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European fitness landscape for children and adolescents: updated reference values, fitness maps and country rankings based on nearly 8 million test results from 34 countries gathered by the FitBack network

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► Additional supplemental material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/bjsports-2022-106176>).

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Accepted 18 November 2022
Published Online First
9 January 2023



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To cite: Ortega FB, Leskošek B, Blagus R, et al. *Br J Sports Med* 2023;**57**:299–310.

ABSTRACT

Objectives (1) To develop reference values for health-related fitness in European children and adolescents aged 6–18 years that are the foundation for the web-based, open-access and multilingual fitness platform (FitBack); (2) to provide comparisons across European countries.

Methods This study builds on a previous large fitness reference study in European youth by (1) widening the age demographic, (2) identifying the most recent and representative country-level data and (3) including national data from existing fitness surveillance and monitoring systems. We used the Assessing Levels of Physical Activity and fitness at population level (ALPHA) test battery as it comprises tests with the highest test–retest reliability, criterion/construct validity and health-related predictive validity: the 20 m shuttle run (cardiorespiratory fitness); handgrip strength and standing long jump (muscular strength); and body height, body mass, body mass index and waist circumference (anthropometry). Percentile values were obtained using the generalised additive models for location, scale and shape method.

Results A total of 7 966 693 test results from 34 countries (106 datasets) were used to develop sex-specific and age-specific percentile values. In addition, country-level rankings based on mean percentiles are

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Fitness testing in youth is important from health, educational and sport points of view.
- ⇒ The European Union-funded ALPHA project reviewed the existing evidence and proposed a selection of field-based fitness tests that showed the highest test–retest reliability, criterion/construct validity and health-related predictive validity among available tests.

WHAT THIS STUDY ADDS

- ⇒ The FitBack project provides the most up-to-date and geographically diverse reference fitness values for Europeans 6–18 years of age.
- ⇒ This study introduces the first web-based, open-access and multilingual fitness reporting platform (FitBack) providing interactive information and visual mapping of the European fitness landscape.

provided for each fitness test, as well as an overall fitness ranking. Finally, an interactive fitness platform, including individual and group reporting and European fitness maps, is provided and freely available online (www.fitbackeurope.eu).

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ From a health perspective, very low fitness levels are a non-invasive indicator of poor health at both individual and group levels (eg, school and region), which have utility for health screening and may guide public health policy. There are already examples of regional and national fitness testing systems that are integrated into healthcare systems.
- ⇒ From an educational perspective, fitness testing is part of the school curriculum in many countries, and the FitBack platform offers physical education teachers an easy-to-use tool for interpreting fitness test results by sex and age.
- ⇒ From a sport perspective, these reference values can help identify young individuals who are talented in specific fitness components.

Conclusion This study discusses the major implications of fitness assessment in youth from health, educational and sport perspectives, and how the FitBack reference values and interactive web-based platform contribute to it. Fitness testing can be conducted in school and/or sport settings, and the interpreted results be integrated in the healthcare systems across Europe.

INTRODUCTION

Robust and consistent evidence supports that physical fitness is a powerful marker of health in children and adolescents.^{1,2} Among the different fitness components, cardiorespiratory fitness (CRF, used in the literature and this article interchangeably with aerobic fitness) and muscular strength (used in the literature and this article interchangeably with muscular fitness) have shown the strongest and most consistent health-related associations and are therefore considered to be the main health-related fitness components.^{3,4} Other fitness components include flexibility, motor fitness and body composition/anthropometry (height, body mass, body mass index (BMI) and waist circumference). Recently, data from large registries have added compelling evidence linking both CRF and muscular strength in late adolescence with all-cause mortality and cardiovascular-specific and cancer-specific mortality in later life.^{5–8} In addition, these two fitness components predict severe, chronic and irreversible all-cause disease 30 years later as indicated by granted disability pensions,^{9–12} and also specifically cardiovascular, musculoskeletal, neurological and psychiatric diseases granted by a disability pension.^{9–12} Particularly, CRF is the most well-studied and strongest predictor of future health.² Indeed, a position stand from the American Heart Association has highlighted the clinical value of CRF in youth and recommended that it be regularly assessed.¹³ In addition to the well-documented associations between fitness and physical/mental health among youth,^{1–4,14} emerging evidence supports that better fitness is related to better cognition, academic performance, and healthier structural and functional brain outcomes.^{15–29} For example, recent observations from the ActiveBrains project have shown that total brain size, as well as total grey and white matter volumes, is larger in fit compared with unfit children with overweight/obesity.³⁰ This is important because total brain size is positively associated with intelligence.³¹ These findings are in line with those from Chaddock and colleagues, who included children also with normal weight, and found that fitter kids had larger grey matter volumes

in subcortical brain regions such as hippocampus¹⁷ and dorsal striatum.¹⁹

The evidence hereby presented about fitness as a powerful marker of health in youth supports the relevance of fitness assessment at the individual and population levels. However, the availability of different fitness batteries/tests leads to a lack of consistency and comparability across studies. To address this problem, the European Commission funded the ALPHA project. By conducting a set of systematic reviews^{2,32,33} and methodological papers, the ALPHA consortium aimed to identify the field-based fitness tests that demonstrated the highest test-retest reliability, criterion/construct validity and health-related predictive validity (see ALPHA summary article³⁴). Anthropometry and body composition are known to be tightly linked to fitness performance and health and were therefore considered as fitness components in the ALPHA project. The final output of the project was the ALPHA-fitness test battery for children and adolescents, which in its high-priority version (a shorter, more suitable version for school-based use) recommended using: the 20m shuttle run test for assessing CRF; the handgrip and standing long jump tests for assessing muscular strength and power; and BMI and waist circumference as indicators of total and central obesity, respectively. A year later and after following a similar systematic review process, the US Institute of Medicine (now the National Academy of Medicine) recommended these same tests for the assessment of youth physical fitness,^{35,36} strengthening the recommendation of using the ALPHA fitness test battery.

As the next step to the ALPHA project, the European Commission funded the FitBack consortium (www.fitbackeurope.eu), representing the European Network for the Support of Development of Systems for Monitoring Physical Fitness of Children and Adolescents. The major goal of the network is to take an important step toward the implementation of fitness surveillance and monitoring across Europe as an educational tool for physical literacy.³⁷ The final output of the FitBack project has been the development of a web-based, open-access and multilingual fitness platform which allows the results of fitness testing to be automatically and interactively interpreted based on sex-specific and age-specific reference values and is supported by user-friendly visual feedback and tips for improvement. For this purpose, we gathered available fitness data on European children and adolescents. Previous fitness reference values published were mostly from individual countries (see references in online supplemental table 1) or multicentre EU projects (eg, IDEFICS - Identification and prevention of Dietary- and lifestyle-induced health EFfects in Children and infantS - and HELENA - Healthy Lifestyle in Europe by Nutrition in Adolescence - projects^{38,39}) collecting data in one to two cities per country. The study by Tomkinson and colleagues provided the first European reference values that included numerous countries and covered a wide age demographic (subjects 9–17 years old).⁴⁰ However, until now, European reference values have not covered all school-age children (primary, secondary and high school) from age 6 years to 18 years. Also, the writing group was aware of nationally representative fitness monitoring systems and large datasets not included in Tomkinson's study, indicating the need to update existing reference values. There was also a pressing need to develop an automated, freely accessible web platform containing these normative values to facilitate the interpretation of sex-specific and age-specific fitness test results.

The aim of this article is to develop health-related fitness reference values for European children and adolescents aged 6–18 years. Additionally, we provide European fitness maps and

country ranking for the main health-related fitness components, all together as part the new, free-access, FitBack web platform (www.fitbackeurope.eu). Since paediatric obesity is being comprehensively monitored by other organisations (eg, World Obesity Federation, www.worldobesity.org/; WHO-Europe www.euro.who.int/en/health-topics/disease-prevention/nutrition/activities/who-european-childhood-obesity-surveillance-initiative-cosi), the focus of this article is mainly on CRF and muscular strength. Nonetheless, we also provide reference values and European maps for anthropometric measures (body height, body mass, BMI and waist circumference) as online supplemental material.

METHODS

Data search and pooling

A systematic review of existing datasets including fitness tests in children and adolescents was previously performed by Tomkinson *et al* and details of the search have been published.⁴⁰ These data were included in the FitBack dataset, with Monte Carlo simulation used to produce pseudo data (from reported means and SDs) when raw data were unavailable. In addition to this, the authors of the FitBack network conducted a centralised narrative search based on fitness terms to identify new datasets not included in the Tomkinson *et al* review.⁴⁰ For inclusion, valid data on sex, age and at least one of the ALPHA fitness tests (high-priority version) was required. In the previous study by Tomkinson *et al*, the age range was 9–17 year old, whereas in this study, we widened the age demographic to include subjects aged 6–18 years old. It is important to note that our search strategy was focused on fitness, and specific searches on adiposity, BMI or waist circumference were not conducted for pragmatic reasons (eg, the very large number of studies including these key words). Therefore, it is possible that we missed relevant anthropometry-specific datasets. This, together with the fact that other organisations are comprehensively monitoring paediatric obesity, is the reason why we primarily focused on CRF and muscular strength, and reported results for anthropometric measures (body height, body mass, BMI and waist circumference) as online supplemental material.

The FitBack network involved numerous experienced researchers working in paediatric fitness across Europe, which helped to identify unpublished fitness datasets that were pooled with gathered data. Moreover, large datasets from existing surveillance systems in Europe such as SLOfit,⁴¹ NETFIT⁴² and Fitescola⁴³ were also included. Further, we excluded older datasets if a more recent and more representative dataset was available for certain countries. The ambition was to use the most recent available data for each country, which in some cases was a single large dataset, while in others was the accumulation of several studies or datasets covering different geographical regions within a country. Sources used for generating the reference values are available on the FitBack website (www.fitbackeurope.eu/en-us/fitness-map/sources) as well as in online supplemental table 1.

Physical fitness measures

The FitBack dataset was compiled for studies that used the ALPHA fitness test battery^{2 32–34} since these tests have shown to be feasible, reliable, valid, and scalable for children and adolescents. Moreover, some of them are used in well-established European national fitness surveillance and monitoring systems like SLOfit,⁴¹ NETFIT⁴² and Fitescola.⁴³ Specifically, CRF was assessed using the 20m shuttle run test.⁴⁴ The number of completed stages was used as an indicator of CRF. However,

different studies had expressed the result of the 20m shuttle run test in other units, such as completed laps (shuttles) or speed at the last completed stage, and there are at least three known protocols/versions of this test.⁴⁵ All data were converted and harmonised into completed stages according to the original Léger protocol,⁴⁴ as described elsewhere.⁴⁵ Muscular strength was assessed by the handgrip strength (ie, upper-limb muscular strength) and standing long jump tests (ie, lower-limb muscular strength). Total and abdominal adiposities were assessed by BMI and waist circumference, respectively, following standardised procedures. For handgrip, most studies collected data from both hands, with the average of the best performance from both hands used in our analyses. Two studies had handgrip strength data only for the dominant hand, which is known to be systematically higher compared with the non-dominant hand. Exploratory analyses on Spanish data in children⁴⁶ showed a 0.6 kg mean difference between hands, and thus, we applied a –0.3 kg correction factor to these two studies to estimate the average score.

Statistical analysis

We applied different cleansing procedures to the data. First, data were trimmed to remove values outside the probable lower and upper limits. The limits were defined based on authors' experiences working with previous large datasets. The limits used were 20m shuttle run (0–21 stages), handgrip strength (0–80 kg), standing long jump (15–330 cm), body height (80–220 cm), body mass (0–200 kg), BMI (7–60 kg/m²) and waist circumference (40–130 cm). Second, outliers were identified and removed as follows. For each fitness measure, herein referred to as the *test*, a multivariate regression model including the test as the dependent variable and age (modelled as a cubic spline with 5 degrees of freedom (df)), sex and their interaction as independent variables was fitted. Studentised residuals were obtained, and then 0.01% of the subjects with the smallest and largest studentised residuals were removed from further analysis. Weights were computed via iterative poststratification (aka iterative proportional fitting)⁴⁷ to match the sample joint distributions by age, sex and country to population data. Country-specific population values were obtained from EUROSTAT. The sample weights were trimmed to avoid excessively large sampling variances.⁴⁷

Percentile curves and reference values were developed using generalised additive models for location, scale and shape (GAMLSS).⁴⁸ Several continuous (Box-Cox Cole and Green (BCCG), Box-Cox power exponential (BCPE), Box-Cox-*t* (BCT), generalised inverse Gaussian) distributions were fitted to the data, optimising the df for P-splines fit for all parameters of the respective distributions using Schwarz Bayesian criterion (SBC); appropriate link functions were used for the parameters. BCCG is routinely used in the lambda mu sigma (LMS) method.⁴⁹ BCPE and BCT are extensions of LMS adding an extra parameter, ν , to allow modelling (positive or negative) kurtosis (with $\nu = 2$ BCPE and BCCG (LMS) coincide). In all the models, $\lambda = 1/3$ and $\lambda = 1/2$ were used for the power transformation of age. Separate analyses were performed for boys and girls. The final model for each test and sex was determined by using SBC. The analysis was performed using R language for statistical computing (R V.3.6.3)⁵⁰; GAMLSS were fitted using R package GAMLSS⁵¹; poststratification weights were obtained using R package survey.⁵¹ The best fitting model for each test is presented in online supplemental table 2.

