon, 1982), while more recent analyses have shown a gradual reduction of these disparities (Dobosz, 2012; Przewęda & Dobosz 2005). Despite this overall convergence, contemporary trends exhibit clear spatial differentiation. Large urban centers continue to show positive, albeit increasingly moderate, increases in body height (Charzewska et al., 2004; Krawczyński et al., 2003; Kryst et al., 2022), whereas populations residing in less

urbanized areas display weaker secular dynamics (Asienkiewicz & Tatarczuk, 2018; Nowicki 2000).

Eastern Poland remains one of the least economically developed regions of the European Union. According to European Commission data (2023), the gross domestic product per capita, expressed in purchasing power standards (PPS), is slightly above 50% of the EU average. Persistent socio-economic constraints are reflected in the tempo and structure of physical development among children and adolescents. Studies show that rural populations in this region have lower mean body height and mass and slower secular changes compared with other parts of the country (Saczuk, 2018; Wilczewski, 2013). The most recent analyses covering the period 1986–2021 further indicate increases in body mass without proportional gains in height, resulting in elevated risks of overweight and obesity among adolescents living in rural areas (Saczuk & Wasiluk, 2014; Wasiluk & Saczuk, 2025).

In light of these findings, it is justified to examine long-term changes in body height, body mass, and BMI among boys residing in rural areas of eastern Poland between 1986 and 2021.

Materials and methods

Sections below describe the subjects and methods of this study that were also recently reported for the girls in this cohort (Wasiluk & Saczuk, 2026).

Study area and measurement procedures

The study was conducted in rural areas of eastern Poland, which in 1986 included the former Suwałki, Białystok, Biała Podlaska, Chełm, Zamość, Przemysł, and Krosno provinces. Follow-

ing the administrative reform of 1999, these areas became part of the Podlaskie, Lubelskie, and Podkarpackie provinces, and partially the Warmińsko-Mazurskie and Mazowieckie provinces. The first round of measurements was carried out in 1986 within the national programme “Problem Węzłowy 10.7.”. At this stage, schools were selected randomly based on regional education authority registers. In 1996, 2006, 2016, and 2021, measurements were conducted in the same schools, ensuring high temporal comparability of the data. Subsequent stages of data collection were implemented as part of statutory research projects at the Józef Piłsudski University of Physical Education in Warsaw (projects D.S. 49 and D.S. 203). Additionally, the 2021 dataset included measurements of boys participating in the nationwide programme “Aktywny powrót do szkoły – WF z AWF”. In each survey wave, all available children aged 7–15 years attending the selected schools were invited to participate. Inclusion criteria comprised residence in rural areas and school attendance at the time of measurement.

Study population

A total of 14,685 boys aged 7–15 years living in rural areas of eastern Poland were included in the analysis. This number also comprised 3,598 boys examined in 2021 within the “WF z AWF” programme. The study had a cross-sectional design, and data were collected at five time points: 1986, 1996, 2006, 2016, and 2021. The detailed age distribution of the sample by calendar age and survey year is presented in Table 1. No analyses were conducted regarding potential differences in the distribution of exact ages within yearly age groups across survey years.

Table 1. Sample size of boys by chronological age and year of observation

Age	1986	1996	2006	2016	2021	Total
7	75	33	113	222	647	1090
8	93	83	483	304	1074	2037
9	113	86	434	185	963	1781
10	134	83	374	606	739	1936
11	147	103	429	698	621	1998
12	161	88	401	646	494	1790
13	173	147	368	331	473	1492
14	174	149	393	258	303	1277
15	189	158	367	285	285	1284
Total	1259	930	3362	3535	5599	14685

Ethical considerations

Informed consent was obtained from the parents or legal guardians of all participants, and participation in the study was voluntary. Ethical approval for the initial surveys (1986, 1996, and 2006) was obtained from the relevant Faculty Ethics Committee of the Józef Piłsudski University of Physical Education in Warsaw. For the later survey waves (2016 and 2021), the study protocol was approved by the Ethics Committee of the Józef Piłsudski University of Physical Education in Warsaw (SKE 01-13/2014; 30 June 2014) (see Ethics statement for further details).

