

This is a self-archived version of an original article. This version may differ from the original in pagination and typographic details.

Author(s): Ortega, Francisco B.; Leskošek, Bojan; Blagus, Rok; Gil-Cosano, José J.; Mäestu, Jarek; Tomkinson, Grant R.; Ruiz, Jonatan R.; Mäestu, Evelin; Starc, Gregor; Milanovic, Ivana; Tammelin, Tuija H.; Sorić, Maroje; Scheuer, Claude; Carraro, Attilio; Kaj, Mónica; Csányi, Tamás; Sardinha, Luis B.; Lenoir, Matthieu; Emeljanovas, Arunas; Mieziene, Brigita; Sidossis, Labros S.; Pihu, Maret;

Title: 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

Year: 2023

Version: Published version

Copyright: © Author(s) (or their employer(s)) 2023. Re-use permitted under CC BY-NC. No co

Rights: CC BY-NC 4.0

Rights url: <https://creativecommons.org/licenses/by-nc/4.0/>

Please cite the original version:

Ortega, Francisco B., Leskošek, Bojan, Blagus, Rok, Gil-Cosano, José J., Mäestu, Jarek, Tomkinson, Grant R., Ruiz, Jonatan R., Mäestu, Evelin, Starc, Gregor, Milanovic, Ivana, Tammelin, Tuija H., Sorić, Maroje, Scheuer, Claude, Carraro, Attilio, Kaj, Mónica, Csányi, Tamás, Sardinha, Luis B., Lenoir, Matthieu, Emeljanovas, Arunas, Mieziene, Brigita, Sidossis, Labros S., Pihu, Maret, Lovecchio, Nicola, Konstabel, Kenn, Tambalis, Konstantinos D., Štefan, Lovro, Drenowatz, Clemens, Rubín, Lukáš, Gontarev, Seryozha, Castro-Piñero, José, Vanhelst, Jérémy, O'Keeffe, Brendan, Veiga, Oscar L., Gisladottir, Thordis, Sandercock, Gavin, Misigoj-Durakovic, Marjeta, Niessner, Claudia, Riso, Eva-Maria, Popovic, Stevo, Kuu, Saima, Chinapaw, Mai, Clavel,



OPEN ACCESS

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

Francisco B Ortega ^{1,2,3} Bojan Leskošek,⁴ Rok Blagus ^{4,5,6}
José J Gil-Cosano ^{1,7} Jarek Mäestu ⁸ Grant R Tomkinson ⁹
Jonatan R Ruiz ^{1,3,10} Evelin Mäestu,⁸ Gregor Starc ⁴ Ivana Milanovic,¹¹
Tuija H Tammelin ¹² Maroje Sorić ^{4,13} Claude Scheuer ^{14,15}
Attilio Carraro ¹⁶ Mónica Kaj,¹⁷ Tamás Csányi ^{17,18,19} Luis B Sardinha ²⁰
Matthieu Lenoir ²¹ Arunas Emeljanovas,²² Brigita Mieziene,²² Labros S Sidossis,²³
Maret Pihu,⁸ Nicola Lovecchio ^{24,25} Kenn Konstabel ^{26,27}
Konstantinos D Tambalis,^{28,29} Lovro Štefan ^{13,30,31} Clemens Drenowatz,³²
Lukáš Rubín ^{33,34} Seryozha Gontarev,³⁵ José Castro-Piñero ^{36,37}
Jérémy Vanhelst ³⁸ Brendan O'Keeffe ³⁹ Oscar L Veiga,⁴⁰ Thordis Gisladottir,⁴¹
Gavin Sandercock ⁴² Marjeta Misigoj-Durakovic,¹³ Claudia Niessner,⁴³
Eva-Maria Riso,⁸ Stevo Popovic,^{44,45} Saima Kuu,⁴⁶ Mai Chinapaw,⁴⁷ Iván Clavel,^{48,49}
Idoia Labayen ⁵⁰ Janusz Dobosz ⁵¹ Dario Colella,⁵² Susi Kriemler ⁵³
Sanja Salaj,¹³ Maria Jose Noriega,⁵⁴ Klaus Bös,⁴³ Mairena Sánchez-López ^{55,56}
Timo A Lakka ^{57,58,59} Garden Tabacchi,⁶⁰ Dario Novak,¹³ Wolfgang Ahrens,⁶¹
Niels Wedderkopp ⁶² Gregor Jurak ⁴ the FitBack, HELENA and IDEFICS consortia

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

For numbered affiliations see end of article.