Table 1 Reference values (percentiles) for cardiorespiratory fitness as assessed by the 20 m shuttle run test (expressed in completed stages as a decimal) in European children and adolescents (N=1 026 077)

	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
Girls' ages (years)													
6.0–6.9	0.6	0.8	0.9	1.1	1.4	1.6	1.8	2.1	2.4	2.8	3.4	4.1	5.5
7.0–7.9	0.6	0.8	1.0	1.3	1.5	1.8	2.1	2.4	2.7	3.2	3.9	4.6	6.1
8.0–8.9	0.5	0.9	1.1	1.5	1.8	2.1	2.4	2.8	3.2	3.7	4.5	5.3	6.9
9.0–9.9	0.5	1.0	1.3	1.7	2.1	2.5	2.9	3.3	3.7	4.4	5.3	6.1	7.9
10.0–10.9	0.5	1.1	1.4	2.0	2.4	2.8	3.3	3.7	4.3	4.9	5.9	6.9	8.7
11.0–11.9	0.6	1.2	1.6	2.2	2.7	3.1	3.6	4.1	4.6	5.3	6.4	7.3	9.2
12.0–12.9	0.7	1.4	1.8	2.4	2.9	3.4	3.8	4.3	4.9	5.6	6.6	7.5	9.3
13.0–13.9	0.8	1.4	1.9	2.5	3.0	3.4	3.9	4.4	4.9	5.6	6.6	7.5	9.3
14.0–14.9	0.8	1.5	1.9	2.5	3.0	3.5	3.9	4.4	5.0	5.6	6.6	7.5	9.3
15.0–15.9	0.8	1.5	1.9	2.5	3.0	3.5	3.9	4.4	5.0	5.6	6.6	7.5	9.3
16.0–16.9	0.7	1.4	1.9	2.5	3.0	3.5	3.9	4.4	4.9	5.6	6.6	7.4	9.2
17.0–17.9	0.7	1.4	1.9	2.5	3.0	3.4	3.8	4.3	4.8	5.5	6.4	7.3	9.0
18.0–18.9	0.7	1.4	1.8	2.4	2.9	3.3	3.8	4.2	4.7	5.4	6.3	7.1	8.8
Boys' ages (years)													
6.0–6.9	0.6	0.8	0.9	1.2	1.4	1.7	2.0	2.4	2.9	3.4	4.2	5.0	6.4
7.0–7.9	0.6	0.9	1.1	1.4	1.7	2.1	2.5	2.9	3.4	4.0	4.9	5.7	7.2
8.0–8.9	0.6	1.0	1.2	1.7	2.1	2.5	3.0	3.5	4.1	4.8	5.8	6.7	8.2
9.0–9.9	0.6	1.1	1.5	2.0	2.6	3.1	3.6	4.2	4.9	5.7	6.8	7.7	9.4
10.0–10.9	0.6	1.3	1.7	2.4	3.0	3.6	4.2	4.8	5.5	6.4	7.5	8.5	10.2
11.0–11.9	0.7	1.4	2.0	2.7	3.4	4.0	4.6	5.3	6.0	6.8	8.0	9.0	10.7
12.0–12.9	0.8	1.6	2.2	3.1	3.8	4.4	5.0	5.7	6.4	7.3	8.5	9.4	11.1
13.0–13.9	0.9	1.9	2.6	3.5	4.2	4.9	5.5	6.2	7.0	7.8	9.0	9.9	11.7
14.0–14.9	1.0	2.2	2.9	3.9	4.7	5.4	6.1	6.8	7.5	8.4	9.6	10.5	12.3
15.0–15.9	1.1	2.4	3.2	4.3	5.1	5.8	6.5	7.2	7.9	8.8	10.0	11.0	12.8
16.0–16.9	1.1	2.5	3.4	4.4	5.2	6.0	6.7	7.3	8.1	8.9	10.1	11.1	12.8
17.0–17.9	1.1	2.5	3.4	4.5	5.3	6.0	6.6	7.3	8.0	8.8	10.0	10.9	12.6
18.0–18.9	1.0	2.5	3.3	4.4	5.2	5.9	6.5	7.2	7.8	8.6	9.7	10.6	12.2

Smoothed percentiles were calculated using the generalised additive model for location, scale and shape method, and weights were applied according to country population. Age at the midpoint of each interval was selected to provide percentiles. For instance, for the interval 6.0–6.9, data presented were those corresponding to an exact age of a 6.5-year-old child. P10 indicates 10th percentile; other percentiles are abbreviated accordingly. Data sources are available online (www.fitbackeurope.eu/en-us/fitness-map/) and in online supplemental table 1.

RESULTS

After cleaning and removing outliers, 7966693 test results were available, including 1026077 for the 20 m shuttle run; 787966 for handgrip strength, 1345159 for standing long jump, 1466821 for body height, 1466295 for body mass, 1464795 for BMI, and 409580 for waist circumference. These data came from 106 datasets belonging to 34 European countries, on children and adolescents aged 6 to 18 years. We originally aimed to collect data as recent as possible to obtain up-to-date reference values, preferably since 2000. Most (69%) datasets (representing 95% of all test results) were collected post-2000; however, pre-2000 data were included when post-2000 were unavailable at the country level. Using these data, we developed CRF and muscular strength reference values (tables 1–3) and corresponding percentile curves (figure 1). Reference values for body height, body mass, BMI and waist circumference are presented in online supplemental tables 3–6 and online supplemental figures 1 and 2. Percentile curves for CRF and muscular strength are higher for boys compared with girls across all ages, with differences increasing with age. The age-related increase in fitness performance tends to stabilise from age 14 years to 15 years onwards. Variation between the fittest (eg, percentiles 90–99) and least fit (eg, percentiles 1–10) is larger for boys compared with girls, particularly for the 20 m shuttle run and handgrip strength tests.

Mean country-level percentiles and rankings are shown in table 4. Country-level rankings based on mean percentiles are provided for each fitness test, as well as an average estimate for each fitness component (CRF, muscular strength) and the overall European fitness ranking. The top 5 most aerobically fit countries were Iceland, Norway, Slovenia, Denmark and Finland, and the top 5 physically strong countries were Denmark, Czech Republic, The Netherlands (only one muscular strength test available), Slovenia and Finland. Online supplemental tables 7 and 8 show the corresponding country-level mean percentile and ranking positions for body height, body mass, BMI and waist circumference.

Country comparisons according to mean percentiles are also graphically represented in figure 2, with European fitness maps for each test shown separately. The traffic light colour code was used to represent country-specific percentile ranks, with red indicating lower fitness levels, yellow indicating intermediate fitness levels and green indicating higher fitness levels. The corresponding European maps for BMI and waist circumference are presented as online supplemental figure 3. These maps are available in an interactive mode at the FitBack web platform (www.fitbackeurope.eu/en-us/fitness-map/) for boys and girls, together and separately. Visual inspection of the fitness maps shows that Southern European countries and the UK generally performed the worst. The correlation between country-level CRF and muscular strength

Table 2 Reference values (percentiles) for muscular strength as assessed by the handgrip strength test (expressed in kg, average of the maxima for both hands) in European children and adolescents (N=787 966)

	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
Girls' ages (years)													
6.0–6.9	4.2	5.6	6.3	7.2	7.8	8.3	8.8	9.3	9.9	10.7	11.8	12.9	15.5
7.0–7.9	4.7	6.4	7.3	8.4	9.1	9.7	10.4	11.0	11.7	12.6	13.9	15.3	18.4
8.0–8.9	5.2	7.4	8.5	9.8	10.7	11.4	12.2	13.0	13.8	14.9	16.6	18.1	21.9
9.0–9.9	5.8	8.4	9.7	11.3	12.3	13.3	14.1	15.1	16.1	17.3	19.3	21.1	25.6
10.0–10.9	6.7	9.7	11.3	13.0	14.3	15.3	16.3	17.4	18.5	20.0	22.2	24.3	29.3
11.0–11.9	8.0	11.6	13.3	15.3	16.8	18.0	19.1	20.3	21.6	23.2	25.7	28.1	33.7
12.0–12.9	9.5	13.6	15.5	17.8	19.3	20.7	21.9	23.2	24.6	26.4	29.1	31.6	37.8
13.0–13.9	11.1	15.5	17.7	20.0	21.7	23.1	24.5	25.8	27.3	29.2	32.0	34.7	41.1
14.0–14.9	12.4	17.1	19.3	21.8	23.5	25.0	26.4	27.8	29.3	31.2	34.1	36.9	43.4
15.0–15.9	13.1	18.0	20.2	22.8	24.6	26.0	27.4	28.8	30.4	32.3	35.2	38.0	44.6
16.0–16.9	13.4	18.4	20.8	23.4	25.1	26.6	28.0	29.4	31.0	32.9	35.8	38.6	45.2
17.0–17.9	13.7	18.9	21.3	23.9	25.7	27.2	28.6	30.0	31.5	33.4	36.3	39.1	45.7
18.0–18.9	14.3	19.6	22.0	24.6	26.4	27.9	29.2	30.6	32.2	34.1	37.0	39.7	46.3
Boys' Ages (years)													
6.0–6.9	4.8	6.4	7.1	8.0	8.7	9.2	9.8	10.3	11.0	11.7	13.0	14.1	17.1
7.0–7.9	5.5	7.3	8.3	9.4	10.2	10.9	11.5	12.2	13.0	13.9	15.4	16.8	20.3
8.0–8.9	6.2	8.5	9.6	10.9	11.9	12.7	13.5	14.3	15.3	16.4	18.2	19.9	24.0
9.0–9.9	7.0	9.5	10.8	12.4	13.5	14.5	15.4	16.4	17.5	18.8	20.9	22.8	27.4
10.0–10.9	7.8	10.7	12.1	13.9	15.2	16.3	17.4	18.5	19.7	21.3	23.6	25.8	30.9
11.0–11.9	8.9	12.2	13.9	15.9	17.4	18.7	20.0	21.2	22.7	24.4	27.1	29.6	35.3
12.0–12.9	10.2	14.1	16.1	18.5	20.3	21.8	23.3	24.8	26.5	28.5	31.7	34.6	41.1
13.0–13.9	12.2	16.9	19.3	22.2	24.4	26.2	28.0	29.8	31.8	34.3	38.0	41.4	49.0
14.0–14.9	14.9	20.3	23.2	26.7	29.2	31.4	33.5	35.6	37.9	40.8	45.1	49.0	57.4
15.0–15.9	17.7	23.8	27.0	30.9	33.6	36.0	38.3	40.6	43.2	46.3	50.9	55.0	63.7
16.0–16.9	20.2	26.7	30.1	34.1	37.0	39.5	41.9	44.3	46.9	50.1	54.8	58.9	67.6
17.0–17.9	22.4	29.1	32.6	36.7	39.7	42.2	44.6	47.0	49.7	52.9	57.5	61.6	70.0
18.0–18.9	24.4	31.2	34.8	39.0	42.0	44.5	46.9	49.4	52.0	55.2	59.7	63.7	71.9

Smoothed percentiles were calculated using the generalised additive model for location, scale and shape method, and weights were applied according to country population. Age at the midpoint of each interval was selected to provide percentiles. For instance, for the interval 6.0–6.9, data presented were those corresponding to an exact age of a 6.5-year-old child. P10 indicates 10th percentile; other percentiles are abbreviated accordingly. Data sources are available online (www.fitbackeurope.eu/en-us/fitness-map/sources) and in online supplemental table 1.

rankings was moderate ($r=0.59$) and is graphically represented in figure 3. Shaded areas represent those countries ranked in the top 10 for CRF, muscular strength or both.

DISCUSSION

Main findings in the context of previous literature

This article provides the most up-to-date and comprehensive reference values for the health-related fitness of European children and adolescents aged 6–18 years. We also provided country-level mean percentiles for each fitness component. Our overall country-level fitness rankings suggest that Northern (Denmark, Finland, Iceland and Norway) and Central Eastern European countries (Slovenia, Czech Republic and Slovakia) have the fittest children and adolescents, while Southern European countries (Spain, Italy and Greece) and the UK are comparatively less fit. Interestingly, we observed a moderate positive correlation between country-level CRF and muscular strength, indicating that despite being different fitness components, countries having higher CRF levels generally also had higher muscular strength levels. A major contribution of the present study is that it comes together with the FitBack interactive web platform (www.fitbackeurope.eu), which is free, multilingual (English, Spanish, French, German and Italian) and ready to be used by researchers and practitioners in physical education, sport and health, as well as by policy makers across Europe. FitBack can be useful

and informative even for other continents temporally until they develop their own normative values and similar web platforms. The FitBack platform provides individual and group-based fitness reports supported by educational materials for implementation of fitness monitoring to support fitness education (ie, to help understand why fitness and fitness testing are important, how to interpret fitness test results, how to set exercise goals, how to improve fitness levels, etc) and improve physical literacy, as well as interactive European fitness maps based on our reference values.

To date, the largest and best available fitness reference values for European children and adolescents were those published by Tomkinson *et al* in 2018.⁴⁰ Our study updates such work by adding new data and expanding the age range from 9 years to 17 years to 6–18 years.⁴⁰ It is challenging to directly compare the previous and current reference values, given between-study differences in included studies, countries, ages and sexes. Nevertheless, as an example, the 50th percentile values for the 20 m shuttle run ranged from 3.4 to 4.1 stages in girls aged 9–17 years and from 4.4 to 7.7 stages in boys aged 9–17 years in Tomkinson's study, with the corresponding FitBack values ranging from 2.9 to 3.8 in girls and from 3.6 to 6.6 in boys. For handgrip, the corresponding values were 13.6–28.4 kg in girls and 15.3–45.0 kg in boys in Tomkinson's study and 14.1–28.6 kg in girls

Table 3 Reference values (percentiles) for muscular strength as assessed by the standing long jump test (expressed in cm) in European children and adolescents (N=1 345 159)