Assessment of calendar age

Dates of birth were obtained from questionnaires and used to calculate decimal age to 2 decimal places. Age was determined as the difference between the measurement date and date of birth, and subsequently classified into one-year age groups using half-year intervals (e.g., 7.50–8.49 years as the 8-year-old group), in accordance with population-based anthropometric standards.

Anthropometric measurements

Anthropometric measurements were performed using standardized anthropometric procedures appropriate for each survey period (IBP, 1969; Lohman et al., 1988). Body height was measured as standard standing height (unstretched) using a GPM Model 101 anthropometer (GPM, Switzerland), accurate to 0.1 cm, and body mass was assessed using calibrated medical scales appropriate to each survey period. From 2016 onwards, a SECA 875 electronic medical scale (SECA GmbH, Germany), accurate to 0.1 kg, was used. Participants were measured barefoot, in light clothing, in the standard anatomical position, with the head oriented in the Frankfurt plane. Body mass index (BMI) was calculated as body mass (kg) divided by height squared (m^2).

BMI categorization

BMI categories of underweight, normal weight, overweight, and obesity were determined using international age- and sex-specific BMI cut-off points proposed by Cole et al. (2000; 2007). For each

participant, BMI was calculated within the relevant age category. Underweight was divided into two groups: severe underweight (combining grade I and II underweight) and mild underweight (corresponding to grade III underweight), to ensure sufficient sample sizes in the lowest-weight categories. To provide stable estimates of prevalence, analyses were conducted within three aggregated age groups: 7–9, 10–12, and 13–15 years. For each age group, the proportion of boys classified into BMI categories was calculated for each survey year. Due to the absence of individual data in 1996, which made BMI computation impossible, this year was excluded from analyses of BMI category prevalence.

Statistical analysis

For body height, body mass, and BMI, arithmetic means and standard deviations were calculated. Differences among the five survey years were assessed using one-way analysis of variance (ANOVA). Pairwise comparisons were performed with the Games–Howell post hoc test, which is appropriate for unequal sample sizes and heterogeneous variances. To assess the overall direction and magnitude of changes across the 35-year observation period, linear regression analysis was applied as a descriptive method. The regression slope (B) was used to estimate average annual changes in body height, body mass, and BMI, whereas the R^2 value assessed model fit and the proportion of variance explained by time. Differences in BMI category prevalence among survey years were evaluated with the chi-square (χ^2) test. Statistical significance was set at $p \leq 0.05$. All analyses were performed in Statistica 13.0 (StatSoft, Kraków, Poland).

Results

One-way analysis of variance revealed significant differences in body height across survey years in all analyzed age groups ($p \leq 0.05$), as presented in Table 2. The observed changes in mean body height are illustrated in Figure 1. In the total population, between 1986 and 2021, mean body height increased by 7.85 cm, with the greatest 35-year gains observed in 13-year-olds (+10.62 cm), 9-year-olds (+8.77 cm), and 14-year-olds (+8.76 cm). The smallest changes were recorded among 7-year-olds (+5.17 cm) and 8-year-olds (+6.17 cm).

The Games–Howell post hoc test showed that significant differences in height most frequently occurred between 1986 and the values recorded in 2016 and 2021, while in the older age groups significant contrasts were also observed between 1996 and later surveys. Comparisons between consecutive stages indicated that the largest increases in body height took place between 1996 and 2006, with an average difference of 2.67 cm in the total population. The most pronounced increases in this interval were recorded in 15-year-olds (+4.86 cm) and 10-year-olds (+4.52 cm). In contrast, during the most recent interval (2016–2021), clear acceleration of height increase was noted particularly among 9-year-olds (+4.64 cm) and 13-year-olds (+4.82 cm). The smallest changes between consecutive surveys occurred during the first decade, 1986–1996 (mean: 0.57 cm), with statistically significant differences observed only in 7-, 12-, and 15-year-olds.