Correspondence to

Francisco B Ortega;
ortegaf@ugr.es
Gregor Jurak;
Gregor.Jurak@fsp.uni-lj.si

Accepted 18 November 2022
Published Online First
9 January 2023



© Author(s) (or their employer(s)) 2023. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

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

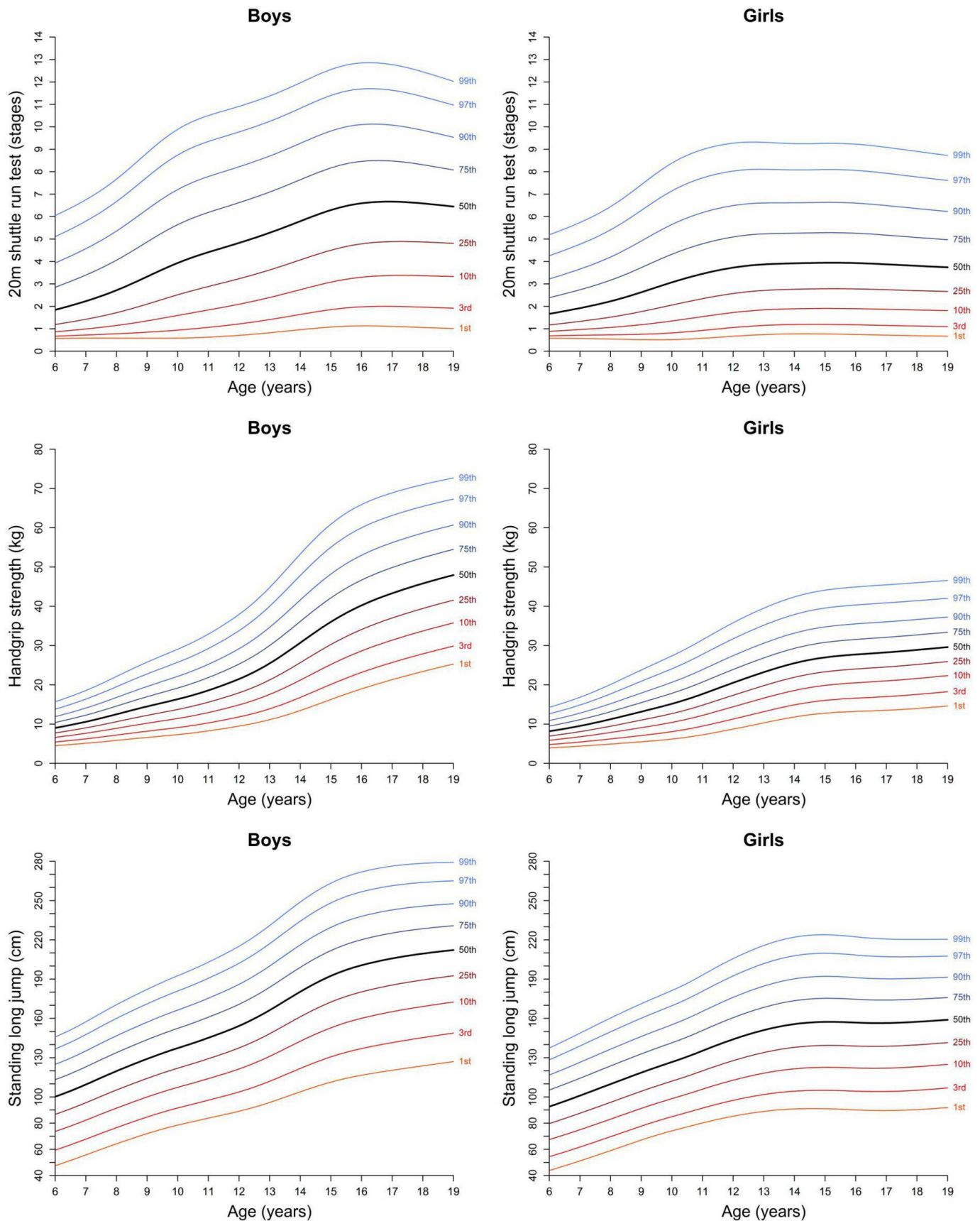


Figure 1 Percentile curves for cardiorespiratory and muscular strength tests among European children and adolescents. Smoothed percentiles were calculated using the generalised additive model for location, scale and shape method, and weights were applied according to country population. Data sources 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												Handgrip strength												Standing long jump											
	Boys			Girls			Boys			Girls			Boys			Girls			Boys			Girls			Boys			Girls								
	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	Rank	Centile	Rank	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	2	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	2	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	11	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	58.7	9	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	42.9	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	-	-	-	-	-	-	DEN	-	-	-	-	-	-	-	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 Both (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-fit-back-map/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.