	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
Girls' ages (years)													
6.0–6.9	47.4	63.3	71.1	80.2	86.5	91.9	96.8	101.6	106.9	113.0	121.5	128.8	143.0
7.0–7.9	55.1	71.1	79.0	88.3	94.8	100.3	105.5	110.6	116.0	122.5	131.6	139.3	154.6
8.0–8.9	63.1	79.1	87.2	96.7	103.4	109.0	114.3	119.5	125.2	131.9	141.4	149.6	165.8
9.0–9.9	70.8	87.0	95.1	104.8	111.6	117.3	122.7	128.1	134.0	140.9	150.8	159.2	176.3
10.0–10.9	77.2	93.8	102.3	112.2	119.2	125.2	130.8	136.4	142.5	149.7	160.0	168.9	186.8
11.0–11.9	82.9	100.6	109.6	120.1	127.6	133.9	139.9	145.8	152.3	159.9	170.9	180.4	199.6
12.0–12.9	87.3	106.2	115.7	126.9	134.8	141.6	147.8	154.1	161.0	169.1	180.7	190.7	211.1
13.0–13.9	90.2	110.1	120.1	131.9	140.2	147.2	153.7	160.3	167.4	175.8	187.9	198.3	219.4
14.0–14.9	91.1	112.0	122.3	134.4	142.9	150.1	156.8	163.5	170.8	179.4	191.6	202.2	223.5
15.0–15.9	90.7	112.0	122.5	134.8	143.3	150.5	157.2	163.9	171.2	179.7	191.8	202.3	223.4
16.0–16.9	89.7	111.4	121.9	134.2	142.7	149.8	156.5	163.1	170.2	178.6	190.5	200.7	221.3
17.0–17.9	89.9	111.8	122.4	134.7	143.1	150.3	156.8	163.3	170.3	178.6	190.3	200.3	220.3
18.0–18.9	91.1	113.3	124.0	136.2	144.6	151.6	158.1	164.6	171.5	179.6	191.0	200.8	220.3
Boys' ages (years)													
6.0–6.9	51.6	69.3	77.8	87.4	94.1	99.6	104.6	109.6	114.9	121.1	129.7	137.0	151.2
7.0–7.9	60.0	78.2	87.0	96.9	103.8	109.5	114.7	119.9	125.5	131.9	141.1	148.8	164.0
8.0–8.9	68.2	86.9	95.9	106.1	113.2	119.1	124.6	130.0	135.7	142.5	152.1	160.2	176.5
9.0–9.9	75.5	94.7	103.9	114.4	121.7	127.8	133.4	139.0	145.0	152.0	162.0	170.5	187.6
10.0–10.9	81.2	101.1	110.7	121.5	129.1	135.3	141.1	146.9	153.1	160.4	170.7	179.6	197.5
11.0–11.9	86.4	107.5	117.6	129.0	136.9	143.5	149.5	155.6	162.0	169.7	180.5	189.8	208.8
12.0–12.9	92.2	115.1	125.9	138.1	146.4	153.4	159.8	166.2	173.0	181.1	192.5	202.4	222.5
13.0–13.9	99.8	125.0	136.8	150.0	159.0	166.5	173.3	180.1	187.4	196.0	208.2	218.7	240.1
14.0–14.9	107.8	135.4	148.0	162.1	171.7	179.6	186.9	194.0	201.7	210.7	223.4	234.4	256.8
15.0–15.9	114.3	143.6	156.9	171.5	181.4	189.6	197.0	204.4	212.2	221.4	234.4	245.5	268.3
16.0–16.9	118.6	149.1	162.8	177.7	187.7	195.9	203.4	210.8	218.6	227.8	240.7	251.8	274.4
17.0–17.9	122.1	153.4	167.2	182.2	192.2	200.4	207.8	215.1	222.8	231.8	244.5	255.4	277.6
18.0–18.9	125.4	157.1	170.9	185.8	195.6	203.7	210.9	218.0	225.6	234.4	246.8	257.4	279.0

Smoothed percentiles were calculated using the generalised additive model for location, scale and shape method and weights were applied according to country population. Age at the midpoint of each interval was selected to provide percentiles. For instance, for the interval 6.0–6.9, data presented were those corresponding to an exact age of a 6.5-year-old child. P10 indicates 10th percentile; other percentiles are abbreviated accordingly. Data sources are available online (www.fitbackeurope.eu/en-us/fitness-map/sources) and in online supplemental table 1.

and 15.4–44.6 kg in boys in FitBack. Further, the corresponding values for the standing long jump test were 123.9–156.4 cm in girls and 133.8–205.8 cm in boys Tomkinson's study, and 122.7–156.8 cm in girls and 133.4–207.8 cm in boys in FitBack. Thus, the median fitness levels in the FitBack study are slightly lower than those in Tomkinson's study for the 20 m shuttle run, and nearly identical for handgrip strength and the standing long jump. These between-study differences are likely because the included datasets differ in sample size, collection time frames, country representation and sample representativeness. Tomkinson's reference values for the 20 m shuttle run were based on 445 092 data points from 24 countries (see table 9 of Tomkinson *et al* study⁴⁰), whereas the FitBack reference values were based on 1 026 077 data points from 30 European countries. The corresponding sample sizes for handgrip strength and standing long jump are n=203 295 vs 787 966 and n=464 900 vs 1 345 159 for Tomkinson *et al*'s study versus FitBack, respectively.

Usefulness and practical implications of fitness testing and monitoring

Our reference values, when integrated into the interactive FitBack web platform, have practical utility and implications. First, fitness testing and monitoring is extremely important from a public health and clinical point of view, as recently acknowledged by the American Heart Association¹³ and

others.⁵² Measuring cardiometabolic risk factors from blood samples is invasive and ethically questionable for youth at the population level. Likewise, mental and cognitive health assessments are often complex, sensitive and time consuming. Since physical fitness has repeatedly and consistently been shown to be a powerful marker of physical, mental and cognitive health in youth, fitness testing and monitoring will provide valuable insights into the health status of youth at individual and group levels. However, clinicians may not have the time, resources, facilities or expertise to conduct fitness testing (eg, the 20 m shuttle run test) in clinical settings. Therefore, we believe that the most feasible alternative and future goal is that population-level fitness testing be conducted in schools, with test results and interpretation incorporated into the healthcare system databases and forming part of an individual's medical records that can be viewed by paediatricians and school doctors/nurses. This might be even more relevant in low-to- middle-income countries. Such practice has been implemented at the regional level in Galicia, Spain,⁵³ and at the national level in Slovenia⁴⁰ and Finland.⁵⁴ In addition, our article and the interactive FitBack website provide a valuable and cost-effective solution for establishing fitness monitoring at the school, community, regional and national levels. For instance, policy makers at education, sport and health institutions can obtain valuable information about regional differences or temporal trends by monitoring

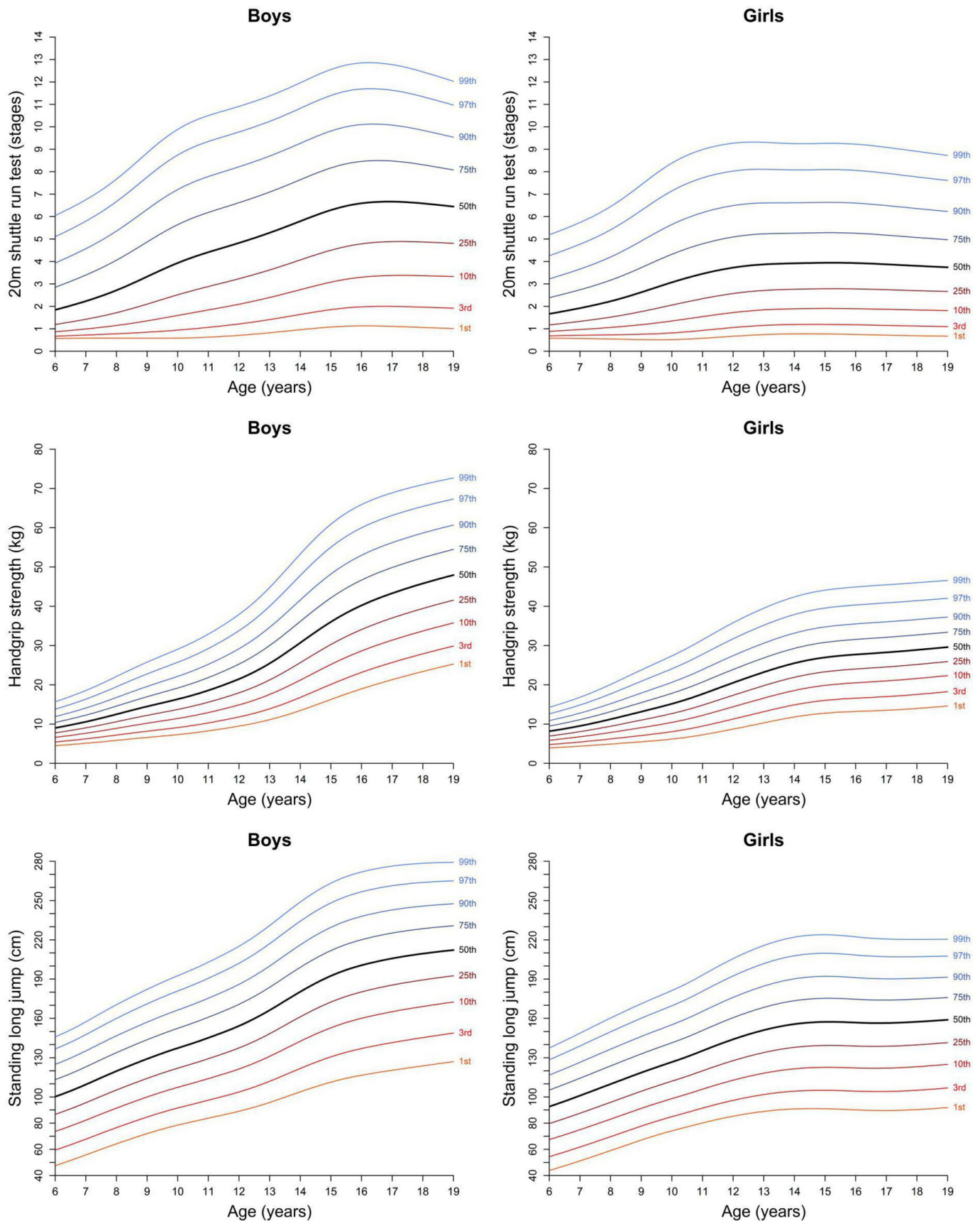


Figure 1 Percentile curves for cardiorespiratory and muscular strength tests among European children and adolescents. Smoothed percentiles were calculated using the generalised additive model for location, scale and shape method, and weights were applied according to country population. Data sources are available online (<https://www.fitbackeurope.eu/en-us/fitness-map/sources>) and in online supplemental table 1.

Table 4 Mean percentile and ranking position of each country according to the pooled EU reference values

N	20m shuttle run test												Standing long jump												Overall fitness ranking			
	Handgrip strength						Standing long jump						Handgrip strength						Standing long jump									
	Boys		Girls		Both		Boys		Girls		Both		Boys		Girls		Both		Boys		Girls		Both					
	Centile	Rank	Centile	Rank	Centile	Rank	N	Centile	Rank	Centile	Rank	Centile	Rank	N	Centile	Rank	Centile	Rank	Centile	Rank	Centile	Rank	N	Centile		Rank	Centile	Rank
ISL	6127	81.3	1	85.2	1	77.7	1	SLO	4648	75.4	1	74.8	1	75.8	1	ISL	6589	72.4	1	74.7	1	70.2	1	DEN	2	4	3	1
NOR	2302	75.3	2	76.5	2	74.2	2	DEN	5938	64.7	2	64.2	3	65.2	2	CZE	439	69.1	2	72	2	66.2	3	NET	3	-	3	1
SVN	4752	73	3	75.9	3	70.2	4	NET	1713	64.6	3	68.3	2	60.8	6	BUL	497	68	3	67.1	5	68.9	2	FIN	5	5	5	2
DEN	9178	68.9	4	67.7	5	70.8	3	BEL	18102	61.2	4	60.6	4	61.9	4	SVN	211629	66.5	4	68.4	4	64.7	5	SVN	7	3	5	2
FIN	2077	66.5	5	68.8	4	63.8	5	LIT	3188	60.1	5	56.4	6	64.4	3	FIN	1393	66	5	67.1	6	64.9	4	CZE	2	9	5.5	3
FRA	11627	61.4	6	61	8	61.9	7	KOS	742	57.6	6	52.9	10	61.7	5	CRO	22135	65.9	6	70.1	3	60.7	8	ISL	10	1	5.5	3
CYP	1058	61	7	63.7	6	58.6	10	GER	1399	55.9	7	59.9	5	52	11	SLO	5163	65.2	7	66.3	7	64.4	6	SLO	4	8	6	4
SLO	4709	60.8	8	59.1	11	62.1	6	POL	47061	55.8	8	53.2	9	58.2	7	SVI	2982	64.4	8	64.6	8	64.2	7	NOR	11	2	6.5	5
CZE	1561	60.7	9	63.2	7	58.4	11	HUN	614569	54.4	9	55.2	7	53.7	9	EST	4997	61.5	9	62.8	9	60.2	9	BUL	7	-	7	6
GER	1968	59.3	10	60.5	9	58.2	13	SVN	4828	54.1	10	54.3	8	54	8	LIT	12158	58.6	10	58.5	10	58.7	10	BEL	8.5	12	10.3	7
IRE	1055	59	11	59.8	10	58.2	12	BUL	497	51.5	11	49.3	13	53.6	10	NOR	2490	58.5	11	61.2	10	55.9	11	SVI	8	13	10.5	8
BEL	19623	57.8	12	54.8	14	60.5	8	EST	1681	51.4	12	52.5	11	50.3	14	AUS	595	56.2	12	57.5	12	54.8	12	GER	11.5	10	10.8	9
SVI	3699	56.7	13	54.7	15	57.7	15	AUS	389	50.6	13	49.6	12	51.6	12	BEL	19161	55.5	13	56.7	13	54.3	14	LIT	7.5	14	10.8	9
LIT	8397	56.3	14	57.6	12	55	16	MCD	7177	48.8	14	46	18	51.4	13	LAT	7743	54.6	14	54.5	14	54.7	13	CRO	6	16	11	10
UK	40841	55.7	15	53.5	17	57.7	15	CYP	1204	47.8	15	47.6	15	48	15	SWE	1076	53.4	15	53.4	15	53.4	15	CYP	18.5	7	12.8	11
CRO	595	55.5	16	52.5	18	58.1	14	SWE	2719	46.1	16	45	19	47.2	16	GER	5999	53.4	16	54.6	16	52.2	18	FRA	22	6	14	12
SWE	950	52.3	17	54.8	13	49.4	19	POR	7199	45.8	17	47.8	14	43.7	18	POL	47326	52.3	17	51.2	20	53.3	16	EST	10.5	18	14.3	13
EST	4647	51.1	18	53.7	16	48.6	20	GRE	688	45.4	18	46.7	16	43.9	17	LUX	1128	51.5	18	52.9	18	50.4	21	SWE	15.5	17	16.3	14
SPA	25877	48.3	19	46.4	22	50.2	17	ISL	387	44.1	19	46.4	17	42.2	19	HUN	604114	51.4	19	53.1	17	49.8	22	POL	12.5	21	16.8	15
POR	30265	47.1	20	44.3	23	50	18	LAT	7743	42.3	20	42.5	21	42.1	20	ITA	21448	51.4	20	51.8	19	50.9	19	AUS	12.5	22	17.3	16
POL	45925	46.9	21	48.1	20	45.8	22	UK	23373	42.3	21	42.9	20	41.6	21	FRA	32943	51.3	21	50.3	21	52.3	17	IRE	25	11	18	17
AUS	270	46.4	22	49.1	19	43.7	24	IRE	1149	40.3	22	40.6	22	40	24	CYP	1193	49.5	22	48.1	23	50.8	20	LUX	18	-	18	17
ITA	4084	44.6	23	43.1	24	45.9	21	FRA	813	40.1	23	38.8	25	41.5	22	ALB	2114	47.4	23	49.4	22	45.7	25	HUN	14	24	19	18
HUN	5,93,803	44.6	24	47.6	21	41.7	25	ITA	5768	39.9	24	39.3	24	40.4	23	GRE	256826	44.7	24	42.9	26	46.5	23	UK	25	15	20	19
GRE	1,76,056	44.1	25	42.7	25	45.4	23	SPA	22097	39.3	25	39.6	23	39	25	SRB	20341	44.4	25	43	25	45.9	24	POR	22	20	21	20
KOS	741	39.1	26	41.3	26	37.2	27	ALB	1984	17.7	26	16.4	26	18.8	26	SPA	27218	44.9	26	42.3	28	43.4	27	KOS	18	26	22	21
MCD	1011	38	27	36.2	28	39.7	26	BIH	-	-	-	-	-	-	POR	7715	42.5	27	40.2	30	44.9	26	SPA	25.5	19	22.3	22	
SRB	18772	36.4	28	36.5	27	36.4	28	CRO	-	-	-	-	-	-	IRE	1158	41.8	28	43.5	24	40.1	30	ITA	22	23	22.5	23	
LAT	3264	30.1	29	28.6	29	31.4	29	CZE	-	-	-	-	-	-	UK	13981	41.3	29	40.8	29	41.9	28	GRE	21	25	23	24	
BIH	843	26.3	30	24.2	30	28.3	30	FIN	-	-	-	-	-	-	KOS	742	40.8	30	42.9	27	39	31	LAT	17	29	23	24	
ALB	-	-	-	-	-	-	-	LUX	-	-	-	-	-	-	BIH	843	39.2	31	36.5	31	41.6	29	ALB	24.5	-	24.5	25	
BUL	-	-	-	-	-	-	-	NOR	-	-	-	-	-	-	MCD	1023	34.6	32	32.8	32	36.3	32	MCD	23	27	25	26	
LUX	-	-	-	-	-	-	-	SRB	-	-	-	-	-	-	DEF	-	-	-	-	-	-	-	SRB	25	28	26.5	27	
NET	-	-	-	-	-	-	-	SVI	-	-	-	-	-	-	NET	-	-	-	-	-	-	-	BIH	31	30	30.5	28	
N	1026077	-	-	-	-	-	-	N	787966	-	-	-	-	-	N	1345159	-	-	-	-	-	-	-	-	-	-	-	-