Linear regression analysis further confirmed a significant association between survey year and body height in all age groups ($p \leq 0.05$). The regression slopes (B) indicated a systematic increase in mean values over time, averaging 0.20–0.25 cm

per year, which corresponds to approximately 1.5–2.5 cm per decade. High coefficients of determination ($R^2 = 0.82\text{--}0.96$) demonstrated a stable and consistent pattern of changes throughout the study period. These findings suggest a sustained

improvement in growth conditions in the studied population, although the relatively moderate rate of increase may indicate a gradual stabilization of secular trends, reflecting changing environmental and socioeconomic influences.

Table 2. One-way ANOVA, Games–Howell post hoc, and linear regression results for body height in rural boys from eastern Poland (1986–2021)

Age	F	p	Test post hoc Games-Howell	B	R ²
7	18.91*	<0.001	1986<2016*, 1986<2021*, 2006<2016*, 2006<2021*	0.14*	0.82
8	67.65*	<0.001	1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.19*	0.82
9	79.93*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2021*, 2006<2021*, 2016<2021*	0.21*	0.85
10	55.02*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.25*	0.91
11	59.08*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.23*	0.96
12	40.63*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2021*, 2006<2021*, 2016<2021*	0.22*	0.93
13	50.10*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2021*, 2006<2021*, 2016<2021*	0.25*	0.89
14	41.72*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*	0.25*	0.96
15	57.45*	<0.001	1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*	0.25	0.73

Age – age in years; F – ANOVA F-value; p – significance level; B – regression coefficient; R^2 – model fit.
*Statistically significant at $p \leq 0.05$

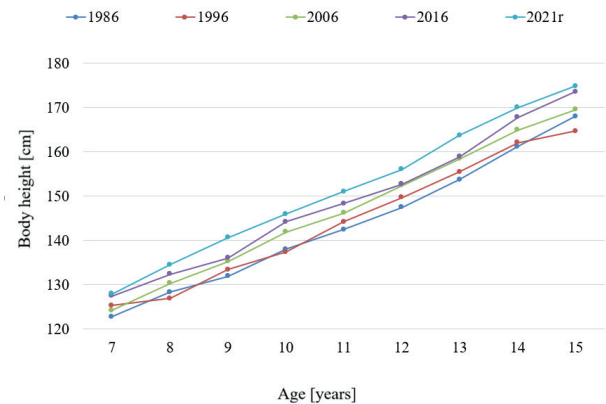


Figure 1. Mean body height of rural boys aged 7–15 years in eastern Poland across survey years

Body mass was the second somatic characteristic analysed in the present study. The results of statistical analyses are presented in Table 3, while changes in mean body mass are illustrated in Figure 2. In the total population, mean body mass increased by 5.83 kg between 1986 and 2021; however, the rate and magnitude of these changes varied across age groups. The greatest 35-year gains were observed among 14-year-olds (+8.94 kg), 15-year-olds (+8.87 kg), and 13-year-olds (+8.49 kg). In contrast, the smallest increases were recorded in 7-year-olds (+3.73 kg) and 8-year-olds (+4.33 kg).

To more precisely describe the temporal differentiation of body mass changes, the Games–Howell post hoc test was performed. This analysis showed that significant differences between survey years most frequently involved comparisons with 1986, especially in relation to 2016 and 2021. In the older age groups, significant contrasts were also observed between 1996 and later years, indicating widening disparities over time.

Comparisons between consecutive survey intervals demonstrated that the largest increase in body mass occurred between 1996 and 2006, when the mean difference for the total popula-

tion reached 2.67 kg. During this period, the greatest increases were found in 15-year-olds (+4.86 kg) and 13-year-olds (+3.65 kg). During the most recent interval, 2016–2021, the rate of change accelerated again, particularly in 14-year-olds (+3.00 kg) and boys aged 12 and 13 years (+2.71 kg and +2.72 kg, respectively). The least pronounced differences between successive survey years occurred between 1986 and 1996, when the mean increase amounted to only 0.44 kg, with statistically significant differences observed in just three age groups (7, 12, and 15 years).

The association between body mass and survey year was further confirmed by linear regression analysis. The regression slopes (B) indicated a systematic increase in body mass over time, with an average rate of 0.16–0.37 kg per year, corresponding to an increase of 1.6–3.7 kg per decade. The coefficients of determination (R^2), ranging from 0.69 to 0.91, demonstrated good model fit and a consistent pattern of changes across the study period. These findings indicate a progressive increase in body mass in the studied population and suggest a growing risk of excessive body weight among children and adolescents.

