NORMATIVE-REFERENCED VALUES FOR HEALTH-RELATED FITNESS AMONG CZECH YOUTH: PHYSICAL FITNESS DATA FROM THE STUDY IPEN ADOLESCENT CZECH REPUBLIC

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SUMMARY

Objectives: The aim of this study was to developed sex- and age-specific normative-referenced percentile values for health-related fitness among 12 to 18 years old Czech youth.

Methods: This study included cross-sectional data from 1,173 participants (50.7% boys) collected between 2013 and 2016. Participants were recruited from 32 elementary or secondary schools across eight cities located in the Czech Republic. Health-related fitness was objectively measured using both anthropometric (height, body mass, and sum of skinfolds) and performance (20-m shuttle run for cardiorespiratory endurance, modified push-ups for muscular strength/endurance, and V sit-and-reach for flexibility) tests. Sex- and age-specific normative values were calculated using the Lambda Mu Sigma method. Sex- and age-related differences in means were expressed as standardized effect sizes.

Results: Normative percentiles were tabulated and displayed as smoothed curves. Among boys, measures of health-related fitness generally increased with age, except for an age-related decline in the sum of skinfolds and a plateau in V sit-and-reach. Among girls, most measures of health-related fitness increased from age 12 to 16 years before stabilizing, except for the sum of skinfolds, which remained stable from age 12 to 18 years. The sex-related differences were large with boys having higher cardiorespiratory endurance and muscular strength/endurance than girls. Girls compared to boys had higher flexibility.

Conclusions: This study presents the most up-to-date sex- and age-specific normative-referenced percentile values for health-related fitness among Czech youth. Normative values may be useful for fitness and public health screening and surveillance, for example, by helping to identify youth with low fitness who might benefit from a fitness-enhancing intervention.

Key words: physical fitness, anthropometry, performance, normative data, percentiles, youth

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INTRODUCTION

Physical fitness is a set of attributes that relates to an individual's ability to perform physical activity (1, 2). Low physical fitness (especially cardiorespiratory and muscular fitness) in childhood and adolescence is associated with poor cardiovascular health, skeletal health, self-esteem, and health-related quality of life (3–5), and is predictive of adverse health outcomes in later life (e.g., premature death) (6–9). Physical fitness levels also track moderately well from childhood and adolescence into the adulthood (10). This evidence highlights why physical fitness in childhood and adolescence is an important marker of current and future health (11). Unfortunately, several recent meta-analyses have found international declines in cardiorespiratory and muscular fitness performance among children and adolescents (herein youth) since the early 2000s (12–15). Such declines are suggestive of corresponding declines in population health and highlight the urgent need for broader support of fitness-enhancing policies, interventions, and programmes.

One way to monitor and potentially improve the general health and fitness of a population is through effective population surveillance (16). In the Czech Republic for example, the free, multilingual, online INDARES (International Database for Research and Educational Support) surveillance system is used to support healthy behaviours across the population (17). Among its many functions, the INDARES system records, analyses, and compares the physical fitness levels of registered users, and provides feedback and advice for improvement. Normative-referenced percentile values can help provide individualized feedback by comparing an individual's fitness test result with a reference population. Normative values can be used to identify individuals with low fitness who may need intervention; better than, worse than, or expected developmental changes; or high fitness who may possess the fitness characteristics for sporting/athletic success.

Because normative-referenced values are time dependent and often outdated, such data need to be updated to best reflect the fitness levels of contemporary youth (18). While international (19), regional (20), and country-specific (21–29) fitness normative values are available for a range of fitness tests and age groups, only outdated normative values (pre-2000) exist for Czech youth (30–33). Furthermore, existing Czech normative-referenced values were developed using fitness tests that are no longer used in schools or not considered health-related, and often, these normative values were not developed using modern rigorous statistical methods (such as the widely used Lambda Mu Sigma (LMS) method (34). Thus, the aim of this study was to develop sex- and age-specific normative-referenced percentile values for health-related fitness among youth aged 12–18 years from the Czech Republic.