The three-digit country codes were used to abbreviate the full country names (https://en.wikipedia.org/wiki/List_of_UNDP_country_codes). For each fitness test, the countries were sorted according to their rank position in the Boys (girls and boys) column. The ranking for muscular strength was computed as the average of the country ranking position in handgrip and standing long jump tests, while ranking for cardiorespiratory fitness directly reflects the country ranking position in the 20 m shuttle run test. Sex-specific and age-specific percentile values were calculated using available country-level data and were averaged across sexes and ages to obtain the mean percentile for each country compared to the European Union reference values. Smoothed percentiles were calculated using the generalised additive model for location, scale and shape method and weights were applied according to country population. Not all countries have representative data, and therefore caution should be paid when interpreting country comparisons presented in this study and in the platform. Data sources are available online (www.fitback.eu/eu/en-us/fitness-maps/sources) and in online supplemental table 1. ALB, Albania; AUS, Austria; BEL, Belgium; BIH, Bosnia and Herzegovina; BUL, Bulgaria; CYP, Cyprus; CZE, Czech Republic; DEN, Denmark; EST, Estonia; FIN, Finland; FRA, France; GER, Germany; GRE, Greece; HUN, Hungary; IRE, Ireland; ISL, Iceland; ITA, Italy; KOS, Kosovo; LAT, Latvia; LIT, Lithuania; LUX, Luxembourg; MCD, North Macedonia; MS, muscular strength; N, sample size and total sample size at the bottom of the table; NET, Netherlands; NOR, Norway; POL, Poland; POR, Portugal; SLO, Slovakia; SPA, Spain; SRB, Serbia; SVN, Slovenia; SWE, Sweden; SVI, Switzerland.

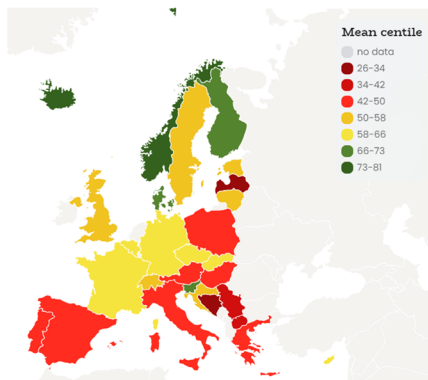
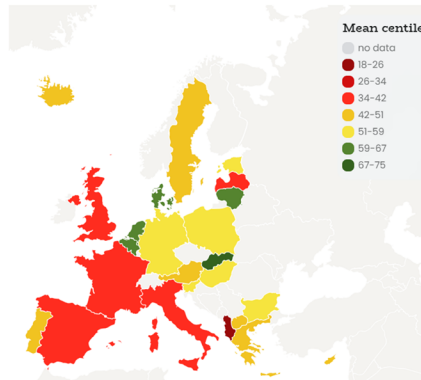
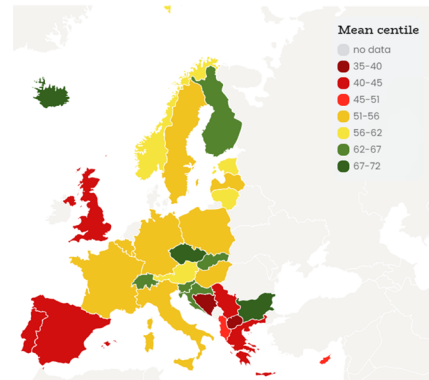
EU cardiorespiratory fitness landscape
(20-m shuttle run test)EU muscular strength landscape
(Handgrip test)EU muscular strength landscape
(Standing long jump test)

Figure 2 European fitness maps for cardiorespiratory and muscular strength in children and adolescents. Sex-specific and age-specific percentile values were calculated using available country-level data and were averaged across sexes and ages to obtain the mean percentile for each country compared with the EU reference values. Smoothed percentiles were calculated using the generalised additive model for location, scale and shape method, and weights were applied according to country population. Separate European fitness maps for girls and boys for these tests (as well as those for the obesity markers of body mass index and waist circumference) are available online (www.fitbackeurope.eu/en-us/fitness-map). The website map is interactive so that detailed information for each country is shown with the mouseover function. Not all countries have representative data, and therefore, caution should be paid when interpreting country comparisons presented in this study and in the platform. Data sources are available online (www.fitbackeurope.eu/en-us/fitness-map/sources) and in online supplemental table 1. EU, European Union.

fitness levels over time and use these reference values and the FitBack tool for proper sex-specific and age-specific interpretation. Indeed, the use of fitness surveillance to inform decision making is one of the top-ranked priorities in paediatric fitness according to international experts.⁵⁵ As a timely example, fitness monitoring can flag a sudden decline in fitness, and therefore health, due to unique/unexpected situations, such as COVID-19 pandemic-related lockdowns and the substantial, rapid declines in youth fitness levels reported in countries with fitness surveillance systems.^{56 57} Thus, interventions for specific target groups can be implemented to prevent worse deterioration of fitness levels.

Second, fitness monitoring is part of physical education curricula in many European countries, but most European teachers do not currently have access to an easy-to-use and automatic tool for interpreting sex-specific and age-specific fitness test results. With our article and the FitBack platform, we aimed to contribute to an extensive implementation of fitness monitoring across European schools. In this context, the FitBack platform also provides information to avoid undesirable practices, such as grading students based on their fitness levels and fitness competitions among students, by using fitness testing as an educational tool to facilitate learning and understanding about fitness and its importance to health and sport and setting individual goals for improvement. Such an approach to fitness testing should help improve physical literacy among European youth. Physical literacy can be defined as ‘the motivation, confidence, physical competence, knowledge and understanding to value, and take responsibility for, maintaining purposeful physical pursuits/activities throughout the life course’.⁵⁸ Despite some debate how fitness and its monitoring correspond to the physical literacy paradigm,⁵⁹ the FitBack consortium supports the interpretation that fitness and motor skills collectively represent physical competence, which is a key component of physical literacy. In line with this, some physical literacy

assessment tools (eg, Canadian Assessment for Physical Literacy and Passport For Life) assess motor skills and physical fitness for physical competence.⁵⁹ In this context, fitness testing should be much more than just ‘one more school assessment’. Schools are in a unique position to positively affect the lifelong physical activity and physical fitness levels of their students by instilling values and developing skills that will help children throughout their lives. Moreover, the FitBack network has recently been granted by Erasmus+Sport programme with a new project called ‘FitBack4Literacy’, which aims to design and test a physical literacy toolkit including the FitBack reporting system. In the next 3 years (2023–2025), this toolkit will be developed and provided in 15 European languages and made freely available on the FitBack platform. Thus, the FitBack platform will have greater potential to be transformed in pedagogical practice by physical education teachers as well as generalist teachers who also conduct physical education classes in the early schooling years. Thus, enhancing physical fitness through goal setting and an appropriate physical activity programme and tracking individual changes through fitness monitoring may improve students’ physical literacy journey. Those with better fitness education may be more attuned to their body and what is required for good function, and may be able to foster lifelong physical activity habits.

Third, our reference values can be used for sport/athletic profiling and monitoring, as well as talent identification and development.^{43 60} Youth who have fitness levels above the 90th percentiles may be considered talented in certain fitness components, and sports participation could be promoted to them and their family. Likewise, changes in fitness levels in response to a lifestyle intervention could be tracked against our sex-specific and age-specific percentile bands to identify expected, better than expected or worse than expected developmental changes.

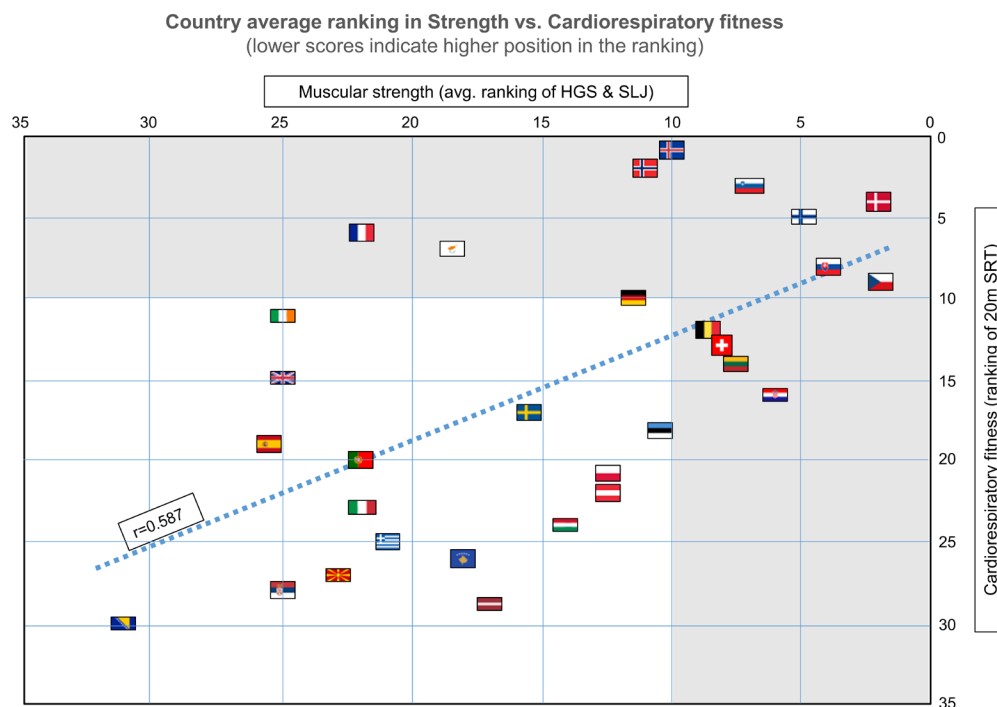


Figure 3 Country average ranking in muscular strength and CRF in European children and adolescents. CRF in European children and adolescents. The ranking for muscular strength was computed as the average of the country ranking position in HGS and SLJ tests, while ranking for CRF directly reflects the country ranking position in the 20mSRT. Grey shaded areas indicate countries ranked in the top 10 for either muscular strength, CRF or both. This figure was created based on the data presented in table 4. Four countries (Albania, Bulgaria, Luxembourg and The Netherlands) were not included since they had either missing muscular strength or CRF data. Not all countries have representative data and therefore caution should be paid when interpreting country comparisons presented in this study and in the platform. Data sources are available online (www.fitbackeurope.eu/en-us/fitness-map/sources) and in online supplemental table 1. 20mSRT, 20 m shuttle run test; CRF, cardiorespiratory fitness; HGS, handgrip strength; SLJ, standing long jump.