Table 3. One-way ANOVA, Games–Howell post hoc, and linear regression results for body mass in rural boys from eastern Poland (1986–2021)

Age	F	p	Test post hoc Games-Howell	B	R ²
7	28.76*	<0.001	1986<2016*, 1986<2021*, 1996<2021*, 2006<2021*, 2016<2021*	0.16*	0.91
8	64.18*	<0.001	1986<2016*, 1986<2021*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.17*	0.78
9	69.52*	<0.001	1986<2016*, 1986<2021*, 1996<2016*, 1996<2021*, 2006<2021*, 2016<2021*	0.21	0.77
10	54.63*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.25*	0.88

Table 3 (cont.)

Age	F	p	Test post hoc Games-Howell	B	R ²
11	63.95*	<0.001	1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.23	0.69
12	66.39*	<0.001	1986<2016*, 1986<2021*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.27*	0.81
13	53.28*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2021*, 2016<2021*	0.30*	0.84
14	49.21*	<0.001	1986<2006*, 1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2021*, 2016<2021*	0.34*	0.86
15	72.89*	<0.001	1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.37*	0.77

Age – age in years; F – ANOVA F-value; p – significance level; B – regression coefficient; R² – model fit.
*Statistically significant at p ≤ 0.05

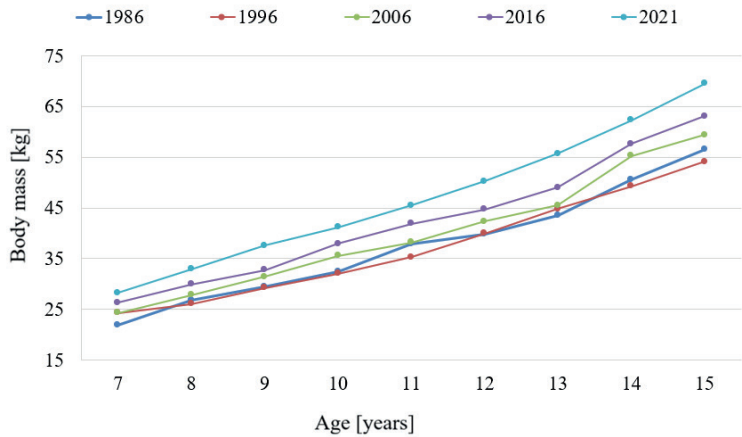


Figure 2. Mean body mass of rural boys aged 7–15 years from eastern Poland in successive survey years

The increases in body height and body mass observed across subsequent decades were accompanied by significant changes in BMI values, which reflected the overall direction of somatic development in the studied population. One-way analysis of variance confirmed that BMI differed significantly between survey years in all analyzed age groups ($p \leq 0.05$), as presented in Table 4. Changes in mean BMI values are illustrated in Figure 3.

Over the 35 years, mean BMI increased by approximately 1.21 kg/m² in the total population of boys. The largest gains were found in 14-year-olds (+1.90 kg/m²) and 15-year-olds (+1.80 kg/m²). In contrast, the smallest changes were recorded among 7-year-olds (+0.88 kg/m²) and 8-year-olds (+0.95 kg/m²), indicating that BMI increased more moderately in younger boys than in those in early adolescence.

The Games–Howell post hoc test showed that significant differences most frequently involved comparisons between 1986 and the years 2016 and 2021. In the older age groups, significant contrasts also occurred between 1996 and later survey years, suggesting that BMI changes accumulated gradually over time, with more pronounced variation among older boys.

Analysis of differences between consecutive survey intervals revealed that the most rapid increase in BMI occurred between 1996 and 2006, when the mean change in the total population reached 0.58 kg/m². The most substantial increases during this interval were observed in 14-year-olds (+1.03 kg/m²) and 15-year-olds (+0.90 kg/m²). In the most recent interval (2016–2021), BMI continued to rise, although at a slower rate, primarily among boys aged 12–15

years (increases of 0.30–0.45 kg/m²). The smallest changes were recorded between 1986 and 1996, when the mean difference amounted to only 0.09 kg/m², with statistically significant differences found in just two age groups (12 and 15 years).