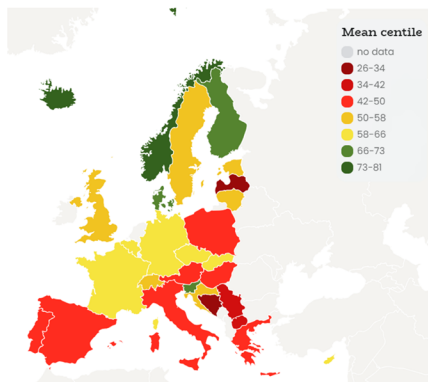
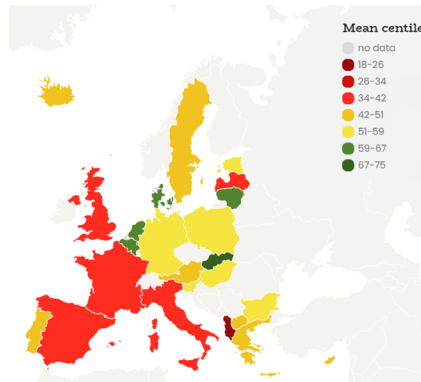
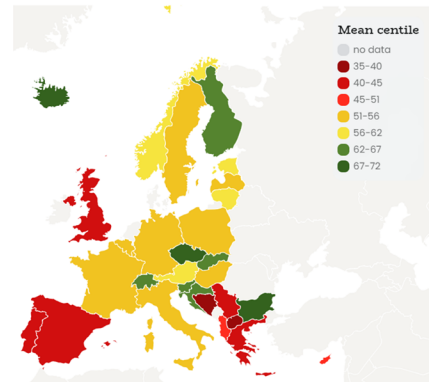
EU cardiorespiratory fitness landscape
(20-m shuttle run test)EU muscular strength landscape
(Handgrip test)EU muscular strength landscape
(Standing long jump test)

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.

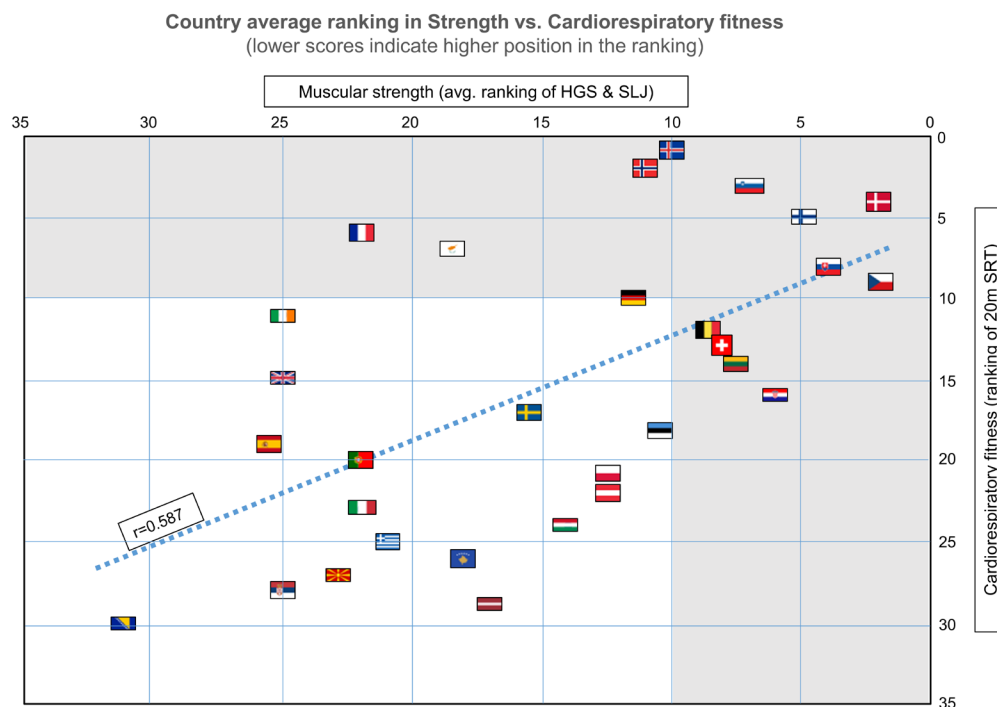


Figure 3 Country average ranking in muscular strength and CRF in European children and adolescents. CRF in European children and adolescents. The ranking for muscular strength was computed as the average of the country ranking position in HGS and SLJ tests, while ranking for CRF directly reflects the 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.

