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childhood Obesity Policy

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D2.3: Peer-reviewed publication on trends in BMI and height in children and adolescents from five to 19 years of age

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Dissemination Level

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1 Summary

1.1 Background

Much of global health and nutrition research and monitoring has focused on children younger than five years, and there are limited comparable data on older children and adolescents globally and in Europe. We aimed to estimate age trajectories and time trends in mean height and mean body-mass index (BMI), which measures weight gain beyond what is expected due to change in height, for school-aged children and adolescents aged five to 19 years. The deliverable contains a draft manuscript that is being submitted for publication. The manuscript has a global scope as it relies on a statistical approach that combines data from all countries to derive national estimates, but the annex provides a focus on results for Europe.

1.2 Methods

We used data from 2,086 population-based studies, with measurements of height and weight in 65 million participants. We applied a Bayesian hierarchical model to estimate trends from 1985 to 2019 in 200 countries for mean height and mean BMI in one-year age groups. The model allowed for non-linear changes over time in height and BMI, and for non-linear changes with age including periods of rapid growth during adolescence.

1.3 Results

In 2019, there was a ≥20 cm difference in mean height of 19-year-olds between the tallest (Netherlands, Estonia, Montenegro and Bosnia and Herzegovina for boys; Netherlands, Denmark, Iceland and Latvia for girls) and shortest (Timor-Leste, Lao PDR, Papua New Guinea and Solomon Islands for boys; Guatemala, Nepal, Timor-Leste and Bangladesh for girls) populations. In the same year, the difference between the highest mean BMI (Pacific island countries, Kuwait, Bahrain, Saudi Arabia, Bahamas, Chile, the USA, New Zealand and, for girls, South Africa) and lowest (boys and girls in India, Bangladesh, Timor Leste, Ethiopia and Chad, and girls in Japan and Romania) was ~9-10 kg/m^2. In some countries, five-year-olds started with height or BMI that was healthier than the global median, and in some cases as healthy as the best performing countries, but became progressively less healthy relative to their comparators by not growing as tall (e.g., boys in Austria and Chile; girls in Belgium and Puerto Rico) or gaining too much weight for their height (e.g., boys and girls in Kuwait, Saudi Arabia and Fiji; girls in Mexico and South Africa; and boys in China). In other countries, growing children overtook their comparators' height (e.g., Latvia, Czech Republic, Morocco and Iran) in late childhood and adolescence or curbed their weight gain (e.g., girls in Sweden, France, Switzerland and Croatia). When changes in both height and BMI are considered, South Korean children, girls in some central Asian countries (e.g., Armenia, Azerbaijan, Turkey) and boys in central and western Europe (e.g., Portugal, Denmark, Poland, Montenegro) experienced the healthiest changes in anthropometric status over the past 3.5 decades because, compared to other countries, they achieved a much larger gain in height than they did in BMI. The unhealthiest changes – i.e., gaining too little height and/or too much weight for their height compared to other countries – were experienced in many countries in sub-Saharan Africa, Pacific island nations, New Zealand and the USA; boys in Malaysia; and girls in Mexico.

1.4 Interpretation

School-aged children and adolescents’ height and BMI trajectories over age and time are highly variable across countries, which indicates heterogeneous nutritional quality and life-long health advantages and risks.

1.5 Funding

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2 Research in Context

Added value of this study

This study presents the first comparable estimates of height in school-aged children and adolescents for all countries in the world, and does so alongside estimates of BMI, which together are pathways from nutrition and environment during childhood and adolescence to lifelong health. We also analysed height and BMI age trajectories to investigate ages when growth in different countries is more versus less healthy, and to identify the need for intervention.

Implications of all the available evidence

Age trajectories and time trends in mean height and BMI of school-aged children and adolescents are highly variable across countries, and indicate heterogeneous nutritional quality and life-long health advantages and risks. When both height and BMI are considered, South Korean children, girls in some central Asian countries (e.g., Armenia, Azerbaijan, Turkey) and boys in central and western Europe (e.g., Portugal, Denmark, Poland, Montenegro) experienced the healthiest changes in anthropometric status over the past 3.5 decades because, compared to other countries, they achieved a much larger gain in height than in BMI, which measures weight gain beyond what is expected due to change in height. The unhealthiest changes – i.e., gaining too little height and/or too much weight compared to other countries – were experienced in many countries in sub-Saharan Africa, Pacific island nations, New Zealand and the USA; for boys in Malaysia; and for girls in Mexico. Global and national nutrition and health programmes should extend to school years in order to consolidate gains in under-five children and enable healthy growth through the entire developmental period.

3 Introduction

Growth and development through childhood and adolescents are affected by social, nutritional and environmental factors at home, school and community. For school-aged children and adolescents, these factors amplify or mitigate adversity in infancy and early childhood, and can help consolidate gains from early childhood and correct nutritional inadequacies and imbalances.[1-3] Therefore, investing in school-aged children and adolescents' nutrition is crucial for a healthy transition to adulthood.[4-8]

Height and body-mass index (BMI) are anthropometric measures of the quality of nutrition and healthiness of the living environment during childhood and adolescence, and are highly predictive of health and developmental outcomes throughout life.[9-18] Having low height-for-age and being underweight increases the risk of morbidity and mortality, impairs cognitive development, and reduces educational performance and work productivity in later life.[11,15,17] Childhood overweight and obesity are associated with poor mental health and educational outcomes, as well as higher risk of disability and premature death in adulthood.[16,18]

Much of global health and nutrition research and policy has focused on the period from pre-conception to five years of age.[19-21] For school-aged children and adolescents, global information is available only on BMI,[22] and no study has reported global trends in height for these ages. We present consistent and comparable global estimates of height and BMI for school-aged children from 1985 to 2019, and assess how countries perform in terms of growing taller without excessive weight gain. We also evaluate height and BMI trajectories by age to understand when change is more or less healthy, to identify the need for intervention. See annex for diagrams showing changes in height and BMI between 1985 and 2019 in Europe.