The importance of time in shaping BMI values was further confirmed by linear regression models. The regression slopes (B) indicated a systematic increase in BMI ranging from 0.15 to 0.25 kg/m² per decade, whereas the coefficients of determination ($R^2 = 0.31$ – 0.74) showed that although BMI consistently increased, the rate of change varied across age groups and was more heterogeneous than for body height or body mass. These findings indicate a progressive increase in BMI in the studied population and suggest a growing risk of overweight and obesity among children and adolescents.

Table 4. One-way ANOVA, Games–Howell post hoc, and linear regression results for BMI in rural boys from eastern Poland (1986–2021)

Age	F	p	Test post hoc Games-Howell	B	R ²
7	17.35*	<0.001	1986<2016*, 1986<2021*, 1996<2021*, 2006<2021*, 2016<2021*	0.05*	0.87
8	35.26*	<0.001	1986<2021*, 1996<2021*, 2006<2021*, 2016<2021*	0.05	0.69
9	32.44*	<0.001	1986<2021*, 1996<2021*, 2006<2021*, 2016<2021*	0.05	0.64
10	22.57*	<0.001	1986<2021*, 1996<2016*, 1996<2021*, 2006<2021*, 2016<2021*	0.05	0.64
11	62.37*	<0.001	1986<2016*, 1986<2021*, 1996<2016*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.08	0.67
12	38.77*	<0.001	1986<2016*, 1986<2021*, 1996<2021*, 2006<2016*, 2006<2021*, 2016<2021*	0.07	0.73
13	21.12*	<0.001	1986<2016*, 1986<2021*, 1996<2016*, 1996<2021*, 2006<2021*	0.05*	0.86
14	21.62*	<0.001	1986<2016*, 1986<2021*, 1996<2006*, 1996<2016*, 1996<2021*, 2006<2021*	0.06	0.73
15	33.17*	<0.001	1986<2021*, 1996<2016*, 1996<2021*, 2006<2021*, 2016<2021*	0.06	0.64

Age – age in years; F – ANOVA F-value; p – significance level; B – regression coefficient; R² – model fit.

*Statistically significant at $p \leq 0.05$

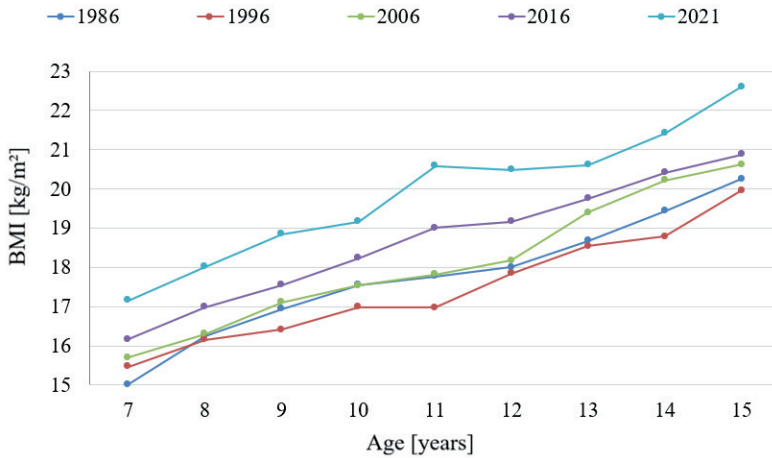


Figure 3. Mean BMI of rural boys aged 7–15 years from eastern Poland in successive survey years

To assess how the nutritional status structure evolved in the studied population, the prevalence of severe and mild underweight, normal weight, overweight, and obesity was examined across survey years, as illustrated in Figure 4. The analysis revealed statistically significant transformations in the distribution of these categories in all three age groups, as confirmed by the χ^2 test results presented in Table 5. The percentage values presented in the figure indicate a systematic increase in the proportion of boys with excessive body mass throughout the study period. The greatest increase in the combined prevalence of overweight and obesity was observed in the youngest age group (7–9 years), where it rose by 26.8% between 1986 and 2021. Comparable dynamics were noted in the 10–12-year group (+26.3%) and the 13–15-year group (+26.2%). The upward trend was consistent: both overweight and obesity increased in frequency, which was confirmed by statistically significant χ^2 results.