Limitation and strengths

While the FitBack network gathered roughly 8 million test results for the development of new health-related reference values, the included data are not representative of all European youth. Some countries such as Slovenia, Hungary and Portugal (www.fitbackeurope.eu/en-us/monitoring-fitness/best-practice) have established fitness monitoring systems that cover all school ages and all country regions. Other countries such as Greece⁶¹ and Poland⁶² have conducted nationally representative fitness testing at particular points in time, while most European countries do not have nationally representative fitness data available. This implies that our country-level comparisons should be taken cautiously, given that not all data are representative of their source populations. Our ambition was to identify the best available and most recent data (using the ALPHA fitness tests) for each country to update existing CRF and muscular strength reference values, and to strengthen the evidence supporting the FitBack platform. Unfortunately, included fitness data were collected at different times, and temporal trends in fitness may have biased our results. To minimise the potential for bias, old data collected in the 1980s were excluded from our analyses (see online supplemental table 1). Only harmonised cross-country testing at the same time will provide the most accurate comparisons. While not nationally representative, the HELENA study collected harmonised fitness data in 2005–2008 across 10 European cities, and the results suggested that adolescents living in Southern Europe (Spain, Italy and Greece) had lower levels

of CRF and muscular strength, as well as more total and central adiposities, than their peers living in Central Northern Europe.⁶³ These findings are consistent with the FitBack results hereby presented and are in line with previous reports.^{64 65} Another limitation of our study is the protocol variation across studies. In order to improve this moving forward, we recommend researchers use the ALPHA fitness test battery manuals of operations and explanatory videos that are freely available (<http://profith.ugr.es/alpha-children> available in English and Spanish), and which have been incorporated into the FitBack platform (www.fitbackeurope.eu/en-us/make-report/about-testing). Finally, while we obtained data from 77% (34/44) of European countries (<https://www.schengenvisa.info/countries-in-europe/>), additional data are required from the remaining countries to paint a complete European fitness picture. On the other hand, there are some important strengths/contributions from our study and the FitBack network, including (1) the development of the largest and most up-to-date fitness reference values for school-age Europeans; (2) increased awareness of the importance of fitness surveillance and monitoring; (3) the identification of countries that have access to large fitness databases and those which do not, and (4) to facilitate fitness testing and interpretation through the FitBack platform, which we hope will improve the amount, quality and availability of future fitness data. All these points can add to ongoing international initiatives such as country report cards to support the Active Healthy Kids Global Matrix (<https://www.activehealthykids.com/>).

org/global-matrix/), which now includes physical fitness as a core indicator.

CONCLUSION

There is overwhelming evidence supporting the importance of fitness testing from a health, educational and sport point of view. Further, the EU-funded ALPHA project identified the most reliable and valid fitness tests, providing the methods (manuals of operations and videos) needed to evaluate youth health-related fitness levels in a standardised manner across Europe. Now, the FitBack project provides the scientific and practitioner communities with the steps needed for the implementation of youth-based fitness assessment and interpretation in school or sporting settings across Europe. Our sex-specific and age-specific reference values have practical implications and are the foundation of the FitBack platform for interactive individual and group-based interpretation of fitness levels. These reference values should be revisited in the future as more countries introduce national surveillance systems to reflect the updated fitness levels of European youth. The FitBack network, therefore, welcomes new members and is searching for missing and new fitness data.

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Acknowledgements The authors acknowledge the support of all FitBack network members who provided data on physical fitness of children and adolescents (see www.fitbackeurope.eu/en-us/fitness-map/sources and online supplemental table 1), including also large European Union-funded consortium projects such as HELENA and IDEFICS. We thank D Mayorga-Vega for his assistance on obtaining the fitness data from Poland.

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Funding This research was co-funded by the Erasmus+ Sport Programme of the European Union within the project FitBack No 613010-EPP-1-2019-1-SI-SPO-SCP and Slovenian Research Agency within the Research programme Bio-psycho-social context of kinesiology (number P5-0142). FBO, JIG-C, JRR and IL are supported by the University of Granada, Plan Propio de Investigación, Visiting Scholar grants and Excellence actions: Units of Excellence; Unit of Excellence on Exercise, Nutrition and Health and by the Junta de Andalucía, Consejería de Conocimiento, Investigación y Universidades and European Regional Development Fund (SOMM17/6107/UGR) and CIBERobn Physiopathology of Obesity and Nutrition.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants. The entire Fitback procedures for pooling together existing fitness data were evaluated and approved by the ethics committee in sports science at the University of Ljubljana, Slovenia (the University coordinator the FitBack project). The participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. This article includes data from more than 100 datasets. Data sharing permission should be requested to the researchers of each individual dataset. References for each dataset can be found in online supplemental table 1.

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ONLINE SUPPLEMENTARY MATERIAL

European Fitness Landscape for Children and Adolescents: updated reference values, fitness maps, and country rankings based on nearly 8 million test results from 34 countries gathered by the FitBack network

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Online Supplementary Table 1. Summary of the sources used for generating the FitBack reference values and centiles.

Country	Year of testing	% male	Age (years)	Sample size					Reference
				BMI	WC	20mSRT	SLJ	HGS	
Albania	1994-95	53.7%	10–18	2,115			2,114	1,984	Markola et al. 1997 *
Austria	2006-08	48.9%	13–18	425	415	269	390	388	Ortega et al. 2011
Austria	2015-17	48.0%	8–10	204			204		Greier et al. 2019
Belgium	2006-08	46.4%	13–18	343	337	332	334	337	Ortega et al. 2011
Belgium	2007	53.0%	6–14	2,893	2,689	2,373	2,795	2,800	Vandendriessche et al. 2012
Belgium	2007-08	48.5%	6–10			650	707	705	De Miguel-Etayo et al. 2014
Belgium	1997	58.0%	13–18	515		554	561	262	Baquet et al. 2000 *
Belgium	2002?	48.9%	10–11	591		591	591	591	Cardon et al. 2004 *
Belgium	1994-04	51.9%	11–18	6,493		6,418	6,526	6,537	Heyters & Marique 2004 *
Belgium	1993-97	49.9%	13–18	5,683		5,535	5,660	5,690	Lefèvre et al. 1998 *
Belgium	2005	44.8%	13–18	3,135					Matton et al. 2007 *
Belgium	1994-95	52.5%	13–16	2,225		2,225	895		Telama et al. 2002 *
Belgium	2002-04	49.1%	10–13	1,055		1,055	1,055	1,055	Verstraete et al. 2007 *
Bosnia and Herzegovina	2015-16	52.3%	12–15	843		843	843		Budimlic et al. 2016
Bulgaria	1998-99	52.5%	10–18	497			497	497	Dimitrova, 2001 *
Crete	2006-08	47.4%	12–18	336	324	192	319	327	Ortega et al. 2011
Croatia	2015	50.5%	15–18	794	820	596	505		Štefan et al. 2017
Croatia	2015-18	51.6%	6–8	1200			349		Šalaj et al. 2018
Croatia	2019	44.6%	16–18	1,036	1,033		1,036		Zvonar et al. 2019
Croatia	2008-09	44.8%	11–18	20,616			20,594		Štefan et al. 2021
Cyprus	2007-08	51.3%	6–10			1,111	1,173	1,184	De Miguel-Etayo et al. 2014
Czechia	2013-16	51.3%	12–18	1,154		1,086			Rubín et al. 2018 *
Czechia	1994-95	51.0%	13–16	439		439	439		Telama et al. 2002 *
Denmark	2008	47.5%	6–16	1,009	1,010			5,904	Hébert et al. 2020

Denmark	1996-97	39.6%	16–18			9,342			Nielsen & Andersen, 2003 *
Estonia	2017	47.0%	13–14			142	155	158	Sepp et al. 2017
Estonia	2018-	49.9%	8–11	212				215	10.23736/S0022-4707.20.10550-4
Estonia	2016-	51.7%	7–9	256	256	222	226	226	Riso et al. 2019
Estonia	2016	50.9%	8–9	145	146	136	137	137	Reisberg et al. 2020
Estonia	2018-	56.4%	13–17	413	413	413	413	413	Galan-Lopez et al. 2019
Estonia	2017	51.5%	12–18	3,052		3,056	3,103		https://www.sportest.eu/
Estonia	2007-08	47.5%	6–9			725	745	745	De Miguel-Etayo et al. 2014
Finland	2013	47.6%	9–15	970	970				Joensuu et al. 2020
Finland	2007-09	51.3%	9–11	374	374		374		Lintu et al. 2015
Finland	1995	46.6%	13–16	1,109		1,109	1,019		Telama et al. 2002 *
France	2006-08	42.2%	12–17	307	308	258	304	306	Ortega et al. 2011
France	2009-13	49.8%	9–16	9,669		10,862			Vanhelst et al. 2016
France	2010-18	51.0%	6–18	31,748			31,748		Vanhelst et al. 2020
France	1997	50.7%	12–15	507		507	507	507	Baquet et al. 2001 *
Germany	2006-08	58.9%	12–18	495	473	392	433	445	Ortega et al. 2011
Germany	2009-12	50.0%	6–18	3,039	3,023		3,043		Niessner et al. 2020
Germany	2007-08	48.3%	6–10			638	944	952	De Miguel-Etayo et al. 2014
Germany	1994-95	51.0%	13–16	977		977	863		Telama et al. 2002 *
Greece	2014	51.5%	6–18	306,217	304,619	176,844	256,026		Tambalis et al. 2015
Greece	2006-08	48.6%	12–18	369	366	346	359	361	Ortega et al. 2011
Hungary	2006-08	49.5%	13–17	397	393	393	394	395	Ortega et al. 2011
Hungary	2013,2019	51.1%	10–18	580,056		574,375	581,464	591,669	Csányi et al. 2014 **
Hungary	2007-08	49.6%	6–10			548	1,230	1,228	De Miguel-Etayo et al. 2014
Hungary	1994-95	48.7%	13–16	439		439	434		Telama et al. 2002 *
Iceland	2017	54.0%	12–16	387	387	387	387	387	Galan-Lopez et al. 2018
Iceland	1998	51.8%	10–16			6,130	6,202		Gunnarsson & Sigríksson 1999 *
Ireland	2018-19	49.9%	12–16	1,147		1,002	1,158	1,149	O’Keeffe et al. 2020
Italy	2006-08	38.8%	13–18	321	320	263	266	268	Ortega et al. 2011
Italy	2001-02	55.2%	6–18	4,456					Lovecchio & Zago. 2019

	2004-05								
	2007-08								
	2009-10								
	2010-11								
	2011-12								
Italy	2001-02	48.7%	12–14	6,197			5,898		
	2004-05								
	2007-08								
	2009-10								
	2010-11								
	2011-12								Lovecchio & Zago, 2019
Italy	2001-02	50.9%	12–14	558					
	2004-05								
	2007-08								
	2009-10								
	2010-11								
	2011-12								Lovecchio & Zago, 2019
Italy	2004-13	53.0%	12–16	3,331			3,331		Lovecchio et al. 2019
Italy	2004-13	51.5%	6–18	4,376			3,705		Lovecchio et al. 2019
Italy	2004-13	48.4%	6–18	629			510		Lovecchio et al. 2020
Italy	2013	62.5%	13–18	789	722	634	738	770	Jemni et al. 2017
Italy	2013-14	49.5%	8–10	99			99	99	Colella et al. 2019
Italy	2007-08	50.2%	6–9				1,160	1,147	De Miguel-Etayo et al. 2014
Italy	1997	52.9%	13–18	3,638		3,203	3,740	3,415	Cilia et al. 1997 *
Kosovo	2016-17	52.8%	12–18	742		742	742	742	Berisha & Çilli, 2018 *
Latvia	2004-09	53.6%	10–18	7,743		3,400	7,743	7,743	Sauka et al. 2010 *
Lithuania	2002, 2012	53.6%	11–18	5,339		5,228	5,600		Venckunas et al. 2018
Lithuania	2016	49.8%	7–11	3,214			3,368		Emeljanovas et al. 2020
Lithuania	1992	46.4%	12–18	3,188		3,188	3,188	3,188	Jūrimāe & Volbekiene, 2006 *
Luxembourg	2003-06	55.1%	9–18				1,128		Woll et al. 2011
Montenegro	2018-19	51.5%	6–18	5,877	3,601				NCD-RisC, 2020
Netherlands	2017-19	48.9%	8–14					1,713	Anselma et al., 2021
North Macedonia	2012	51.4%	6–11	1,156	1,153	1,159	1,159	1,157	Gontarev et al. 2018

North Macedonia	2012	51.1%	10–15					6,156	Gontarev & Ruzdija, 2014 *
Norway	2004	51.9%	14–16	2,604		2,305	2,490		Haugen et al. 2013 *
Poland	2009-10	51.7%	6–18	47,404		45,925	47,326	47,061	Dobosz et al. 2015
Portugal	2008	48.4%	10–18	22,004	21,982	22,004			Santos et al. 2014
Portugal	2018	48.6%	10–18	8,700	8,635	8,289	7,714	7,198	Unpublished data
Serbia	2012-13	48.1%	9–18	20,677		18,778	20,341		Milanovic et al. 2019
Slovakia	1993	49.9%	15–15	689		689	689	689	Belej et al. 1995 *
Slovakia	1996	52.0%	12–15	368		287	323	329	Kasa & Majherová, 1997 *
Slovakia	1993-95	0.0%	16–16	95		111	95		Kyselovicová O. 2000 *
Slovakia	1993	59.7%	10–18	3,630		3,630	3,630	3,630	Moravec et al. 1996 *
Slovakia	2014-15	51.9%	10–12	426			426		Krska et al. 2015 *
Slovenia	2013-14	50.6%	6–18	4,745	4,688	4,598	4,670	4,673	Morrison et al. 2021
Slovenia	2018	50.9%	6–18	210,037			206,804		Sorić et al. 2020
Spain	2006-08	48.2%	12–17	413	414	308	397	398	Ortega et al. 2011
Spain	2012-20	49.5%	6–18	14,645	13,952	13,450	14,129	14,155	Iglesias-Soler et al. 2021
Spain	2018	49.4%	9–11	173	173	171	171	173	Cadenas-Sánchez et al. 2021
Spain	2017	48.1%	9–12	558	557	551	554	555	Martínez-Vizcaíno et al. 2022
Spain	2013-14	46.5%	6–7	518	519	522	519		Martínez-Vizcaíno et al. 2020
Spain	2010	50.5%	8–12	1,122		1,061	1,116	1,118	Torrijos-Niño et al. 2014
Spain	2019	52.0%	8–16	284	284	284	289	289	Medrano et al. 2020
Spain	2010-11	51.5%	10–18	905	774	889	879		Unpublished data
Spain	2011-12	51.9%	6–18	2,179	2,178	2,128	2,172	2,173	Castro-Piñero et al., 2014
Spain	2000-02	48.4%	12–18	2,474	2,468	2,087	2,431	2,427	Ortega et al. 2005
Spain	2007-08	47.9%	6–10			38	689	712	De Miguel-Etayo et al. 2014
Sweden	2006-08	39.8%	12–18	361	356	255	306	310	Ortega et al. 2011
Sweden	2007-08	48.8%	6–10			677	750	659	De Miguel-Etayo et al. 2014
Sweden	2001	51.6%	11–17	1,726				1,739	Örjan et al. 2005 *
Switzerland	2004	48.3%	6–13	496	491	501			Meyer et al. 2014
Switzerland	1996-97	49.5%	10–18			2,959	2,982		Cauderay et al. 2000 *
Switzerland	2005	47.9%	12–12	265		265			Shmid et al. 2007

United Kingdom	2006-10	53.4%	9–18	9,642	9,619	9,162	9,397	Sandercock et al. 2012
United Kingdom	1999-10	51.0%	10–11			27,954		Boddy et al. 2012 *
United Kingdom	2000-03	46.5%	10–13	13,152		3,466	13,152	Ridgers et al. 2006 *
United Kingdom	2009-10	51.3%	10–12			821	829	824 Ranson et al. 2015 *

20mSRT indicates the 20-m shuttle run test; HGS, handgrip strength; SLJ, standing long jump; BMI, body mass index; WC, waist circumference

*Pseudodata generated from Tomkinson et al. [40]. ** Database included the NETFIT national dataset from 2019.