4 Methods

4.1 Primary outcomes

Our primary outcomes were population mean height and mean BMI from five to 19 years of age. BMI normalises the weight gain that is simply due to becoming taller, and hence measures being underweight or overweight for a person's height.[23,24] Analysis began at five years of age because children enter school at or around this time, and their nutrition, physical activity and health are influenced by the interplay of their home, school and community environment.[25]

4.2 Data sources

We used a database on cardiometabolic risk factors collated by the Non-Communicable Disease Risk Factor Collaboration (NCD-RisC). Data were obtained from publicly available multi-country and national measurement surveys (e.g., Demographic and Health Surveys (DHS), WHO-STEPwise approach to Surveillance (STEPS) surveys, and those identified via the Inter-University Consortium for Political and Social Research and European Health Interview & Health Examination Surveys Database). With the help of World Health Organization (WHO) and its regional and country offices as well as World Heart Federation, we identified and accessed population-based survey data from national health and statistical agencies. We searched and reviewed published studies as detailed previously[22] and invited eligible studies to join NCD-RisC, as did we with data holders from earlier pooled analysis of cardiometabolic risk factors.[26-29]

We carefully checked that each data source meets our inclusion criteria listed below. Duplicate data were identified by comparing studies from the same country and year, and then discarded. All NCD-RisC members are also periodically asked to review the list of sources from their country, to verify that the included data meet the inclusion criteria and are not duplicates, and to suggest additional sources. The NCD-RisC database is continuously updated through all the above routes. For each data source, we recorded the study population, sampling approach, years of measurement, and measurement methods. Only population-based data were included, and these were assessed in terms of whether they covered the whole country, multiple sub-national regions, or one or a small number of communities, and whether rural, urban, or both participants were included. All submitted data were checked by at least two independent persons. Questions and clarifications were discussed with NCD-RisC members and resolved before data were incorporated in the database.

Anonymised individual data for participants aged 5 to 19 years from the studies in the NCD-RisC database were reanalysed according to a common protocol. Additionally, for analysis of height, participants aged 20 to 30 years were included, assigned to their corresponding birth cohort, because their mean height would be at least that when they were aged 19 years, given that the decline of height with age begins in the third and fourth decades of life.[30] We excluded participants (<0.2% of all participants) with implausible height values (<60 cm or >180 cm for ages <10 years; <80 cm or >200 cm for ages 10-14 years; <100 cm or >250 cm for ages >14 years), or implausible weight values (<5 kg or >90 kg for age <10 years; <8 kg or >150 kg for ages 10-14 years; <12 kg or >300 kg for ages >14 years), or with implausible BMI levels (<6 kg/m^2 or >40 kg/m^2 for ages < 10 years; <8 kg/m^2 or >60 kg/m^2 for ages 10-14 years; <10 kg/m^2 or >80 kg/m^2 for ages >14 years).

We calculated mean height and mean BMI and the associated standard errors by sex and age. All analyses incorporated sample weights and complex survey design, when applicable, in calculating summary statistics, with computer code provided to NCD-RisC members who requested assistance.

Additionally, summary statistics for nationally representative data from sources that were identified but not accessed via the above routes were extracted from published reports. Data were also extracted for nine STEPS surveys that were not publicly available, one Countrywide Integrated Non-communicable Diseases Intervention (CINDI) survey, and five sites of the WHO Multinational MONItoring of trends and determinants in CArdiovascular disease (MONICA) project that were not deposited in the MONICA Data Centre. We also included those data from a previous global-data pooling study,[29] when not accessed through the above routes.

4.3 Data inclusion and exclusion

Data sources were included if:

- measured data on height and weight were available;
- study participants were five years of age and older;
- data were collected using a probabilistic sampling method with a defined sampling frame;
- data were from population samples at the national, sub-national (i.e., covering one or more sub-national regions, with more than three urban or five rural communities), or community level;
- data were from the countries and territories listed in Appendix Table 1.

We excluded all data sources that only used self-reported weight and height without a measurement component because these data are subject to biases that vary with geography, time, age, sex and socioeconomic characteristics.[31-33] We also excluded data on population subgroups whose anthropometric status may differ systematically from the general population, including:

- studies that had included or excluded people based on their health status or cardiovascular risk;
- studies whose participants were only ethnic minorities;
- specific educational, occupational, or socioeconomic subgroups, with the exception noted below;
- those recruited through health facilities, with the exception noted below; and
- females aged 15-19 years in surveys which only sampled ever-married women or measured height and weight only among mothers.

We included school-based data in countries and age-sex groups with enrolment of 70% or higher. We also included data whose sampling frame was health insurance schemes in countries where at least 80% of the population were insured. Finally, we included data collected through general practice and primary care systems in high-income and central European countries with universal insurance, because contact with the primary care systems tends to be as good as or better than response rates for population-based surveys.

4.4 Data used in this paper

For this analysis, we used data from the NCD-RisC database from 1985 to 2019 for analysis of BMI and from 1971 to 2019 for analysis of height. Five-year olds in data from 1971 were born in 1966, and hence were 19 years old in 1985, as were six-year olds in data from 1972, … and 19-year olds in data from 1985. The inclusion of data from different years provided multiple observations of each birth cohort during its life-course, which in turn helped to estimate the relevant parameters in the height model which used birth year as its time scale as described below. A list of the data sources we used in this analysis and their characteristics is provided in Appendix Table 2. These included 2,086 population-based measurement surveys and studies, with anthropometric measurements on 50 million participants aged 5-19 years and 15 million participants aged 20-30 years.

There was at least one data source for 193 of the 200 countries for which estimates were made, covering 98.7% of the world's population in 2019 (Appendix Figure 1); and at least two data sources for 176 countries (98.0% of the world's population). Of these 2,086 sources, 1,214 (58.2%) sampled from national populations, 354 (17.0%) covered one or more sub-national regions, and the remaining 518 (24.8%) were from one or a small number of communities. Regionally, data availability ranged from ~3 data sources per country in Oceania to ~46 sources per country in the high-income Asia Pacific region.

4.5 Conversion of BMI prevalence metrics to mean BMI

In less than 2% of our data points, mostly extracted from published reports or a previous pooling analysis,[29] mean BMI was not reported, but data were available for the prevalence of one or more BMI categories. We used previously validated conversion regressions[22] to estimate mean BMI from the available metric(s). All sources of uncertainty in the conversion – including that of sampling, the regression coefficients and random effects, and the regression residuals – were carried forward by using repeated draws from their joint posterior distribution, accounting for the correlations among the uncertainties of regression coefficients and random effects.

4.6 Statistical methods

We used a Bayesian hierarchical model to estimate mean height and mean BMI by country, year, sex and age. The model is described in detail in statistical[34] and related substantive papers;[22,26-29,35] the computer code for the model is available at www.ncdrisc.org.

In summary, the model had a hierarchical structure in which estimates for each country and year were informed by its own data, if available, and by data from other years in the same country and from other countries, especially those in the same region and "super-region", with data for similar time periods. The extent to which estimates for each country-year were influenced by data from other years and other countries depended on whether the country had data, the sample size of the data, whether they were national, and the within-country and within-region variability of the available data. For the purpose of hierarchical analysis, countries were organised into 21 regions (Appendix Table 1), mostly based on geography and national income. Regions were in turn organised into nine super-regions.