A particularly rapid increase in excessive body mass was recorded during the most recent interval (2016–2021). In the youngest age group, the prevalence rose by 16.7%, while in the oldest group it increased by 13.8%, indicating — as supported by the χ^2 test — a marked acceleration of this trend.

Changes in underweight were considerably more modest, as reflected by both the percentage values shown in the figure and the lower number of statistically significant differences in χ^2 tests. Among boys aged 7–9 years, the prevalence of underweight decreased by 2.2% over the entire study period; however, a slight increase was observed up to 2016 (+3.2%), followed by a substantial decline between 2016 and 2021 (–7.5%). In the 10–12-year group, the prevalence of underweight decreased by 4.2%, and in the 13–15-year group by 5.8%. The most pronounced reductions in underweight occurred in two intervals: 1986–2006 among 10–12-year-olds and 2016–2021 among 7–9-year-olds, both supported by sig-

nificant χ^2 differences. These findings point to a shift in the nutritional status structure of the studied population towards higher body mass categories, highlighting an emerging public health concern.

Table 5. Chi-square test results for BMI category prevalence across age groups and survey years

Age group	BMI category	1986–2006	1986–2016	1986–2021	2006–2016	2006–2021	2016–2021
7–9	Severe underweight	8.005*	13.032*	2.571	0.628	16.434*	22.719*
	Mild underweight	2.899	2.977	3.826	0.015	10.092*	9.613*
	Normal BMI	4.512*	9.720*	59.171*	1.000	12.992	4.585
	Overweight	16.054*	8.797*	146.341*	0.377	24.914*	27.821*
	Obesity	2.926	55.623*	266.387*	21.773*	99.863*	19.427*
10–12	Severe underweight	0.059	15.736*	2.463	15.443*	1.706	21.322*
	Mild underweight	7.572*	8.506*	19.546*	0.142	4.080*	2.499
	Normal BMI	1.927	34.311*	43.013*	19.043*	26.592*	1.036
	Overweight	53.139*	214.770*	209.349*	54.071*	56.833*	0.296
	Obesity	0.139	37.093*	180.306*	28.759*	148.910*	45.545*
13–15	Severe underweight	1.261	0.007	1.604	0.688	0.257	1.166
	Mild underweight	37.164*	33.514*	21.654*	3.852*	0.370	1.326
	Normal BMI	1.452	1.716	22.971*	0.257	15.591*	7.717
	Overweight	99.947*	65.307*	182.738*	1.057	35.390*	14.199*
	Obesity	0.170	15.345*	95.278*	12.681*	85.720*	17.141*

*Statistically significant at $p \leq 0.05$

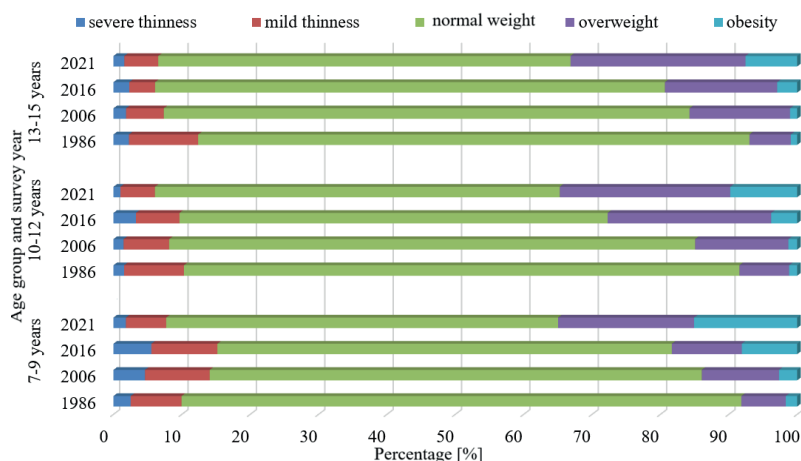


Figure 4. Changes in the prevalence of severe underweight, mild underweight, normal BMI, overweight, and obesity among boys across survey years (1986–2021)