Author affiliations

¹Faculty of Sport Sciences, University of Granada, Department of Physical and Sports Education; Sport and Health University Research Institute (iMUDS), CIBERobn Physiopathology of Obesity and Nutrition, Granada, Spain

²Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

³Department of Biosciences and Nutrition, Karolinska Institutet, Huddinge, Sweden

⁴Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia

⁵Institute for Biostatistics and Medical Informatics, Medical Faculty, University of Ljubljana, Ljubljana, Slovenia

⁶Faculty of Mathematics, Natural Sciences and Information technologies, University of Primorska, Glagoljaška, Slovenia

⁷Department of Communication and Education, Universidad Loyola Andalucía, Dos Hermanas, Spain

⁸Institute of Sport Sciences and Physiotherapy, Faculty of Medicine, University of Tartu, Tartu, Estonia

⁹Alliance for Research in Exercise, Nutrition and Activity (ARENA), UniSA Allied Health and Human Performance, University of South Australia, Adelaide, South Australia, Australia

¹⁰Instituto de Investigación Biosanitaria, IBS.Granada, Granada, Spain

¹¹University of Belgrade, Faculty of Sport and Physical Education, Belgrade, Serbia

¹²JAMK University of Applied Sciences, School of Health and Social Studies, LIKES, Jyväskylä, Finland

¹³University of Zagreb, The Faculty of Kinesiology, Zagreb, Croatia

¹⁴European Physical Education Association (EUPEA)

¹⁵Department of Education and Social Work, University of Luxembourg, Esch-sur-Alzette, Luxembourg

¹⁶Faculty of Education, Free University of Bozen-Bolzano, Brixen, Italy

¹⁷Hungarian School Sport Federation, Budapest, Hungary

¹⁸Department of Physical Education Theory and Methodology, Hungarian University of Sports Science, Budapest, Hungary

¹⁹Department of Physical Education, Faculty of Primary and Pre-School Education, ELTE, Eötvös Loránd University, Budapest, Hungary

²⁰Exercise and Health Laboratory, CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, Lisbon, 1499-002 Cruz-Quebrada, Portugal

²¹Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium

²²Lithuanian Sports University, Department of Physical and Social Education, Kaunas, Lithuania

²³Mediterranean Lifestyle Medicine Institute and Department of Kinesiology and Health, Rutgers University, New Brunswick, USA

²⁴Department of Human and Social Sciences, University of Bergamo, Bergamo, Italy

²⁵Confederation of Italian Associations of Physical Education Teachers (Capdi & LSM), Venezia, Italy

²⁶Department of Chronic Diseases, National Institute for Health Development, Tallinn, Estonia

²⁷Institute of Psychology, University of Tartu, Tartu, Estonia

²⁸Harokopio University, Department of Nutrition and Dietetics, Athens, Greece

²⁹National and Kapodistrian University of Athens, Department of Physical Education and Sport Science, Athens, Greece

³⁰Faculty of Sports Studies, Masaryk University, Brno, Czech Republic

³¹Recruitment and Examination (RECETOX), Faculty of Science, Masaryk University, Brno, Czech Republic

³²Division of Sport, Physical Activity and Health, University of Education Upper Austria, Linz, Austria

³³Institute of Active Lifestyle, Faculty of Physical Culture, Palacký University Olomouc, Olomouc, Czech Republic

³⁴Department of Physical Education and Sport, Faculty of Science, Humanities and Education, Technical University of Liberec, Liberec, Czech Republic

³⁵Faculty of Physical Education, Sport and Health. Ss. Cyril and Methodius University, Skopje, Republic of North Macedonia

³⁶GALENO Research Group, Department of Physical Education, Faculty of Education Sciences, University of Cadiz, Puerto Real, Cadiz, Spain

³⁷Instituto de Investigación e Innovación Biomédica de Cádiz (INIICA), Cádiz, Spain

³⁸Sorbonne Paris Nord University, Inserm U1153, Inrae U1125, Cnam, Nutritional Epidemiology Research Team (EREN), Centre of Research in Epidemiology and Statistics - University of Paris Cité (CRESS), Bobigny, France

³⁹Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland

⁴⁰EstiLIFE Research Group. Department of Physical Education, Sport and Human Movement, Faculty of Teaching Training and Education, Autonomous University of Madrid, Madrid, Spain

⁴¹Center of Sport and Health Sciences, School of Education, University of Iceland, Reykjavik Iceland

⁴²School of Sport Rehabilitation and Exercise Science, University of Essex, Colchester, UK

⁴³Institute of Sports and Sports Science, Karlsruhe Institute of Technology, Karlsruhe, Germany

⁴⁴University of Montenegro, Faculty for Sport and Physical Education, Niksic, Montenegro

⁴⁵Western Balkan Sport Innovation Lab, Podgorica, Montenegro

⁴⁶Tallinn University, School of Natural Sciences and Health, Tallinn, Estonia

⁴⁷Department of Public and Occupational Health, Amsterdam Public Health research institute, Amsterdam UMC, location Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