We used observation year, i.e., the year in which data were collected, as the time-scale for the analysis of BMI and birth year as the time scale for the analysis of height, consistent with previous analyses.[35,36] For BMI, significant societal changes that affect nutrition and physical activity may affect children of different ages simultaneously, whereas for height, these effects accumulate in each birth cohort and a cohort's height-for-age monotonically increases from childhood to late adolescence. The statistical model incorporated non-linear time trends, by having two components, a linear term and a second-order random walk,[37] both modelled hierarchically. The age-association of height and BMI were modelled to allow non-linear changes over age, including periods of rapid as well as slow rise, the former representing adolescent growth spurts.[38] We used a cubic spline to model age non-linearly and flexibly, with the spline parameters permitted to vary across countries based on their own data as well as in a hierarchical structure. We selected the number and position of splines' knots based on a combination of physiological and statistical considerations. Physiologically, growth spurts during puberty occur earlier in girls than in boys, followed by a slow-down of height gain.[38-40] To allow the age model to have sufficient flexibility to capture such patterns, we used four knots in different positions for boys and girls. Statistically, we evaluated the residuals of the age model and used the model that minimized the sum of squares of residuals. Based on these considerations, the four knots were placed at ages 8, 10, 12, 14 years for girls and at 10, 12, 14, 16 years for boys. For BMI, we used only two spline knots (at ages 10 and 15 years) because, at the population level, changes in BMI with age are smoother than those in height.[38,40]

The statistical model accounted for the possibility that height or BMI in sub-national and community samples might differ systematically from nationally representative samples and have larger variation than in national studies. These features were taken into account by including data-driven fixed-effect and random-effect terms for sub-national and community data. The fixed effects adjusted for systematic differences between sub-national or community studies and national studies; and the random effects allowed national data to have greater influence on the estimates than sub-national or community data with similar sample sizes.

All analyses were done separately by sex because there are differences between girls and boys in height and BMI, and their time trends and age associations.[22,35,40] We fitted the statistical model with the Markov chain Monte Carlo (MCMC) algorithm and obtained 5,000 post-burn in samples (or draws) from the posterior distribution of model parameters, which were used to obtain the posterior distributions of mean height and mean BMI. Posterior estimates were made in 1-year age groups from five to 19 years of age for every year from 1985 to 2019. We applied the pool-adjacent-violators algorithm[41,42] on the posterior height estimates to ensure that each birth cohort's height increased monotonically with age. In practice, this had little effect on the results, with height at age 19 years adjusted by an average of less than 0.15 cm for both boys and girls. This was because in only three countries for boys and six for girls was height at 19 years estimated to be >1cm lower than at peak age. The reported credible intervals represent the 2.5th and the 97.5th percentiles of the posterior distributions.

5 Results

5.1 Trends in height

In 2019, the tallest 19-year-olds lived in northwestern and central European countries: Netherlands (184.1 cm; 95% credible interval 181.7-186.6), followed by Estonia, Montenegro and Bosnia and Herzegovina for boys; and Netherlands (170.5 cm; 168.4-172.5), followed by Denmark, Iceland and Latvia for girls (Figure 1a). The shortest were in south and southeast Asia, Andean Latin America and east Africa: Timor-Leste (160.0 cm; 157.8-162.1) followed by Lao PDR, Papua New Guinea and Solomon Islands for boys, and Guatemala (151.0 cm; 149.5-152.4) followed by Nepal, Timor-Leste and Bangladesh for girls. The ≥20 cm difference between countries with the tallest and shortest height represents ~8 years of lost growth potential for girls and ~6 years for boys. For example, 19-year-old girls in three countries (Guatemala, Nepal and Timor Leste) had the same height as 11-

year-old Dutch girls, and those in another 54 countries – such as Bangladesh, Burundi, India, Indonesia, Lao PDR, Pakistan, Peru, the Philippines and Yemen – had the same height as 12-year-old Dutch girls (Figure 2). Similarly, 19-year-old boys in 15 countries throughout Asia, Andean Latin America and sub-Saharan Africa had the same height as Dutch boys aged 13 years.

Although northwestern European children and adolescents were the tallest in the world in 2019, much of this advantage was achieved prior to the late 20th century, and many of these countries experienced below median height change from 1985 to 2019 (Figure 1b). In contrast, central European countries such as Montenegro and Poland achieved a significant part of their height advantage since 1985, especially for boys. The largest gains in height over the last 3.5 decades however were those in emerging economies spanning China (largest gain for boys and third largest for girls), South Korea (third largest for boys and second largest for girls), through parts of southeast Asia, Middle East and north Africa, and Latin America and the Caribbean. In contrast, in many countries in sub-Saharan Africa, not only was the potential to grow taller in late childhood and adolescence not realised, but the height of children and adolescents, especially boys, has on average stagnated or become shorter since 1985.[35,36]

5.2 Trends in BMI

The global distribution of low and high BMI in school-aged children and adolescents in 2019 was unlike that of their height. Pacific island countries in Oceania had the highest BMI, surpassing 28 kg/m^2 for 19-year-olds in many of these nations (Figure 3). Late-adolescence BMI was also high in Middle East and North African countries like Kuwait, Bahrain and Saudi Arabia; Caribbean islands like Bahama; Chile, the USA, and New Zealand; and for girls in South Africa. BMI of 19-year-olds was lowest (<~21 kg/m^2) in countries in south Asia (e.g., India and Bangladesh), southeast Asia (e.g., Timor-Leste); east and central Africa (e.g., Ethiopia and Chad); and, for girls, in Japan and some central European countries (e.g., Romania). The highest and lowest worldwide BMIs were ~9-10 kg/m^2 apart, equivalent to ~25 kg of weight. Change in late-adolescence BMI from 1985 to 2019 ranged from small changes (<0.5 kg/m^2) in Japan, some European countries (e.g., Italy, Russia, Denmark) and, for girls, some central Asian (e.g., Armenia) and sub-Saharan African countries, to increases over 3 kg/m^2 in many countries in Oceania, Malaysia, Brunei and China for boys; and in Mexico for girls.

5.3 Combined change in height and BMI from 1985 to 2019

From 1985 to 2019, 19-year-old girls in some countries in central Asia (e.g., Armenia and Azerbaijan), and 19-year-old boys in some European countries (e.g., Portugal, Denmark, Poland, Montenegro) experienced moderate-to-large gains in height alongside relatively small increases in BMI (Figure 4). Meanwhile in some countries (e.g., boys and girls in South Koreaand Saudi Arabia; girls in Turkey and Viet Nam) children grew much taller, while their BMI increased about the global median. Both of these trends were healthier than those of much of Oceania and sub-Saharan Africa, New Zealand, USA, Malaysia (boys) and Mexico (girls), where there was little height gain and/or much larger weight gain relative to other countries.