Online Supplementary Table 2. Generalized Additive Model for Location, Scale and Shape (GAMLSS) models used to calculate the physical fitness smoothed percentiles.

Test	Sex	Distribution	n	λ	μ	σ	ν	τ	SBC
20mSRT	Girls	BCPE	516,811	1/3	6.16	5.30	3.94	3.39	99,786,154
20mSRT	Boys	BCPE	546,274	1/2	6.67	5.68	4.13	3.43	123,204,436
HGS	Girls	BCT	404,897	1/2	8.26	5.01	2.94	2.66	158,351,826
HGS	Boys	BCT	422,230	1/2	8.32	5.22	3.05	2.41	181,302,718
SLJ	Girls	BCT	677,639	1/2	9.60	5.42	2.84	2.19	269,865,621
SLJ	Boys	BCT	706,134	1/2	9.97	5.42	2.77	2.30	286,593,503
BH	Girls	BCT	717,911	1/2	15.37	5.54	2.10	2.17	211,746,507
BH	Boys	BCT	741,823	1/2	15.28	5.61	2.12	2.12	229,117,658
BM	Girls	BCT	717,526	1/2	9.66	5.52	2.88	2.13	225,657,454
BM	Boys	BCPE	741,678	1/2	9.61	5.61	2.95	3.73	245,281,509
BMI	Girls	BCT	716,750	1/2	10.54	5.57	2.69	2.08	160,587,571
BMI	Boys	BCT	740,973	1/2	10.69	5.63	2.71	2.06	170,674,420
WC	Girls	BCPE	197,832	1/2	10.62	5.20	2.38	3.37	150,768,194
WC	Boys	BCPE	205,870	1/2	10.75	5.15	2.37	3.43	159,088,298

20mSRT indicates 20-m shuttle run test; HGS, handgrip strength; SLJ, standing long jump; BH, body height; BM, body mass; BMI, body mass index; WC, waist circumference; BCT, Box-Cox t distribution; BCPE, Box-Cox power exponential; SBC, Schwarz Bayesian criterion. Parameters of the fitted distribution are lambda (λ), mu (μ), sigma (σ), nu (ν) and tau (τ)

Online Supplementary Table 3. Reference values (centiles) for body height (cm) in European children and adolescents (N=1,466,821)

Girls Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	107.6	111.5	113.4	115.7	117.3	118.7	120.0	121.3	122.7	124.4	127.0	129.2	133.9
7.0-7.9 yrs	112.7	116.9	119.0	121.4	123.2	124.7	126.1	127.5	129.0	130.9	133.5	135.9	140.8
8.0-8.9 yrs	117.5	122.0	124.3	127.0	128.9	130.5	132.1	133.6	135.3	137.3	140.2	142.7	147.9
9.0-9.9 yrs	121.7	126.6	129.1	132.0	134.1	135.9	137.6	139.3	141.1	143.3	146.4	149.1	154.6
10.0-10.9 yrs	125.9	131.2	133.9	137.0	139.3	141.2	143.0	144.8	146.7	149.0	152.4	155.2	161.0
11.0-11.9 yrs	132.4	137.9	140.7	144.0	146.3	148.3	150.2	152.1	154.1	156.5	159.9	162.8	168.7
12.0-12.9 yrs	137.9	143.4	146.1	149.4	151.7	153.7	155.5	157.4	159.4	161.7	165.0	167.9	173.5
13.0-13.9 yrs	143.0	148.2	150.9	154.1	156.3	158.2	159.9	161.7	163.6	165.9	169.0	171.8	177.1
14.0-14.9 yrs	146.1	151.2	153.8	156.8	158.9	160.8	162.5	164.2	166.0	168.1	171.2	173.8	178.8
15.0-15.9 yrs	148.0	152.9	155.4	158.4	160.5	162.3	163.9	165.6	167.4	169.5	172.4	174.9	179.8
16.0-16.9 yrs	148.7	153.5	156.0	158.9	161.0	162.8	164.4	166.0	167.8	169.9	172.8	175.2	179.9
17.0-17.9 yrs	149.2	154.0	156.5	159.4	161.5	163.2	164.8	166.5	168.2	170.2	173.1	175.5	180.1
18.0-18.9 yrs	150.0	154.8	157.2	160.1	162.2	163.9	165.5	167.1	168.8	170.8	173.6	176.0	180.6
Boys Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	108.5	112.4	114.4	116.7	118.3	119.7	121.0	122.4	123.8	125.6	128.1	130.4	135.3
7.0-7.9 yrs	113.8	117.9	120.0	122.4	124.2	125.7	127.1	128.5	130.0	131.9	134.6	137.0	141.9
8.0-8.9 yrs	118.7	123.1	125.4	128.0	129.9	131.5	133.1	134.6	136.2	138.2	141.1	143.6	148.7
9.0-9.9 yrs	122.8	127.5	129.9	132.8	134.9	136.6	138.3	139.9	141.7	143.8	146.9	149.5	154.8
10.0-10.9 yrs	125.8	131.0	133.6	136.7	138.9	140.8	142.6	144.4	146.3	148.6	151.8	154.6	160.1
11.0-11.9 yrs	130.5	136.2	139.0	142.5	144.9	147.0	148.9	150.9	153.0	155.5	159.0	161.9	167.8
12.0-12.9 yrs	135.0	141.1	144.3	148.0	150.6	152.9	154.9	157.0	159.3	161.9	165.6	168.7	174.9
13.0-13.9 yrs	141.4	147.8	151.1	155.0	157.7	160.0	162.2	164.4	166.7	169.4	173.2	176.4	182.5
14.0-14.9 yrs	148.3	154.7	157.9	161.7	164.4	166.7	168.8	170.9	173.2	175.8	179.5	182.6	188.6
15.0-15.9 yrs	154.0	160.1	163.2	166.8	169.4	171.5	173.6	175.6	177.7	180.2	183.7	186.6	192.1
16.0-16.9 yrs	157.6	163.3	166.3	169.7	172.2	174.2	176.1	178.0	180.0	182.4	185.6	188.3	193.5
17.0-17.9 yrs	159.6	165.2	168.0	171.3	173.7	175.6	177.5	179.3	181.2	183.4	186.6	189.1	194.0
18.0-18.9 yrs	161.0	166.5	169.3	172.5	174.8	176.7	178.5	180.3	182.1	184.3	187.3	189.8	194.5

Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population. Age at the midpoint of each interval was selected to provide percentiles. For instance, for the interval 6.0–6.9, data presented were those corresponding to an exact age of a 6.5-year-old child. P10 indicates 10th percentile; other percentiles are abbreviated accordingly. Data sources are available at: www.fitbackeurope.eu/en-us/fitness-map/sources.

Online Supplementary Table 4. Reference values (centiles) for body mass (kg) in European children and adolescents (N=1,466,295)

Girls Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	16.3	17.8	18.7	19.9	20.9	21.9	22.8	23.8	25.0	26.6	29.2	31.7	38.0
7.0-7.9 yrs	17.8	19.7	20.8	22.3	23.5	24.6	25.8	27.1	28.6	30.5	33.7	36.8	44.6
8.0-8.9 yrs	19.6	21.9	23.3	25.1	26.6	28.0	29.4	30.9	32.7	35.1	39.0	42.8	52.3
9.0-9.9 yrs	21.5	24.2	25.8	28.0	29.8	31.4	33.1	34.9	37.1	39.9	44.4	49.0	60.2
10.0-10.9 yrs	23.5	26.7	28.6	31.2	33.2	35.1	37.0	39.1	41.6	44.8	50.1	55.3	68.3
11.0-11.9 yrs	26.2	29.9	32.1	35.1	37.4	39.5	41.7	44.1	46.9	50.5	56.4	62.3	77.0
12.0-12.9 yrs	29.6	33.8	36.2	39.4	42.0	44.3	46.6	49.2	52.1	56.0	62.2	68.4	84.0
13.0-13.9 yrs	33.5	38.0	40.5	43.9	46.5	48.9	51.2	53.8	56.8	60.7	66.9	73.2	88.8
14.0-14.9 yrs	36.7	41.4	44.0	47.4	49.9	52.3	54.6	57.1	60.0	63.8	69.9	75.9	91.2
15.0-15.9 yrs	38.9	43.6	46.2	49.5	52.0	54.3	56.5	59.0	61.7	65.4	71.2	77.1	92.4
16.0-16.9 yrs	40.0	44.9	47.5	50.7	53.2	55.4	57.6	59.9	62.6	66.2	72.0	77.9	93.7
17.0-17.9 yrs	40.6	45.5	48.1	51.4	53.8	56.0	58.1	60.4	63.1	66.6	72.5	78.5	95.5
18.0-18.9 yrs	40.8	45.9	48.5	51.8	54.2	56.3	58.4	60.7	63.4	66.9	72.8	79.2	97.9

Boys Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	16.7	18.3	19.2	20.5	21.5	22.4	23.3	24.2	25.4	27.0	29.6	32.3	39.5
7.0-7.9 yrs	18.4	20.3	21.4	22.9	24.1	25.2	26.3	27.5	29.0	30.9	34.1	37.4	45.8
8.0-8.9 yrs	20.3	22.5	23.8	25.6	27.1	28.5	29.8	31.3	33.1	35.5	39.4	43.3	53.1
9.0-9.9 yrs	22.1	24.6	26.2	28.3	30.1	31.7	33.4	35.2	37.3	40.1	44.7	49.3	60.4
10.0-10.9 yrs	23.7	26.7	28.5	31.0	33.0	34.9	36.8	39.0	41.5	44.8	50.1	55.3	68.0
11.0-11.9 yrs	25.8	29.3	31.4	34.3	36.7	38.9	41.1	43.6	46.5	50.3	56.5	62.5	77.0
12.0-12.9 yrs	28.6	32.6	35.0	38.4	41.1	43.6	46.1	48.9	52.1	56.4	63.3	70.1	86.4
13.0-13.9 yrs	32.4	37.0	39.8	43.6	46.6	49.3	52.0	55.0	58.5	63.1	70.6	78.0	95.7
14.0-14.9 yrs	36.9	42.1	45.3	49.4	52.5	55.4	58.2	61.3	64.9	69.7	77.5	85.1	103.5
15.0-15.9 yrs	41.4	47.0	50.3	54.6	57.8	60.8	63.6	66.6	70.2	75.0	82.8	90.5	109.0
16.0-16.9 yrs	44.8	50.6	54.0	58.4	61.7	64.6	67.3	70.3	73.8	78.5	86.2	93.9	112.3
17.0-17.9 yrs	47.1	53.0	56.5	60.8	64.1	67.0	69.7	72.6	76.1	80.7	88.4	95.9	114.3
18.0-18.9 yrs	48.8	54.8	58.2	62.6	65.8	68.7	71.4	74.3	77.7	82.3	89.9	97.5	116.0

Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population. Age at the midpoint of each interval was selected to provide percentiles. For instance, for the interval 6.0–6.9, data presented were those corresponding to an exact age of a 6.5-year-old child. P10 indicates 10th percentile; other percentiles are abbreviated accordingly. Data sources are available at: www.fitbackeurope.eu/en-us/fitness-map/sources.