⁴⁸Galician Sport Foundation, General Sport Secretariat, Galician Government, Santiago de Compostela, Spain

⁴⁹Performance and Health Group, Faculty of Sport Sciences and Physical Education, Department of Physical Education and Sports, University of A Coruña, Coruña, Spain

⁵⁰Research Institute for Innovation & Sustainable Food Chain Development, Department of Health Sciences, Public University of Navarra, Pamplona, Spain

⁵¹Józef Piłsudski University of Physical Education in Warsaw, Poland

⁵²Department of Biological and Environmental Sciences and Technologies, University of Salento, Lecce, Italy

⁵³Epidemiology, Biostatistics and Prevention Institute, University of Zurich, Zurich, Switzerland

⁵⁴Department of Physiology & Pharmacology University of Cantabria, Cantabria, Spain

⁵⁵Universidad de Castilla-La Mancha, Health and Social Research Center, Cuenca, Spain

⁵⁶Universidad de Castilla-La Mancha, School of Education, Ciudad Real, Spain

⁵⁷Institute of Biomedicine, School of Medicine, University of Eastern Finland, Kuopio Campus, Finland

⁵⁸Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland

⁵⁹Foundation for Research in Health Exercise and Nutrition, Kuopio Research Institute of Exercise Medicine, Kuopio, Finland

⁶⁰Sport and Exercise Sciences Research Unit, Department of Psychology, Educational Science and Human Movement, University of Palermo, Palermo, Italy

⁶¹Leibniz Institute for Prevention Research and Epidemiology – BIPS, Bremen, Germany

⁶²The Pediatric Research Unit, Department of Clinical Research, University of Southern Denmark, Odense, Denmark

Twitter Francisco B Ortega @ortegaporcel, José J Gil-Cosano @gil_cosano, Jonatan R Ruiz @ruizruizjonatan, Brendan O’Keeffe @BrendanOK_, Gavin Sandercock @GRHSANDERCOCK, Iván Clavel @clavelivan, Idoia Labayen @Idoialabgo1 and Sanja Salaj @SportEdu1

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.

Contributors Designed research, contributed to the conception and interpretation of the analyses: FBO, BL, RB, JJC-C, JM, GRT, JRR, EM, GS, IM, TT, MS, CS, AC, MK, TC, LBS and GJ. Statistical analysis: BL and RB. Drafted the manuscript. FBO. Participated/

responsible for fitness data collection: FBO, JM, JRR, EM, GS, IM, MS, MK, TC, LBS, ML, AE, BM, LSS, MP, NL, KK, KDT, LS, CD, LR, SG, JC-P, JV, BOK, OLV, TG, GS, MM-D, CN, E-MR, SP, SKuu, MJMC, IC, IL, JD, DC, SK, SS, MJN, KB, MS-L, TAL, GT, DN, WA and NW. All authors critically revised the manuscript and approved the final version of the manuscript to be submitted. FBO and GJ are the guarantors of this article, and therefore accept full responsibility for the work and/or the conduct of the study, had access to the data and controlled the decision to publish.

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.

Map disclaimer The inclusion of any map (including the depiction of any boundaries therein) or of any geographical or locational reference does not imply the expression of any opinion whatsoever on the part of BMJ concerning the legal status of any country, territory, jurisdiction or area or of its authorities. Any such expression remains solely that of the relevant source and is not endorsed by BMJ. Maps are provided without any warranty of any kind, either express or implied.

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.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Francisco B Ortega <http://orcid.org/0000-0003-2001-1121>
 Rok Blagus <http://orcid.org/0000-0001-7200-894X>
 José J Gil-Cosano <http://orcid.org/0000-0003-0723-876X>
 Jarek Mäestu <http://orcid.org/0000-0002-6931-3932>
 Grant R Tomkinson <http://orcid.org/0000-0001-7601-9670>
 Jonatan R Ruiz <http://orcid.org/0000-0002-7548-7138>
 Gregor Starc <http://orcid.org/0000-0001-9822-0308>
 Tuija H Tammelin <http://orcid.org/0000-0002-1771-3977>
 Maroje Sorić <http://orcid.org/0000-0001-6835-1438>
 Claude Scheuer <http://orcid.org/0000-0002-5376-3197>
 Attilio Carraro <http://orcid.org/0000-0002-5103-6236>
 Tamás Csányi <http://orcid.org/0000-0003-2037-9217>
 Luis B Sardinha <http://orcid.org/0000-0002-6230-6027>
 Matthieu Lenoir <http://orcid.org/0000-0003-3906-1137>
 Nicola Lovecchio <http://orcid.org/0000-0003-4115-0833>
 Kenn Konstabel <http://orcid.org/0000-0002-9673-8469>
 Lovro Štefan <http://orcid.org/0000-0002-7705-7801>
 Lukáš Rubín <http://orcid.org/0000-0003-4920-1113>
 José Castro-Piñero <http://orcid.org/0000-0002-7353-0382>
 Jérémy Vanhelst <http://orcid.org/0000-0002-0570-1522>