5.4 Height and BMI age trajectories

The height and BMI of children who were born in 2000 (i.e., who were 19-year-olds in 2019) in each country is compared to the median of the respective WHO growth reference[40] at each age from 5 to 19 years in Figure 5a. The comparison shows that in many countries, children achieved mean height throughout their late childhood and adolescence that was lower than the median of the WHO reference – by as much as 10-15 cm at some ages in countries like Timor Leste, Lao PDR, Nepal, Yemen and Guatemala. The exception to this pattern was much of Europe and a few countries in Polynesia and the Caribbean (e.g., Dominica and girls in French Polynesia) where mean height throughout late childhood and adolescence was taller than the median of the WHO reference by ~3 cm or more. Elsewhere, either height advantage (i.e., having mean heights that were higher than the WHO reference median) at five years was diminished or reversed as children grew older, or height disadvantage (i.e., having mean height that was shorter than the WHO reference median) increased. This progressive faltering was especially noticeable in Japan, and in middle-income countries in Latin America and the Caribbean (e.g., Chile and Uruguay), the Middle East and north Africa (e.g., United Arab Emirates), and sub-Saharan Africa (e.g., Mauritius and South Africa,) where children had optimal height at five years, but by the time they grew to 19 years of age, their height was up to 2-3 cm shorter than the median of the WHO reference. Very few countries (e.g., Russia and boys in Iran) closed the gap to the WHO reference population during late childhood and adolescence.

For BMI, the “deficit” relative to the WHO reference at age five years, which was seen mainly in sub-Saharan Africa and south and southeast Asia, generally became smaller or disappeared as children grew to adolescence and reached 19 years (Figure 5a). For South Africa and Solomon Islands;, boys in China and many European countries; and girls and boys in Canada, and countries in Latin America and the Caribbean, and the Middle East and north Africa, mean BMI was about the same as the median of WHO reference for five-year olds, but increasingly exceeded the WHO reference median as the children became older.

Comparing height and BMI in each country with the median of all countries (Figure 5b) shows that children and adolescents in some countries had a consistent height advantage or disadvantage relative to others at every age. This was especially the case for countries that occupy the top (e.g., the Netherlands, Denmark, Montenegro, Estonia and Iceland) and bottom (e.g., Timor-Leste, Lao PDR, Nepal, Yemen and Guatemala) global ranks at age 19 years. For other countries, children’s height caught up with or fell behind their comparators during school ages. For example, children in some European countries (e.g., girls in Belgium and boys in Austria), and Latin America and the Caribbean (e.g., girls in Puerto Rico and boys in Chile) had about the same height as Dutch children at five years of age, but progressively fell behind, such that by the time they had reached 19 years they were >5 centimetres shorter than Dutch adolescents. In contrast, as children approached 19 years in Latvia, Czech Republic, Morocco and Iran, they progressively improved their height relative to others.

When age-specific mean BMI is compared to the global median (Figure 5b), whether a country had low mean BMI (e.g., countries in south and southeast Asia) or high (e.g., USA, Chile and countries in Oceania) relative to others, persisted more than was the case for height.[43] Nonetheless, some differences in BMI trajectories occurred across countries. For example, girls in some European countries (e.g., Sweden, France, Switzerland and Croatia) progressively moved towards healthier BMIs relative to other countries, and the difference between their BMI and global median changed from positive to negative. In contrast, relative to girls and boys in other countries, those in middle-income countries like Kuwait, Saudi Arabia, Fiji, girls in South Africa and Mexico, and boys in China had a progressively higher BMI as they became older.

6 Discussion

We found that, except for some mainly European countries, mean height throughout the world progressively fell behind the median of the WHO reference as children grew from five to 19 years. This progressive faltering reversed the gains made in the first five years of life or further exacerbated insufficient growth. Similarly, mean BMI progressively exceeded the median of the WHO reference over these ages or, where underweight existed at five years, it tended to diminish or reverse to overweight. When height and BMI were considered together, the least favourable changes from 1985 to 2019 were observed in sub-Saharan Africa, where population height has stagnated or decreased, and in Pacific island nations, New Zealand, USA, boys in Malaysia and girls in Mexico where small-moderate gains in height coincided with large increases in BMI. These highly variable age-trajectories and time-trends in population mean height and mean BMI likely indicate heterogeneous quality of nutrition and the living environment in late childhood and adolescence, and augur unequal life-long health advantages and risks.

Studies on adolescents in individual countries demonstrate significant variation in how much height has changed throughout the world, as also seen in studies of adult height.[35,36] Our results are consistent with these findings. One study,[44] using cross-sectional height in 53 community-based samples, found significant cross-population variation in height differences from 10 to 17 years of age which is consistent with our findings. Our results are also consistent with prior global analyses[22] in terms of regions and countries with the highest and lowest BMI, but prior studies had not considered age trajectories.

Our study has strengths in scope, data and methods: We present novel estimates of height in school-aged children and adolescents for all countries in the world, and to do so alongside estimates of BMI. We used an unprecedented scale of population-based data from 193 countries covering ~99% of the world population, while maintaining a high standard of data representativeness and quality. Data were analysed according to a consistent protocol, and the characteristics and quality of data from each country were rigorously verified through repeated checks by NCD-RisC members. We used a statistical model that took into account non-linear changes in height and BMI throughout childhood and adolescence, and used all available data while giving more weight to national data than to subnational and community sources.

Like all global analyses, our study has some limitations. Despite our extensive efforts to identify and access worldwide population-based data, some countries, especially those in the Caribbean, Polynesia and Micronesia, Melanesia and sub-Saharan Africa, had fewer data sources. The scarcity of data is reflected in larger uncertainty of our estimates for these countries and regions. Of the studies used, 44% had data for children aged 5-9 years, compared to 87% with data for 10-19-year-olds, which increases uncertainty of findings for the younger age groups. We compared height and BMI in each country to the median of the WHO growth reference.[40] Although the reference is the current international comparison tool,[9] unlike that of under-five children, it is not based on a multi-country sample of predominantly healthy and well-nourished children.[40] Consequently, it may be affected both by genetic and environmental influences as the sample children grew older.[45,46] Additionally, although a combined evaluation of changes in height and BMI more completely captures the influences of environment and nutrition on health than each measure alone, how these two are combined should be a subject of investigation.

The heterogeneous age trajectories and trends of height and BMI seen in our results are due to a number of factors that interact throughout childhood and adolescence, and across generations.[47] First there is an important genetic component to height,[48-50] and to a lesser extent to BMI,[51,52] within populations. However, genetics explain a relatively small part of the variation across countries of the changes over time, especially for BMI.[53-55] Second, some of the observed differences in height and BMI may be intergenerational or due to exposures and experiences during pregnancy,[56] mediated through birth length and weight.[17,57,58] Third, age at puberty, which is influenced by diet,[59-61] physical activity,[62,63] and weight gain[64-67] during childhood, seems to affect height gain during adolescent growth spurt and in late adolescence.[64] There are no comparable data across the world, but national data indicate significant changes in age at menarche and timing of pubertal growth in some countries.[68-72] Finally, all of these pathways are influenced by food and nutrition,[73-75] including energy balance, and adequacy and quality of nutrients especially proteins, fats and micronutrients, and the occurrence and treatment of infections.[46,47,76] Fully establishing the drivers of the observed height and BMI trajectories and trends requires data on the relevant determinants and their distributions in different countries.