Discussion

The results of this 35-year study of rural boys from eastern Poland confirm that secular processes in this population remain active and that their dynamics are closely linked to socio-economic transformations occurring in the region. Over the analyzed period, systematic increases in both body height and body mass were observed, although the rate of change varied across decades. The years 1986–1996 were characterized by relatively small increases, which may reflect the difficult economic conditions of the late 1980s and early 1990s, including inflationary crisis, declining household income, and the dissolution of state agricultural enterprises. Limited material and nutritional resources during this period likely constrained growth potential, which is consistent with the modest somatic changes observed.

A marked acceleration in growth occurred between 1996 and 2006, when improvements in living standards, infrastructure development, and the inflow of pre-accession and EU funds created more favorable conditions for child development in rural areas. This pattern corresponds to the mechanism of catch-up growth commonly described in rural populations, in which improved environmental conditions lead to accelerated growth following earlier constraints. These findings align with observations by Bartkowiak et al., (2022), who reported stable increases in somatic traits and a growing prevalence of overweight among rural youth in Poland between 1986 and 2016.

Particularly concerning is the pronounced increase in excessive body mass in recent years. Between 2016 and 2021, BMI values and the prevalence of over-

weight and obesity rose sharply. Although BMI is widely used as an indicator of nutritional status, it does not account for body composition or maturation status, which may limit its precision in pediatric populations; however, this does not alter the overall pattern of the observed trends. This pattern may have multiple determinants. On the one hand, continued improvements in the economic situation of rural households—supported, for example, by the “Rodzina 500+” child benefit programme (Dz. U. (Journal of Laws of the Republic of Poland) 2023, item 1565) – may have enhanced access to calorie-dense foods in economically disadvantaged regions. While the programme improved economic conditions, it may also have indirectly contributed to increased energy intake, highlighting the complex relationship between socio-economic improvement and health outcomes. On the other hand, COVID-19-related restrictions, including school closures, reduced access to sports facilities, and substantial decreases in children’s physical activity (Dz. U. 2021, item 2069; Dz. U. 2022, item 64), likely contributed to this trend. This effect may have been further intensified by increased sedentary behaviors, including prolonged screen time, observed among children during lockdown periods. Importantly, this effect may reflect not only short-term pandemic-related changes but also a broader, long-term decline in habitual physical activity observed in children and adolescents, which is considered one of the key drivers of increasing body mass and BMI in contemporary populations. Although the present study did not analyze direct economic indicators or correlations, these interpretations are consistent with patterns reported in international research.

The changes observed among rural boys in Poland reflect broader global trends. Studies conducted in China, India, and Mexico over recent decades have shown that rural populations are particularly responsive to modernization and improvements in living conditions. Li et al., (2023) demonstrated that somatic growth among rural Chinese children was strongly associated with improved infrastructure, greater access to education, and rising living standards. More recent analyses (Li et al., 2024) emphasize that although urban–rural disparities persist, rural populations exhibit the greatest sensitivity to socio-economic change. Similar patterns were described by Chanchala et al., (2022) in India and by Dang et al., (2025) in China, where intensified economic development led not only to increases in body height but also to rapid rises in excessive body mass. Findings from studies conducted in other countries suggest that processes of modernization in rural populations lead not only to improvements in living conditions but also to lifestyle changes that promote increases in body mass. Similar mechanisms may also occur in the studied population, particularly in the context of differences between rural and urban areas, where lifestyle changes may result in reduced physical activity and increased availability of high-calorie foods.

In Latin America, the relationship between secular growth trends and socio-economic transformation is particularly well documented. Malina et al., (2018), analyzing a traditional community in southern Mexico, showed that secular somatic changes were associated with epidemiological transition and an increasing prevalence of overweight as living conditions improved. Research by Azcorra and colleagues (2024; 2025) in

Maya communities likewise demonstrated that market integration is a key factor amplifying secular trends — a finding that is especially relevant in the context of post-1996 rural modernization in Poland.