Brendan O’Keeffe <http://orcid.org/0000-0002-4590-3460>
 Gavin Sandercock <http://orcid.org/0000-0002-5443-6518>
 Idoia Labayan <http://orcid.org/0000-0002-4334-3287>
 Janusz Dobosz <http://orcid.org/0000-0002-2425-4932>
 Susi Kriemler <http://orcid.org/0000-0002-3384-7940>
 Mairena Sánchez-López <http://orcid.org/0000-0002-0217-0623>
 Timo A Lakka <http://orcid.org/0000-0002-9199-2871>
 Niels Wedderkopp <http://orcid.org/0000-0002-9660-6618>
 Gregor Jurak <http://orcid.org/0000-0003-4269-0970>

REFERENCES

- Ortega FB, Ruiz JR, Castillo MJ, *et al*. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes* 2008;32:1–11.
- Ruiz JR, Castro-Piñero J, Artero EG, *et al*. Predictive validity of health-related fitness in youth: a systematic review. *Br J Sports Med* 2009;43:909–23.
- García-Hermoso A, Ramírez-Campillo R, Izquierdo M. Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. *Sports Med* 2019;49:1079–94.
- García-Hermoso A, Ramírez-Vélez R, García-Alonso Y, *et al*. Association of cardiorespiratory fitness levels during youth with health risk later in life: a systematic review and meta-analysis. *JAMA Pediatr* 2020;174:952–60.
- Högström G, Ohlsson H, Crump C, *et al*. Aerobic fitness in late adolescence and the risk of cancer and cancer-associated mortality in adulthood: a prospective nationwide study of 1.2 million Swedish men. *Cancer Epidemiol* 2019;59:58–63.
- Crump C, Sundquist J, Winkleby MA, *et al*. Interactive effects of aerobic fitness, strength, and obesity on mortality in men. *Am J Prev Med* 2017;52:353–61.
- Ballin M, Nordström A, Nordström P. Cardiovascular disease and all-cause mortality in male twins with discordant cardiorespiratory fitness: a nationwide cohort study. *Am J Epidemiol* 2020;189:1114–23.
- Ortega FB, Silventoinen K, Tynelius P, *et al*. Muscular strength in male adolescents and premature death: cohort study of one million participants. *BMJ* 2012;345:e7279.
- Henriksson P, Henriksson H, Tynelius P, *et al*. Fitness and body mass index during adolescence and disability later in life. *Ann Intern Med* 2019;170:230–9.
- Henriksson H, Henriksson P, Tynelius P, *et al*. Muscular weakness in adolescence is associated with disability 30 years later: a population-based cohort study of 1.2 million men. *Br J Sports Med* 2019;53:1221–30.
- Henriksson P, Shiroma EJ, Henriksson H, *et al*. Fit for life? Low cardiorespiratory fitness in adolescence is associated with a higher burden of future disability. *Br J Sports Med* 2021;55:128–9.
- Henriksson H, Henriksson P, Tynelius P, *et al*. Cardiorespiratory fitness, muscular strength, and obesity in adolescence and later chronic disability due to cardiovascular disease: a cohort study of 1 million men. *Eur Heart J* 2020;41:1503–10.
- Raghuveer G, Hartz J, Lubans DR, *et al*. Cardiorespiratory fitness in youth: an important marker of health: a scientific statement from the American heart association. *Circulation* 2020;142:E101–18.
- Cadenas-Sanchez C, Mena-Molina A, Torres-Lopez LV, *et al*. Healthier minds in Fitter bodies: a systematic review and meta-analysis of the association between physical fitness and mental health in youth. *Sports Med* 2021;51:2571–605.
- Chaddock-Heyman L, Erickson KI, Holtrop JL, *et al*. Aerobic fitness is associated with greater white matter integrity in children. *Front Hum Neurosci* 2014;8:1–7.
- Raine LB, Lee HK, Saliba BJ, *et al*. The influence of childhood aerobic fitness on learning and memory. *PLoS One* 2013;8:e72666.
- Chaddock L, Erickson KI, Prakash RS, *et al*. A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Res* 2010;1358:172–83.
- Voss MW, Heo S, Prakash RS, *et al*. The influence of aerobic fitness on cerebral white matter integrity and cognitive function in older adults: results of a one-year exercise intervention. *Hum Brain Mapp* 2013;34:2972–85.
- Chaddock L, Erickson KI, Prakash RS, *et al*. Basal ganglia volume is associated with aerobic fitness in preadolescent children. *Dev Neurosci* 2010;32:249–56.
- Chaddock L, Pontifex MB, Hillman CH, *et al*. A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *J Int Neuropsychol Soc* 2011;17:975–85.
- Chaddock L, Hillman CH, Pontifex MB, *et al*. Childhood aerobic fitness predicts cognitive performance one year later. *J Sports Sci* 2012;30:421–30.
- Chaddock-Heyman L, Erickson KI, Kienzler C, *et al*. The role of aerobic fitness in cortical thickness and mathematics achievement in preadolescent children. *PLoS One* 2015;10:e0134115.
- Mora-Gonzalez J, Esteban-Cornejo I, Cadenas-Sanchez C, *et al*. Fitness, physical activity, working memory, and neuroelectric activity in children with overweight/obesity. *Scand J Med Sci Sports* 2019;29:1352–63.
- Valkenborghs SR, Noetel M, Hillman CH, *et al*. The impact of physical activity on brain structure and function in youth: a systematic review. *Pediatrics* 2019;144.
- Ortega FB, Campos D, Cadenas-Sanchez C, *et al*. Physical fitness and shapes of subcortical brain structures in children. *Br J Nutr* 2019;122:549–58.