High-quality nutrition and a healthy living environment enable children to realise their growth potential without gaining excessive weight, with lifelong benefits for their health and wellbeing. Our findings raise the need to re-think two common features of many global health and nutrition programmes. First, there is a need to overcome the disconnect in research and practice between reducing undernutrition and preventing and managing overweight and obesity,[22,47,77,78] through “double-duty actions” that prevent and tackle all forms of malnutrition via enhanced nutritional quality.[79] Second, there has been an imbalance between investment in improving nutrition and growth before five years of age and doing so in school-aged children and adolescents.[45] The finding that children in some countries grow healthily to five years but fail to continue to do so in school years should motivate efforts at home, school, community and the health system to support healthy growth through the entire period from birth to adolescence.

7 NCD Risk Factor Collaboration (NCD-RisC)

7.1 Pooled Analysis and Writing

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Author contributions

ARM, ZB, RB and ME designed the study. Members of the Country and Regional Data Group collected and reanalysed data, and checked pooled data for accuracy of information about their study and other studies in their country. ARM, BZ, and MS led the data collection. ARM led the statistical analysis with input from BZ, JB, JEB, CJP and ME, and prepared results. Members of the Pooled Analysis and Writing Group contributed to study design, collated data, and checked all data sources in consultation with the Country and Regional Data Group. ARM and ME wrote the first draft of the report with input from other members of the Pooled Analysis and Writing Group. Members of the Country and Regional Data Group commented on the draft report. ME oversaw research. The authors alone are responsible for the views expressed in this Article and they do not necessarily represent the views, decisions, or policies of the institutions with which they are affiliated.

Declaration of interests

ME reports a charitable grant from the AstraZeneca Young Health Programme, and personal fees from Prudential and Scor, outside the submitted work. Other authors declare no competing interests. The authors alone are responsible for the views expressed in this Article and they do not necessarily represent the views, decisions, or policies of the institutions with which they are affiliated.