The literature also indicates that rural populations are highly sensitive to resource shortages. Studies from Zambia (Mitsunaga and Yamauchi 2020), Andean communities (Burris et al., 2022), and Timor-Leste (Spencer et al., 2018) clearly show that growth tempo is strongly constrained by environmental conditions, and severe shortages can lead to lasting reductions in developmental parameters. These contrasting examples highlight the degree to which rural populations respond to both improving and deteriorating living conditions.

It is also important to note that secular trends have an intergenerational dimension. Sinha et al., (2017) demonstrated that anthropometric changes are the cumulative result of favorable conditions across generations, underscoring the value of long-term research such as the present study, which spans 35 years of Poland's socio-economic transformation.

The rise in overweight and obesity in younger age groups represents a significant public health concern. Epidemiological evidence indicates that BMI trajectories established during childhood and adolescence are strong predictors of metabolic and cardiovascular risks in adulthood. The present findings therefore highlight the need for continued monitoring of rural populations in Poland and the implementation of preventive measures aimed at promoting healthy eating and physical activity from early childhood.

The strengths of this study include its long 35-year observation period, large

sample size, and high methodological consistency of measurements, all of which enhance the reliability of the assessment of secular trends. The limitations of the study are typical of cross-sectional analyses and should be considered when interpreting the findings. A key limitation is the lack of data on biological maturation, physical activity, diet, and the socio-economic characteristics of the family and school environment, which restricts the ability to identify the mechanisms underlying the observed changes, particularly in the context of the recent increase in body mass and BMI. This limitation is especially important during puberty, when differences in the tempo of maturation may substantially influence anthropometric outcomes. In addition, the cross-sectional design precludes the analysis of individual growth trajectories, which may lead to an underestimation of intra-individual variability. The absence of BMI category data for 1996 introduces a gap in the long-term analysis of nutritional status, while the lack of direct economic indicators further limits causal interpretation. Despite these limitations, they do not undermine the assessment of somatic trends, which was the principal aim of the study. At the same time, they indicate important directions for future, more complex and multidimensional research.

Conclusions

The findings of this study confirm that secular processes among rural boys in eastern Poland remain active and have undergone a gradual transformation. Body height continues to show an upward trend, whereas in recent years, a pronounced increase in body mass and BMI has become evident. This pattern

indicates a shift from classical secular trends associated with improved living conditions toward the contemporary trajectory observed in many rural populations worldwide, in which modernization is accompanied by the rising prevalence of overweight and obesity. The observed changes, particularly prominent in the youngest age groups, underscore the need for preventive initiatives aimed at shaping healthy dietary habits and physical activity. At the same time, the results highlight the importance of continued research incorporating a broader range of environmental and socio-economic factors that may influence growth conditions among rural children. From a public health perspective, the monitoring of rural populations remains a crucial element in assessing the health of children and adolescents in Poland, especially in the context of the growing burden of excessive body mass.

Author contributions

JS: Conceptualization; methodology; study design; data collection; data analysis; interpretation of results; writing—original draft; writing—review and editing; supervision; final approval of the manuscript. AW: Conceptualization; methodology; study design; data collection; data analysis; interpretation of results; writing—original draft; writing—review and editing; supervision; final approval of the manuscript.

Ethics statement

Ethical approval for the initial surveys (1986, 1996, and 2006) was obtained from the relevant Faculty Ethics Committee of the Józef Piłsudski University of Physical Education in Warsaw within

the framework of the State Key Problem 10.7 and the internal research projects D.S. 49 and D.S. 203, in accordance with the national and institutional regulations in force at that time. Formal approval reference numbers were not assigned or are no longer available in archival records. For the later survey waves (2016 and 2021), the study protocol was approved by the Ethics Committee of the Józef Piłsudski University of Physical Education in Warsaw (approval number: SKE 01-13/2014; date of approval: 30 June 2014). Informed consent was obtained from the parents or legal guardians of all participants, and participation in the study was voluntary.

Data availability statement

The datasets generated and analyzed during the current study are not publicly available due to institutional and ethical restrictions but are available from the corresponding author upon reasonable request.

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Conflict of interest

The authors declare that they have no conflict of interest regarding this paper.

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