- 26 Esteban-Cornejo I, Stillman CM, Rodriguez-Ayllon M, *et al.* Physical fitness, hippocampal functional connectivity and academic performance in children with overweight/obesity: the ActiveBrains project. *Brain Behav Immun* 2021;91:284–95.
- 27 Esteban-Cornejo I, Cadenas-Sánchez C, Contreras-Rodriguez O, *et al.* A whole brain volumetric approach in overweight/obese children: examining the association with different physical fitness components and academic performance. The ActiveBrains project. *Neuroimage* 2017;159:346–54.
- 28 Esteban-Cornejo I, Mora-Gonzalez J, Cadenas-Sanchez C, *et al.* Fitness, cortical thickness and surface area in overweight/obese children: the mediating role of body composition and relationship with intelligence. *Neuroimage* 2019;186:771–81.
- 29 Rodriguez-Ayllon M, Esteban-Cornejo I, Verdejo-Román J, *et al.* Physical fitness and white matter microstructure in children with overweight or obesity: the ActiveBrains project. *Sci Rep* 2020;10:12469.
- 30 Cadenas-Sanchez C, Migueles JH, Erickson KI, *et al.* Do fitter kids have bigger brains? *Scand J Med Sci Sports* 2020;30:2498–502.
- 31 Pietschnig J, Penke L, Wicherts JM, *et al.* Meta-Analysis of associations between human brain volume and intelligence differences: how strong are they and what do they mean? *Neurosci Biobehav Rev* 2015;57:411–32.
- 32 Castro-Piñero J, Artero EG, España-Romero V, *et al.* Criterion-related validity of field-based fitness tests in youth: a systematic review. *Br J Sports Med* 2010;44:934–43.
- 33 Artero EG, España-Romero V, Castro-Piñero J, *et al.* Reliability of field-based fitness tests in youth. *Int J Sports Med* 2011;32:159–69.
- 34 Ruiz JR, Castro-Piñero J, España-Romero V, *et al.* Field-based fitness assessment in young people: the alpha health-related fitness test battery for children and adolescents. *Br J Sports Med* 2011;45:518–24.
- 35 Ortega FB, Ruiz JR. Fitness in youth: methodological issues and understanding of its clinical value. *Am J Lifestyle Med* 2015;9:403–8.
- 36 IOM (Institute of Medicine). *Fitness measures and health outcomes in youth*. Washington, DC: The National Academies Press, 2012.
- 37 Whitehead M. The concept of physical literacy. *European Journal of Physical Education* 2001;6:127–38.
- 38 De Miguel-Etayo P, Gracia-Marco L, Ortega FB, *et al.* Physical fitness reference standards in European children: the IDEFICS study. *Int J Obes* 2014;38:S57–66.
- 39 Ortega FB, Artero EG, Ruiz JR, *et al.* Physical fitness levels among European adolescents: the Helena study. *Br J Sports Med* 2011;45:20–9.
- 40 Tomkinson GR, Carver KD, Atkinson F, *et al.* European normative values for physical fitness in children and adolescents aged 9–17 years: results from 2 779 165 Eurofit performances representing 30 countries. *Br J Sports Med* 2018;52:1445–56.
- 41 Jurak G, Leskošek B, Kovač M, *et al.* SLOfit surveillance system of somatic and motor development of children and adolescents: upgrading the Slovenian sports educational chart. *Auc Kineanthropologica* 2020;56:28–40.
- 42 Csányi T, Finn KJ, Welk GJ, *et al.* Overview of the Hungarian national youth fitness study. *Res Q Exerc Sport* 2015;86 Suppl 1:S3–12.
- 43 Henriques-Neto D, Hetherington-Rauth M, Magalhães JP, *et al.* Physical fitness tests as an indicator of potential athletes in a large sample of youth. *Clin Physiol Funct Imaging* 2022;42:88–95.
- 44 Léger LA, Mercier D, Gadoury C, *et al.* The multistage 20 metre shuttle run test for aerobic fitness. *J Sports Sci* 1988;6:93–101.