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9 Annex

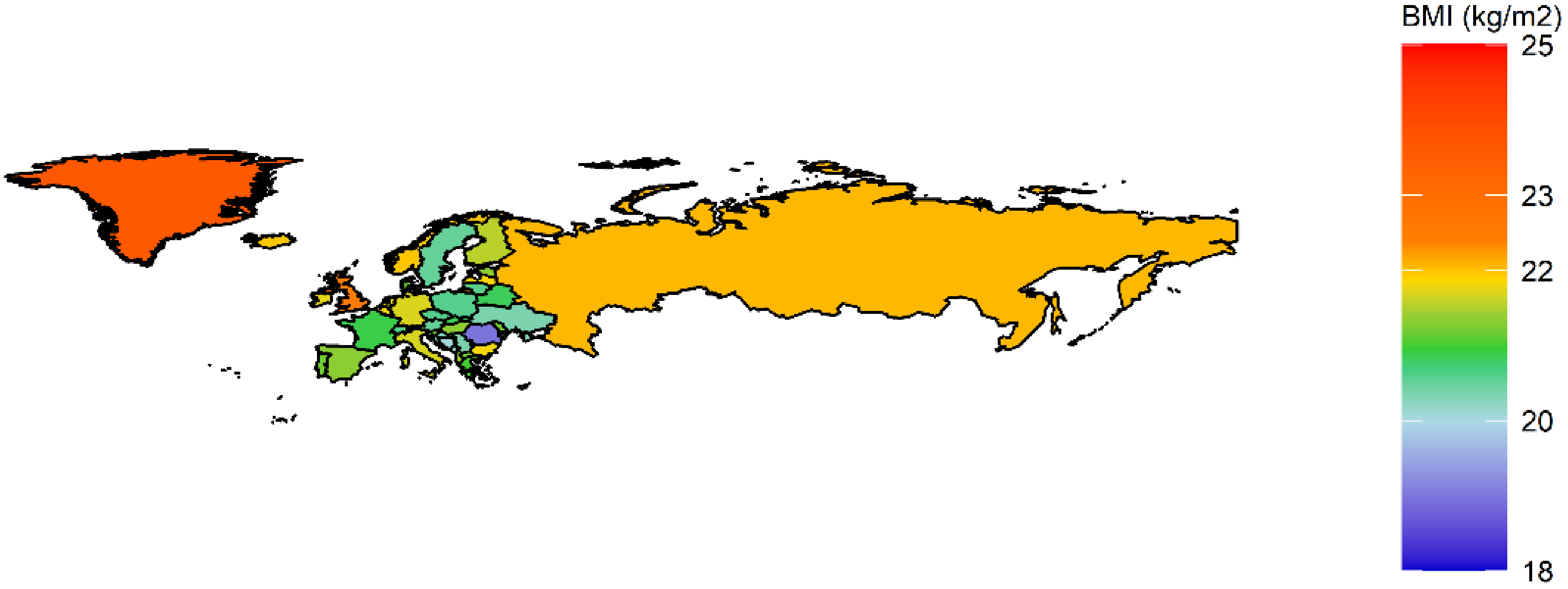

Figure 1: Female BMI 1985, EU

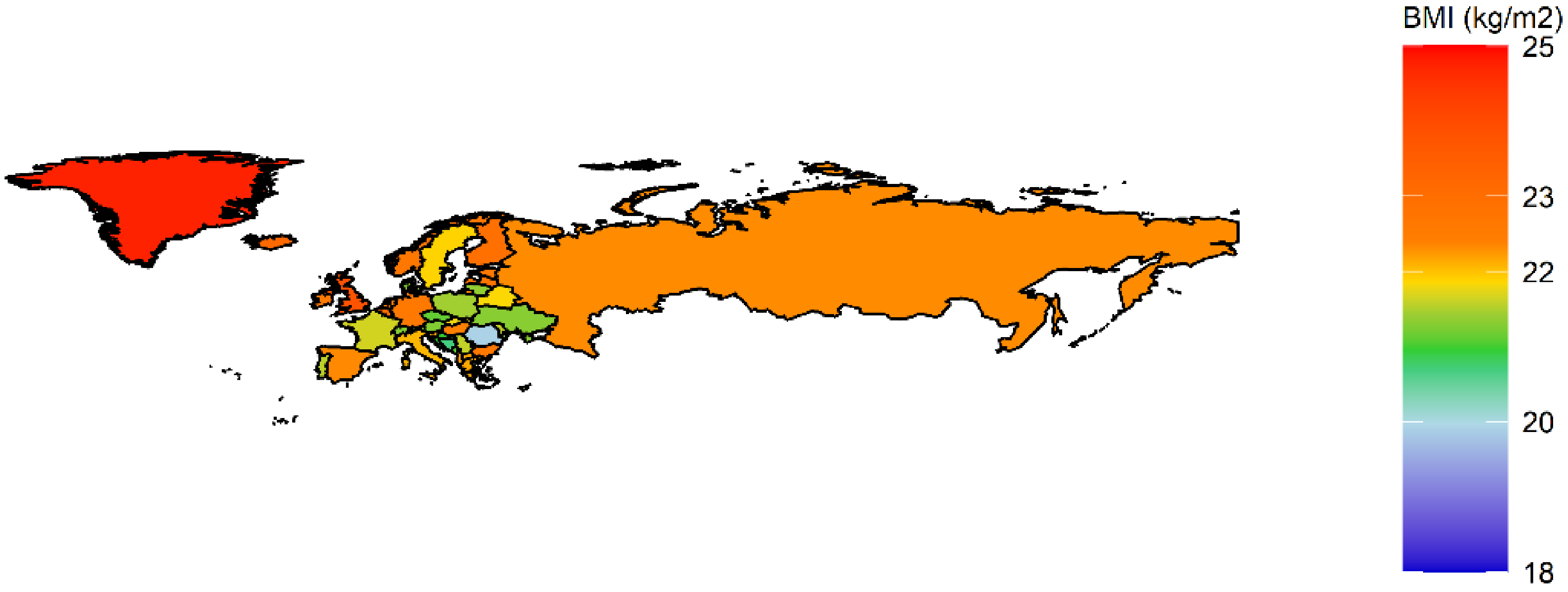

Figure 2: Female BMI 2019, EU

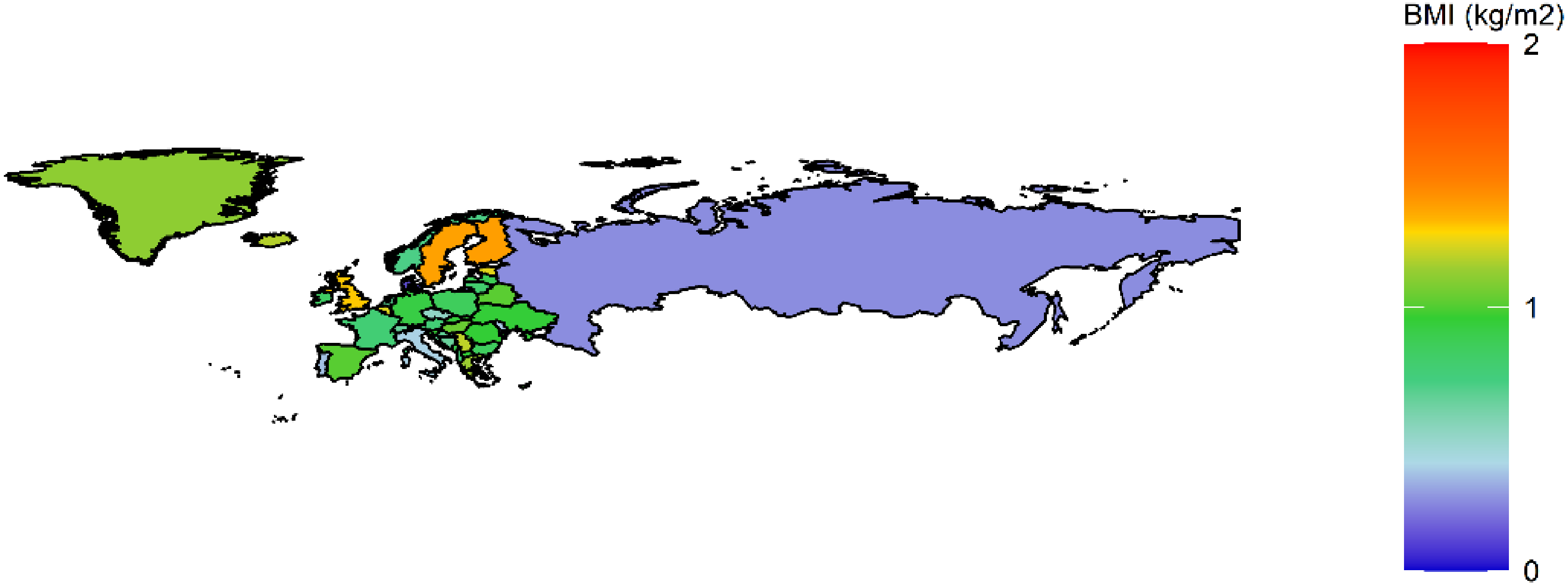