Online Supplementary Table 5. Reference values (centiles) for body mass index (kg/m²) in European children and adolescents (N=1,464,795)

Girls Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	12.3	13.2	13.7	14.3	14.9	15.4	15.8	16.4	17.0	17.8	19.1	20.4	23.4
7.0-7.9 yrs	12.4	13.3	13.8	14.6	15.2	15.7	16.3	16.8	17.5	18.5	19.9	21.4	25.1
8.0-8.9 yrs	12.6	13.6	14.2	15.0	15.7	16.3	16.9	17.5	18.3	19.4	21.0	22.7	27.0
9.0-9.9 yrs	12.9	14.0	14.6	15.5	16.2	16.8	17.5	18.2	19.1	20.2	22.0	23.9	28.7
10.0-10.9 yrs	13.1	14.2	14.9	15.9	16.6	17.3	18.0	18.8	19.7	20.9	22.8	24.8	30.0
11.0-11.9 yrs	13.4	14.6	15.4	16.3	17.1	17.8	18.5	19.3	20.3	21.5	23.6	25.7	31.3
12.0-12.9 yrs	13.9	15.2	15.9	16.9	17.7	18.5	19.2	20.0	21.0	22.3	24.4	26.6	32.3
13.0-13.9 yrs	14.6	15.9	16.7	17.7	18.5	19.2	20.0	20.8	21.8	23.1	25.2	27.4	33.2
14.0-14.9 yrs	15.2	16.5	17.3	18.3	19.1	19.8	20.6	21.4	22.4	23.6	25.7	27.9	33.8
15.0-15.9 yrs	15.5	16.9	17.7	18.7	19.5	20.2	21.0	21.8	22.7	24.0	26.0	28.2	34.1
16.0-16.9 yrs	15.8	17.2	18.0	19.0	19.8	20.5	21.2	22.0	22.9	24.2	26.2	28.4	34.5
17.0-17.9 yrs	15.9	17.3	18.1	19.1	19.9	20.6	21.3	22.1	23.0	24.3	26.3	28.5	35.0
18.0-18.9 yrs	15.9	17.4	18.1	19.1	19.9	20.6	21.3	22.1	23.0	24.2	26.3	28.6	35.4

Boys Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	12.7	13.5	13.9	14.5	15.0	15.5	15.9	16.4	17.0	17.8	19.1	20.4	23.7
7.0-7.9 yrs	12.7	13.6	14.1	14.7	15.3	15.8	16.3	16.8	17.5	18.4	19.9	21.4	25.4
8.0-8.9 yrs	12.9	13.8	14.4	15.1	15.7	16.3	16.9	17.5	18.2	19.2	20.9	22.7	27.4
9.0-9.9 yrs	13.2	14.2	14.8	15.6	16.2	16.8	17.5	18.2	19.0	20.1	22.0	23.9	29.3
10.0-10.9 yrs	13.4	14.4	15.1	15.9	16.6	17.3	18.0	18.7	19.6	20.8	22.9	25.0	31.1
11.0-11.9 yrs	13.6	14.7	15.4	16.3	17.1	17.8	18.5	19.3	20.3	21.6	23.8	26.1	32.7
12.0-12.9 yrs	14.0	15.1	15.9	16.8	17.6	18.3	19.1	19.9	20.9	22.3	24.5	26.9	33.8
13.0-13.9 yrs	14.4	15.7	16.4	17.4	18.2	19.0	19.7	20.6	21.6	23.0	25.3	27.7	34.5
14.0-14.9 yrs	15.0	16.3	17.0	18.1	18.9	19.6	20.4	21.3	22.3	23.6	25.9	28.3	35.1
15.0-15.9 yrs	15.5	16.9	17.7	18.7	19.5	20.3	21.1	21.9	23.0	24.3	26.6	29.0	35.7
16.0-16.9 yrs	16.0	17.4	18.2	19.3	20.1	20.9	21.7	22.5	23.5	24.9	27.2	29.5	36.2
17.0-17.9 yrs	16.3	17.7	18.6	19.6	20.5	21.3	22.1	22.9	23.9	25.3	27.5	29.9	36.6
18.0-18.9 yrs	16.5	18.0	18.9	20.0	20.8	21.6	22.4	23.2	24.2	25.6	27.8	30.2	37.0

Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population. Age at the midpoint of each interval was selected to provide percentiles. For instance, for the interval 6.0–6.9, data presented were those corresponding to an exact age of a 6.5-year-old child. P10 indicates 10th percentile; other percentiles are abbreviated accordingly. Data sources are available at: www.fitbackeurope.eu/en-us/fitness-map/sources.

Online Supplementary Table 6. Reference values (centiles) for waist circumference (cm) in European children and adolescents (N=409,580)

Girls Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	45.2	47.9	49.5	51.6	53.2	54.7	56.1	57.7	59.4	61.7	65.2	68.5	76.0
7.0-7.9 yrs	46.5	49.4	51.1	53.4	55.2	56.9	58.6	60.5	62.5	65.2	69.3	73.1	81.5
8.0-8.9 yrs	48.0	51.0	52.8	55.3	57.4	59.3	61.3	63.4	65.8	68.8	73.5	77.8	87.2
9.0-9.9 yrs	49.0	52.2	54.1	56.8	59.0	61.0	63.2	65.5	68.2	71.5	76.6	81.3	91.6
10.0-10.9 yrs	50.2	53.4	55.4	58.2	60.5	62.7	64.9	67.4	70.2	73.7	79.1	84.1	95.3
11.0-11.9 yrs	51.6	55.0	57.1	59.9	62.3	64.5	66.8	69.2	72.1	75.7	81.2	86.5	98.3
12.0-12.9 yrs	53.0	56.4	58.5	61.4	63.7	65.8	68.1	70.5	73.2	76.7	82.2	87.5	99.4
13.0-13.9 yrs	54.3	57.7	59.8	62.6	64.8	66.9	69.0	71.3	73.9	77.2	82.5	87.6	99.4
14.0-14.9 yrs	55.5	58.9	61.0	63.7	65.9	67.9	69.8	72.0	74.4	77.6	82.7	87.6	99.2
15.0-15.9 yrs	56.5	59.9	62.0	64.6	66.7	68.6	70.5	72.5	74.9	77.9	82.8	87.6	99.1
16.0-16.9 yrs	57.3	60.8	62.8	65.4	67.5	69.3	71.1	73.1	75.3	78.3	83.2	87.9	99.5
17.0-17.9 yrs	57.8	61.2	63.2	65.8	67.8	69.6	71.4	73.3	75.5	78.5	83.3	88.1	100.0
18.0-18.9 yrs	57.8	61.3	63.3	65.9	67.9	69.6	71.4	73.2	75.4	78.3	83.1	88.0	100.3

Boys Age (yr.)	P1	P5	P10	P20	P30	P40	P50	P60	P70	P80	P90	P95	P99
6.0-6.9 yrs	45.9	48.8	50.5	52.6	54.2	55.6	56.9	58.3	59.9	62.1	65.7	69.3	78.3
7.0-7.9 yrs	47.3	50.3	52.1	54.4	56.1	57.7	59.3	61.0	63.0	65.5	69.7	73.7	83.4
8.0-8.9 yrs	49.0	52.1	53.9	56.4	58.4	60.2	62.1	64.1	66.4	69.4	74.2	78.7	89.3
9.0-9.9 yrs	50.4	53.5	55.4	58.0	60.2	62.2	64.3	66.6	69.2	72.6	77.9	82.8	94.3
10.0-10.9 yrs	51.6	54.8	56.8	59.6	61.9	64.0	66.3	68.8	71.7	75.3	81.0	86.4	98.8
11.0-11.9 yrs	53.0	56.3	58.4	61.3	63.6	65.9	68.3	70.9	73.9	77.7	83.7	89.4	102.6
12.0-12.9 yrs	54.4	57.8	60.0	62.9	65.3	67.6	69.9	72.5	75.5	79.3	85.3	91.1	104.8
13.0-13.9 yrs	56.2	59.7	61.9	64.8	67.2	69.4	71.7	74.1	77.0	80.7	86.6	92.4	106.1
14.0-14.9 yrs	58.0	61.7	63.9	66.9	69.2	71.3	73.4	75.8	78.5	82.0	87.7	93.3	107.1
15.0-15.9 yrs	59.7	63.5	65.8	68.7	71.0	73.1	75.1	77.2	79.8	83.2	88.7	94.3	108.2
16.0-16.9 yrs	61.2	65.2	67.5	70.5	72.7	74.7	76.6	78.7	81.1	84.4	90.0	95.6	110.1
17.0-17.9 yrs	62.1	66.4	68.8	71.8	74.0	75.9	77.7	79.7	82.1	85.3	90.8	96.6	112.0
18.0-18.9 yrs	62.5	66.9	69.3	72.3	74.5	76.4	78.1	80.0	82.3	85.4	90.9	96.8	113.2

Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population. Age at the midpoint of each interval was selected to provide percentiles. For instance, for the interval 6.0–6.9, data presented were those corresponding to an exact age of a 6.5-year-old child. P10 indicates 10th percentile; other percentiles are abbreviated accordingly. Data sources are available at: www.fitbackeurope.eu/en-us/fitness-map/sources.

Online Supplementary Table 7. Mean percentile and ranking position of each country according to the pooled EU reference values for body height and weight.

	Body height							Body weight							
	Both		Girls		Boys			Both		Girls		Boys			
	N	Centile	Rank	Centile	Rank	Centile	Rank	N	Centile	Rank	Centile	Rank	Centile	Rank	
MNE	6,551	67.4	1	67.2	1	67.6	1	CRO	23,646	58.2	1	58.9	1	57.3	3
EST	4,113	62.9	2	62.3	3	63.4	2	MNE	6,460	57.6	2	55.4	3	59.7	1
CRO	23,651	60.3	3	62.8	2	57.4	6	MCD	1,022	56.2	3	53.6	8	58.7	2
CZE	1,637	58.9	4	59.6	5	58.3	3	GRE	325,357	55.7	4	54.9	4	56.5	4
SVN	215,493	58.2	5	58.2	6	58.3	4	ISL	387	55.3	5	55.8	2	54.9	6
NOR	2,659	57.1	6	59.7	4	54.7	10	EST	4,091	54.9	6	54.2	6	55.6	5
SRB	20,683	57.0	7	56.5	7	57.6	5	SVN	215,211	53.9	7	53.7	7	54.2	8
DEN	1,041	55.6	8	54.2	14	57.2	7	SRB	20,695	53.4	8	52.5	11	54.3	7
ISL	387	54.7	9	54.4	11	54.9	9	HUN	601,487	53.3	9	53.3	9	53.3	10
GRE	325,078	54.6	10	54.3	13	55.0	8	SPA	26,129	53.2	10	53.1	10	53.3	9
POL	49,550	54.0	11	53.4	15	54.6	11	CZE	1,636	52.0	11	52.3	12	51.7	12
GER	5,229	53.6	12	54.3	12	53.0	13	NOR	2,608	51.8	12	54.3	5	49.6	17
HUN	601,537	53.5	13	53.0	16	54.0	12	AUS	630	51.3	13	50.2	15	52.5	11
LIT	11,854	52.9	14	54.9	10	51.0	18	IRE	1,149	50.2	14	50.1	16	50.3	14
LAT	7,743	52.6	15	54.9	9	50.5	19	GER	5,224	50.0	15	50.3	14	49.7	15
SLO	5,209	52.5	16	55.2	8	50.4	20	POL	49,525	49.4	16	47.8	21	50.9	13
FIN	2,453	51.8	17	52.1	17	51.5	16	ITA	26,467	49.2	17	48.7	18	49.7	16
AUS	630	51.5	18	50.4	18	52.6	15	BEL	23,019	48.1	18	50.7	13	45.5	19
BUL	497	51.4	19	49.8	21	52.8	14	POR	30,731	47.9	19	49.0	17	46.6	18
MCD	1,022	50.6	20	50.0	19	51.3	17	SWE	2,098	46.7	20	48.2	19	45.0	22
IRE	1,161	49.5	21	49.3	23	49.7	21	UK	22,810	46.1	21	47.0	24	45.2	20
ITA	26,568	49.0	22	49.8	20	48.2	22	DEN	1,042	46.0	22	46.7	25	45.2	21
BEL	22,973	48.8	23	49.6	22	48.0	23	FIN	2,453	46.0	23	47.4	23	44.4	25
BIH	843	47.2	24	49.1	24	45.5	25	LAT	7,743	45.8	24	47.5	22	44.4	26
SPA	26,144	45.8	25	45.0	28	46.6	24	BIH	843	45.6	25	48.1	20	43.3	28
FRA	42,700	45.4	26	46.0	26	44.8	26	LIT	11,885	44.7	26	44.9	26	44.4	24

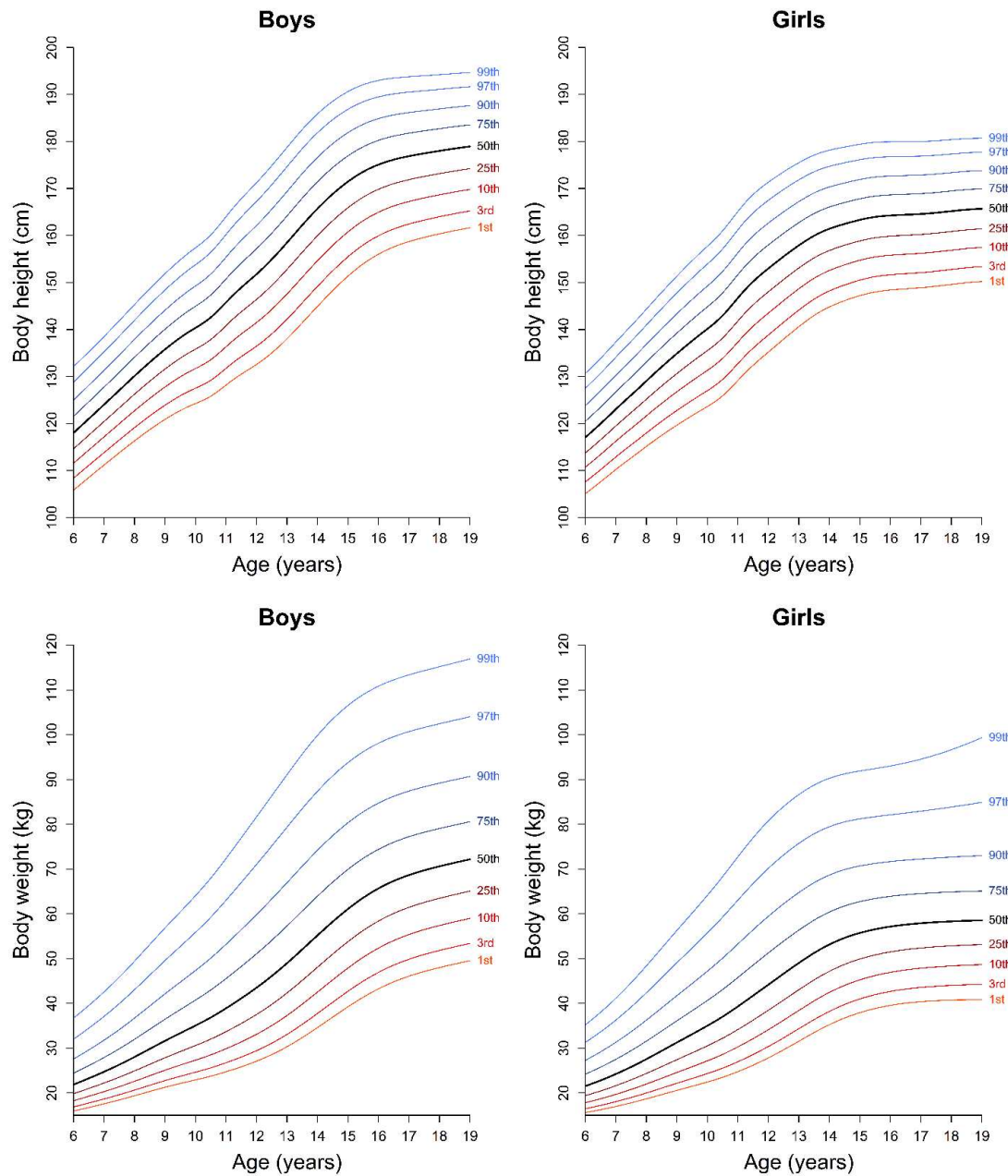
KOS	742	45.3	27	47.4	25	43.4	28	SLO	5,208	44.4	27	43.8	29	44.8	23
SWE	2,089	44.0	28	45.6	27	42.5	30	FRA	42,623	44.2	28	44.9	27	43.6	27
SWI	762	42.4	29	40.7	30	44.3	27	SWI	762	42.5	29	42.3	30	42.8	29
POR	30,740	42.4	30	42.0	29	42.7	29	BUL	497	41.2	30	40.4	31	41.9	30
UK	22,969	39.1	31	38.2	31	40.1	31	KOS	742	40.8	31	44.2	28	37.8	31
ALB	2,113	21.5	32	22.2	32	21.0	32	ALB	2,115	30.0	32	31.2	32	28.9	32
N	1,466,821							N	1,466,295						

N, sample size and total sample size at the bottom of the table. The 3-digit country codes were used to abbreviate the full country names https://en.wikipedia.org/wiki/List_of_UNDP_country_codes as follows: ALB, Albania; AUS, Austria; BEL, Belgium; BIH, Bosnia and Herzegovina; BUL, Bulgaria; CRO, Croatia; CYP, Cyprus; CZE, Czech Republic; DEN, Denmark; EST, Estonia; FIN, Finland; FRA, France; GER, Germany; GRE, Greece; HUN, Hungary; ISL, Iceland; IRE, Ireland; ITA, Italy; KOS, Kosovo; AT, Latvia; LIT, Lithuania; LUX, Luxembourg; NET, Netherlands; MCD, North Macedonia; MNE, Montenegro; NOR, Norway; POL, Poland; POR, Portugal; SRB, Serbia; SLO, Slovakia; SVN, Slovenia; SPA, Spain; SWE, Sweden; SWI, Switzerland; UK, United Kingdom.