- 45 Tomkinson GR, Lang JJ, Tremblay MS, *et al.* International normative 20 m shuttle run values from 1 142 026 children and youth representing 50 countries. *Br J Sports Med* 2017;51:1545–54.
- 46 Esteban-Cornejo I, Tejero-González CM, Martínez-Gomez D, *et al.* Independent and combined influence of the components of physical fitness on academic performance in youth. *J Pediatr* 2014;165:306–12.
- 47 Lumley T. *Complex surveys: a guide to analysis using R*. John Wiley & Sons, Inc, 2010.
- 48 Rigby RA, Stasinopoulos DM. Generalized additive models for location, scale and shape (with discussion). *J Royal Statistical Soc C* 2005;54:507–54.
- 49 Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Stat Med* 1992;11:1305–19.
- 50 R Core Team. R: a language and environment for statistical computing. *R Found. Stat. Comput* 2019 <https://www.r-project.org/>
- 51 Stasinopoulos DM, Rigby RA. Generalized Additive Models for Location Scale and Shape (GAMLSS) in R. *J Stat Softw* 2007;23:1–46.
- 52 Lang JJ, Wolfe Phillips E, Orpana HM, *et al.* Field-based measurement of cardiorespiratory fitness to evaluate physical activity interventions. *Bull World Health Organ* 2018;96:794–6.
- 53 Iglesias-Soler E, Rúa-Alonso M, Rial-Vázquez J, *et al.* Percentiles and principal component analysis of physical fitness from a big sample of children and adolescents aged 6–18 years: the DAFIS project. *Front Psychol* 2021;12:627834.
- 54 The Finnish National Board of Education. Move! – monitoring system for physical functional capacity, 2021. Available: www.oph.fi/en/move [Accessed 12 May 2022].
- 55 Lang JJ, Zhang K, Agostinis-Sobrinho C, *et al.* Top 10 international priorities for physical fitness research and surveillance among children and adolescents: a Twin-Panel Delphi study. *Sports Med* 2022:1–16.
- 56 Jurak G, Morrison SA, Kovač M, *et al.* A COVID-19 crisis in child physical fitness: creating a barometric tool of public health engagement for the Republic of Slovenia. *Front Public Health* 2021;9:1–7.
- 57 Jarnig G, Jaunig J, van Poppel MNM. Association of COVID-19 mitigation measures with changes in cardiorespiratory fitness and body mass index among children aged 7 to 10 years in Austria. *JAMA Netw Open* 2021;4:e2121675–12.
- 58 Association International Physical Literacy. What is physical literacy, 2014. Available: <https://physicalliteracy.ca/physical-literacy/>
- 59 Jean de Dieu H, Zhou K. Physical literacy assessment tools: a systematic literature review for why, what, who, and how. *Int J Environ Res Public Health* 2021;18:7954.
- 60 Rongen F, McKenna J, Cobley S, *et al.* Are youth sport talent identification and development systems necessary and healthy? *Sports Med Open* 2018;4:2–5.
- 61 Tambalis KD, Panagiotakos DB, Psarra G, *et al.* Physical fitness normative values for 6–18-year-old Greek boys and girls, using the empirical distribution and the lambda, mu, and sigma statistical method. *Eur J Sport Sci* 2016;16:736–46.
- 62 Dobosz J, Mayorga-Vega D, Viciana J. Percentile Values of Physical Fitness Levels among Polish Children Aged 7 to 19 Years--a Population-Based Study. *Cent Eur J Public Health* 2015;23:340–51.
- 63 Ortega FB, Ruiz JR, Labayen I, *et al.* Health inequalities in urban adolescents: role of physical activity, diet, and genetics. *Pediatrics* 2014;133:e884–95.
- 64 Tomkinson GR, Olds TS, Borms J. Who are the Eurofittest? *Med Sport Sci* 2007;50:104–28.
- 65 Lang JJ, Tremblay MS, Léger L, *et al.* International variability in 20 m shuttle run performance in children and youth: who are the fittest from a 50-country comparison? A systematic literature review with pooling of aggregate results. *Br J Sports Med* 2018;52:276.