Figure 3: Female change BMI, EU

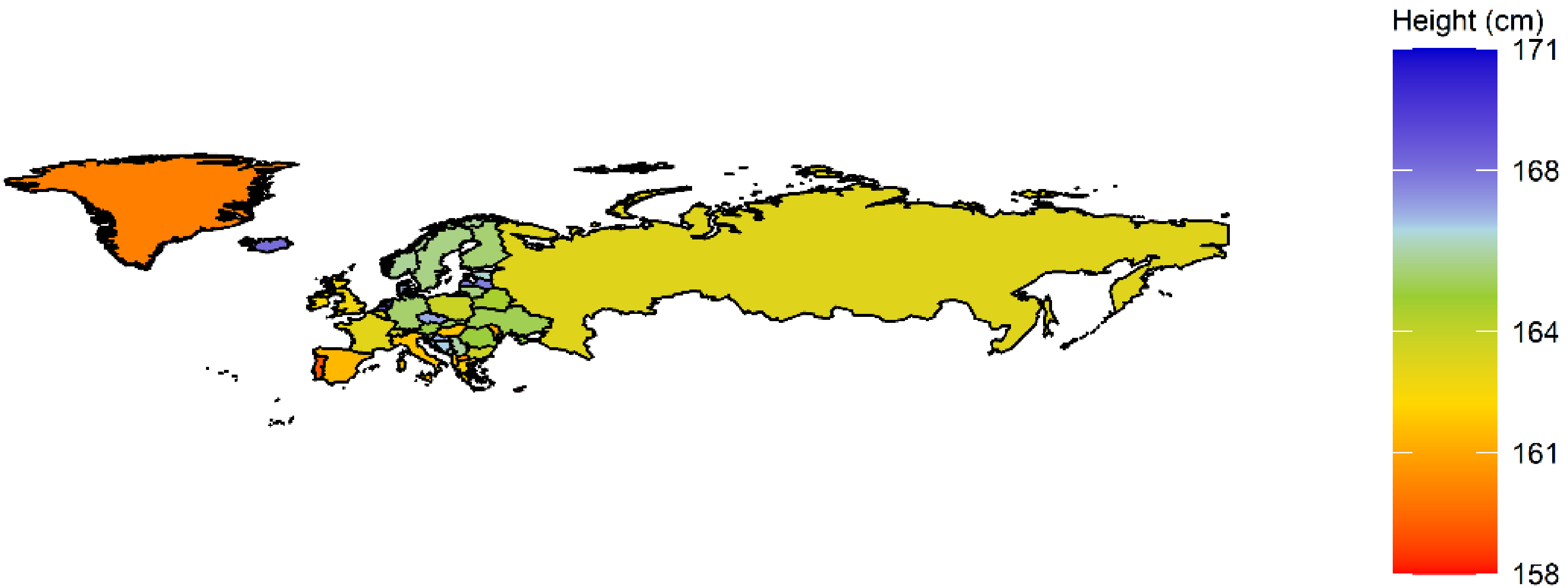

Figure 4: Female height 1985, EU

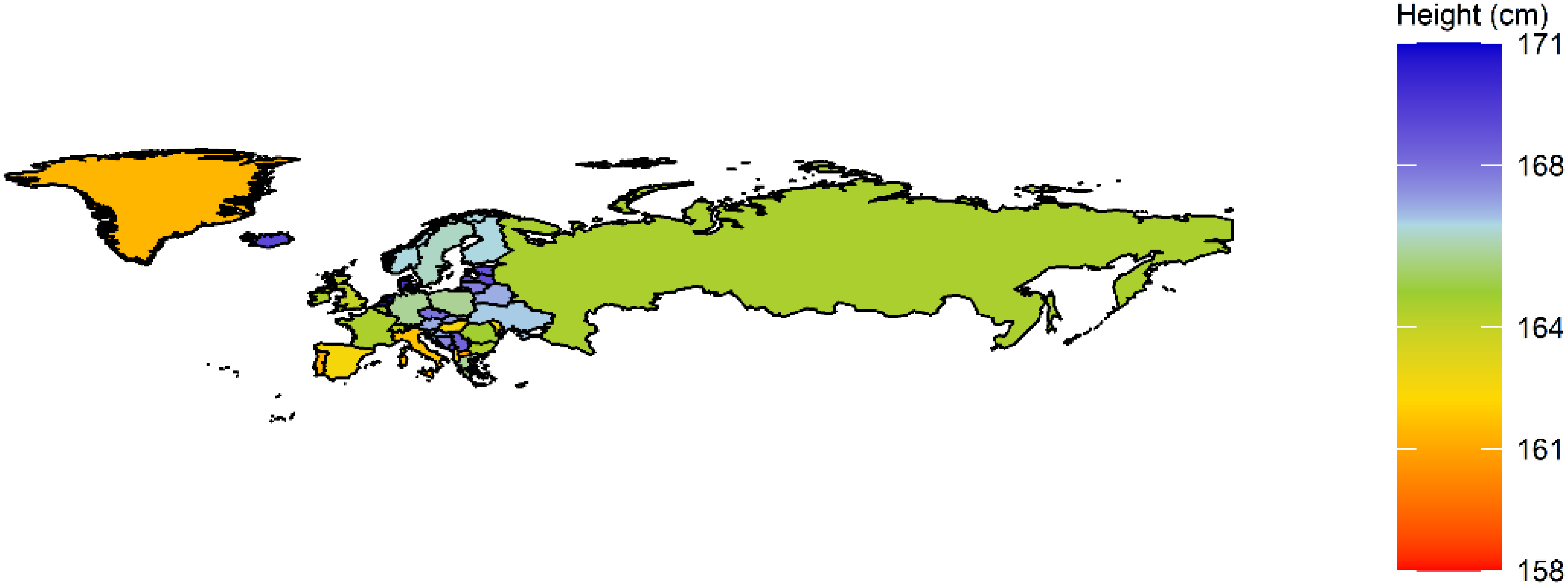

Figure 5: Female height 2019, EU

Figure 6: Female height change, EU

Figure 7: Male BMI 1985, EU