For each test, the countries were sorted according to their rank position in the Both (girls and boys) column. Sex- and age-specific percentile values were calculated using available country-level data and were averaged across sexes and ages to obtain the mean percentile for each country compared to the EU reference values. Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population.

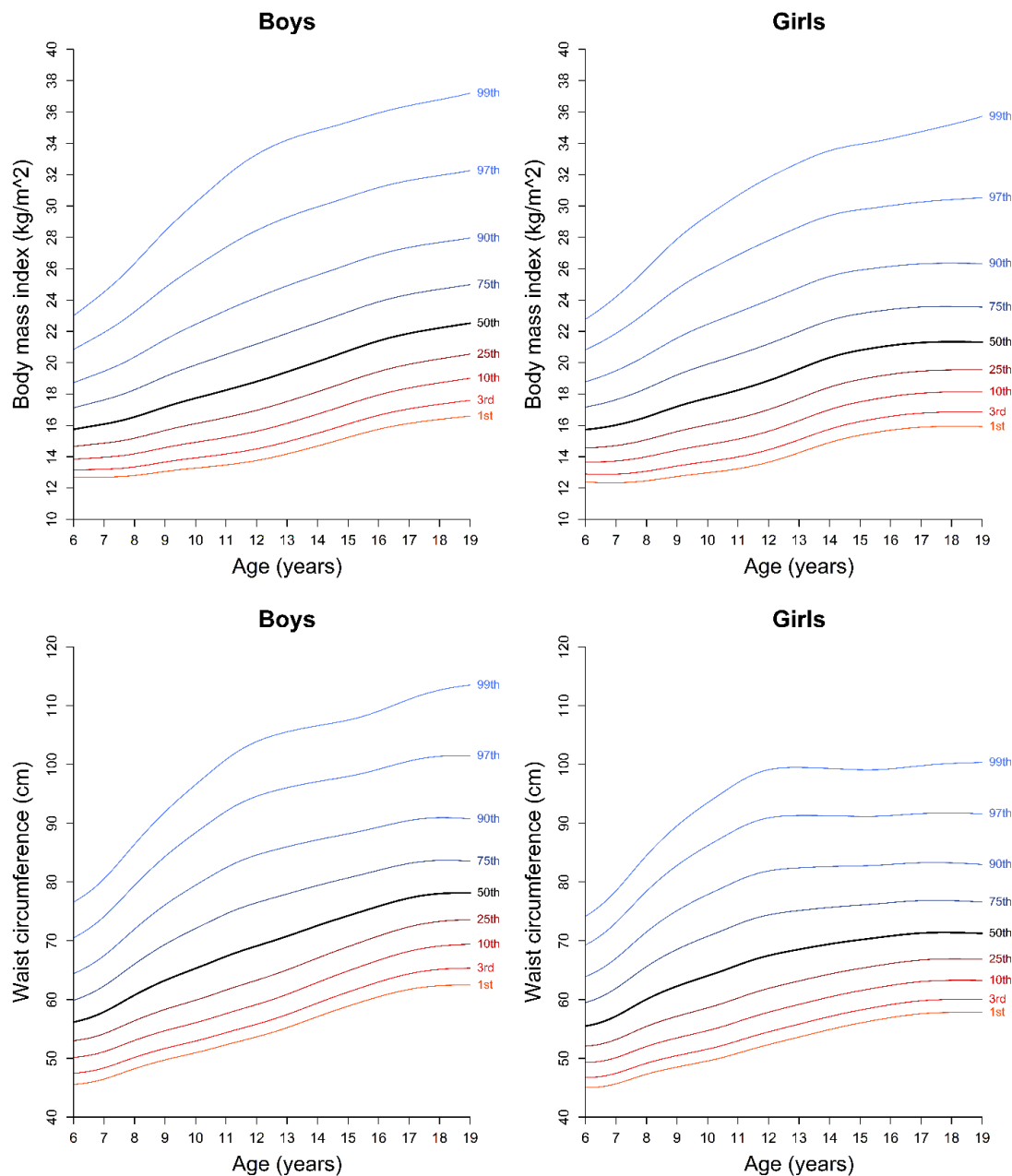
Online Supplementary Table 8. Mean percentile and ranking position of each country according to the pooled EU reference values for body mass index and waist circumference.

	Body mass index								Waist circumference							
	Both		Girls		Boys		N	Both		Girls		Boys				
	N	Centile	Rank	Centile	Rank	Centile		Rank	Centile	Rank	Centile	Rank				
MCD	1,021	58.3	1	55.1	2	61.4	1	MNE	3,914	59.3	1	59.3	1	59.3	1	
SPA	26,024	56.3	2	56.7	1	56.0	2	GRE	322,480	55.8	2	55.6	2	55.9	2	
GRE	324,462	54.5	3	53.7	5	55.2	3	ITA	1,061	52.6	3	48.5	6	55.9	3	
CRO	23,645	53.3	4	52.6	7	54.1	4	AUS	416	50.6	4	50.1	4	51.2	4	
ISL	387	53.2	5	54.1	3	52.3	5	POR	30,620	50.6	5	54.1	3	46.9	7	
UK	22,794	52.1	6	53.8	4	50.5	10	SPA	21,356	49.2	6	49.1	5	49.3	5	
POR	30,707	51.8	7	53.4	6	50.1	13	ISL	387	47.6	7	47.7	8	47.6	6	
HUN	601,480	51.6	8	51.9	8	51.2	7	SWE	356	44.4	8	47.8	7	39.1	16	
SWE	2,087	50.4	9	50.6	9	50.3	12	UK	9,619	43.7	9	44.2	9	43.3	11	
IRE	1,147	50.2	10	50.4	10	49.9	15	MCD	1,020	42.4	10	39.1	14	45.6	8	
AUS	630	50.0	11	49.4	13	50.6	9	EST	815	42.2	11	39.1	13	44.8	9	
SVN	214,944	49.8	12	49.6	12	50.0	14	CRO	1,853	41.7	12	39.0	15	44.7	10	
SRB	20,677	49.7	13	49.0	14	50.4	11	FIN	1,344	40.7	13	41.4	10	40.1	13	
ITA	26,462	49.7	14	48.6	16	50.7	8	GER	4,197	40.7	14	39.5	12	41.8	12	
MNE	6,550	48.6	15	45.7	21	51.5	6	SVN	4,848	39.6	15	39.8	11	39.4	15	
BEL	22,966	48.5	16	50.1	11	47.0	21	HUN	393	37.9	16	36.4	18	39.5	14	
EST	4,079	48.3	17	47.8	18	48.8	16	FRA	308	36.5	17	36.4	17	36.5	17	
NOR	2,604	48.3	18	48.8	15	47.9	18	DEN	1,042	35.2	18	37.4	16	32.7	19	
GER	5,223	47.7	19	47.6	20	47.8	19	BEL	3,059	33.7	19	34.4	19	33.1	18	
CZE	1,634	47.6	20	47.8	19	47.4	20	SWI	492	27.6	20	27.9	20	27.2	20	
POL	49,510	47.0	21	45.7	23	48.3	17			-	-	-	-	-	-	
BIH	843	45.8	22	48.0	17	43.8	23			-	-	-	-	-	-	
FRA	42,615	45.3	23	45.7	22	44.8	22			-	-	-	-	-	-	
FIN	2,453	44.0	24	45.7	24	42.1	28			-	-	-	-	-	-	
ALB	2,115	43.9	25	44.8	27	43.1	26			-	-	-	-	-	-	
SWI	762	43.7	26	45.2	25	42.1	29			-	-	-	-	-	-	



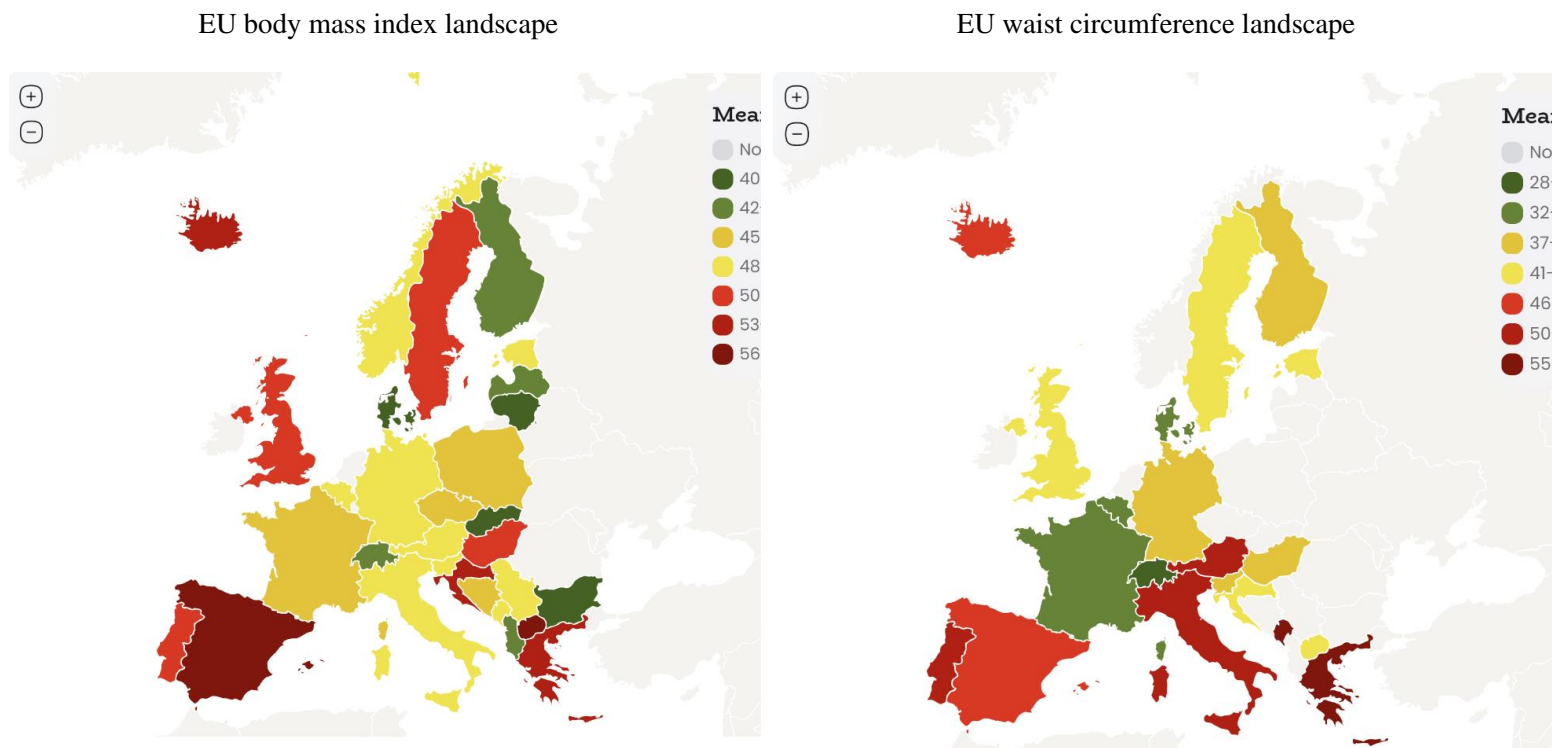
Online Supplementary Figure 1. Percentile curves for body height and body mass in European children and adolescents.

Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population. Data sources are available at: <https://www.fitbackeurope.eu/en-us/fitness-map/sources>.



Online Supplementary Figure 2. Percentile curves for body mass index and waist circumference in European children and adolescents.

Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population. Data sources are available at: <https://www.fitbackeurope.eu/en-us/fitness-map/sources>.



Online Supplementary Figure 3. European maps for body mass index and waist circumference in children and adolescents.

Sex- and age-specific percentile values were calculated using available country-level data and were averaged across sexes and ages to obtain the mean percentile for each country compared to the EU reference values. Smoothed percentiles were calculated using the Generalized Additive Model for Location, Scale and Shape (GAMLSS) method and weights were applied according to country population.

Separate European fitness maps for girls and boys are available at: www.fitbackeurope.eu/en-us/fitness-map. The website map is interactive so that detailed information for each country is shown with the mouseover function.

Not all countries have representative data and therefore caution should be paid when interpreting country comparisons presented this study and in the platform. Data sources are available at: www.fitbackeurope.eu/en-us/fitness-map/sources.