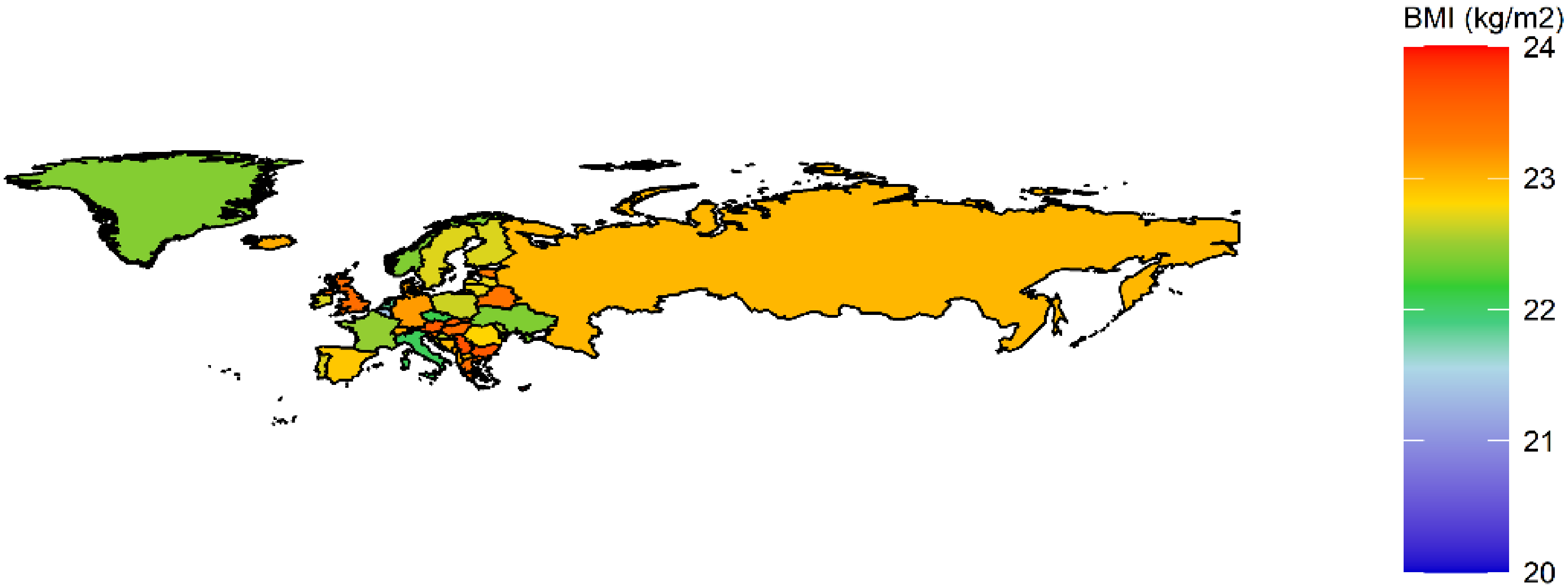

Figure 8: Male BMI 2019, EU

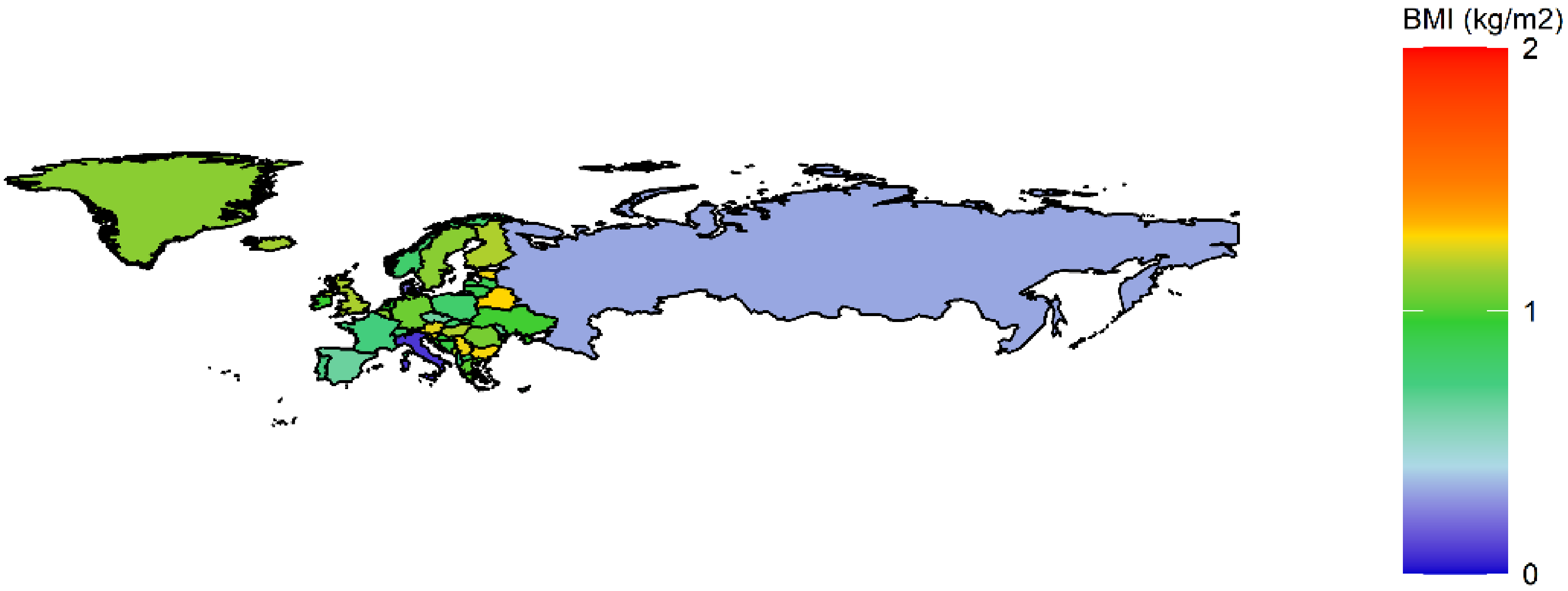

Figure 9: Male change BMI

Figure 10: Male height 1985, EU

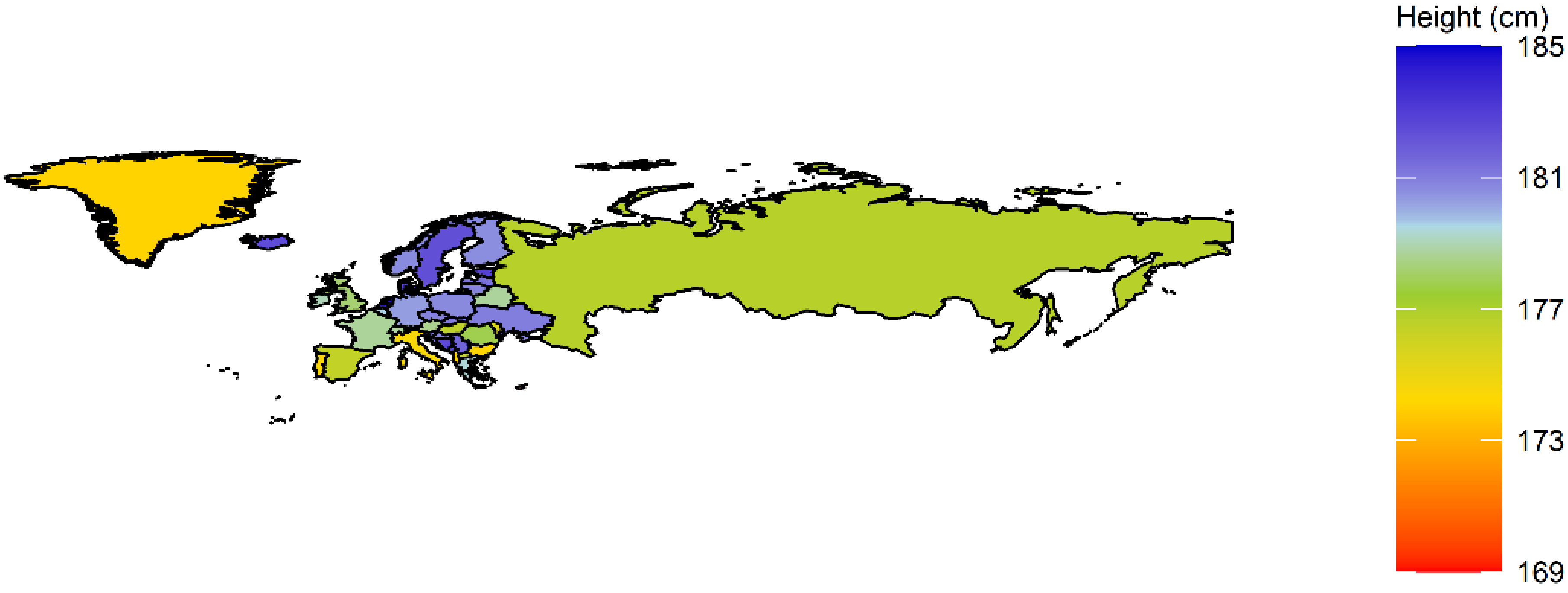

Figure 11: Male height 2019, EU

Figure 12: Male height change, EU