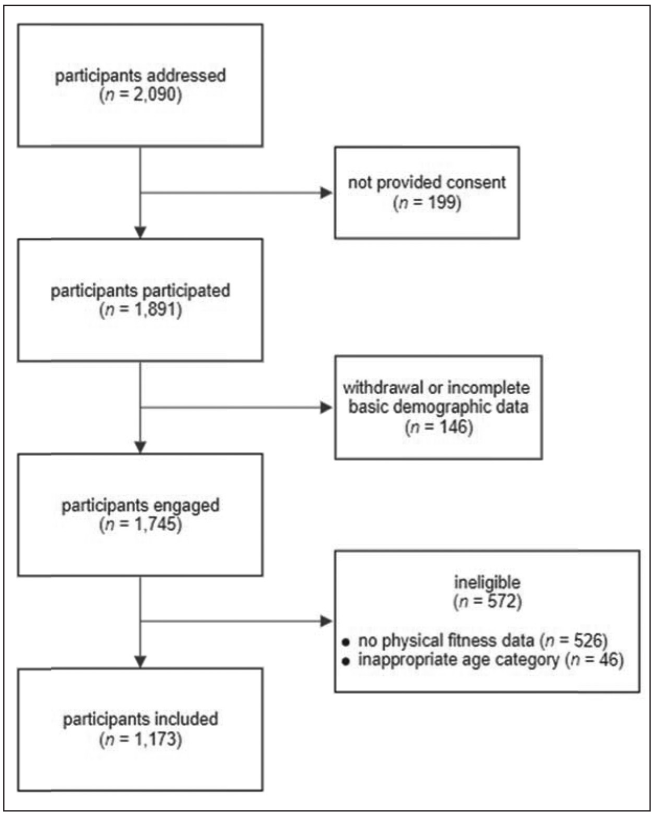

***Fig. 1.** Flowchart outlining the identification of the participants.*

MATERIALS AND METHODS

Study Design and Participants

This study used a cross-sectional design. It was part of the IPEN Adolescent international project and the Czech Science Foundation national project, and therefore, used the same sampling and research methods from these projects (35, 36). Participants were recruited on a voluntary basis from 32 elementary (grades 6–9) or secondary (grades 1–4) schools across eight Czech Republic cities (Brno, České Budějovice, Hradec Králové, Liberec, Olomouc, Ostrava, Rokycany, and Ústí nad Labem) from all three historical Czech lands (Bohemia, Moravia, and Silesia). Sports-specific schools and schools for students with special educational needs were not sampled. A total of 1,745 youth (895 boys and 850 girls) aged 11–19 years (mean ± SD: 15.5 ± 2.1) participated during these projects and provided complete demographic data. For this study, we included only participants with a physical fitness test result who were aged 12–18 years because few 11- and 19-year-olds were sampled (Fig. 1). Hence, the analytic sample comprised 1,173 participants (50.7% boys). This study was approved by the Ethical Committee of the Faculty of Physical Culture, Palacký University Olomouc (37/2013). Written consent was obtained from participants aged ≥ 18 years, or the parent (or legal guardian) of those aged < 18 years.

Testing Procedures

Data collection for this study took place between October 2013 and May 2016. Dressed in sportwear (e.g., sneakers, shorts, short-sleeved shirts), participants were tested indoors during their physical education class by trained researchers (LR and MV) in cooperation with physical education teachers. A single experienced researcher (LR) supervised each data collection throughout the course of the study. Participants were reminded of the objectives of the research and the health-related importance of physical fitness. Prior to testing, the researcher (LR) explained how to correctly perform each fitness test and participants were allowed a single practice trial, excluding the 20-m shuttle run test (20mSRT). Following a 15-minute warm-up, physical fitness was assessed using a national test battery designed to assess the health-related fitness of Czech youth (37). A detailed description of the test battery is available from the "fitness assessment" module of the INDARES system* (17). The fitness test battery included anthropometric (height, body mass, and sum of skinfolds) and performance (20mSRT for cardiorespiratory endurance, modified push-ups for upper-body muscular strength/endurance, and V sit-and-reach for lower back and hamstring flexibility) tests. A brief description of each test is provided below.

Height and Body Mass

Height was measured to the nearest 1 cm using a Leicester Height Measure Mk II stadiometer (Invicta Plastics, Leicester,

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UK). Body mass was measured to the nearest 0.1 kg using Tanita UM-075 digital weighing scale (Tanita, Tokyo, Japan). These portable devices have high reliability and criterion validity and are widely used in research (38–40). Body mass index (BMI – kg/m$^{2)}$ was calculated as mass (kg) divided by height (m) squared.

Sum of Skinfolds

Triceps and calf skinfolds were measured to the nearest 1 mm using Accu-Measure Fitness 3000 caliper (AccuFitness, Denver, CO, USA) using the FitnessGram® protocol (41). Three consecutive measures were taken for each skinfold site and only the median value was used. The results were reported as a sum of skinfolds with percentage body fat estimated using the Slaughter equation (42), which demonstrated high criterion validity in both pubescent ($R^2 = 0.72$) and postpubescent ($R^2 = 0.81$) participants. The use of two skinfolds have been recommended for youth for practical and ethical reasons (43).

20-m Shuttle Run

The 20mSRT involves continuous running back and forth between two parallel lines 20 m apart while keeping pace with audio signals. The test comprises multiple stages lasting about 1 minute, with each stage comprising numerous 20 m laps at a predetermined running speed. We used the FitnessGram® (41) protocol, which required participants to start running at a speed of 8.0 km/h, the second stage is at 9.0 km/h, and thereafter increases in speed by 0.5 km/h each consecutive stage. Participants ran until they could no longer run the 20 m distance in time with the audio signal (on two consecutive occasions) or when they stopped due to volitional fatigue. The 20mSRT performance was recorded as the number of completed laps. Peak oxygen uptake ($\dot{V}O_{2peak}$ in ml/kg/min) was estimated using Nevill's allometric model (44), which demonstrated high criterion validity ($R^2 = 0.77$) in youth and adults. The test-retest reliability of the 20mSRT is high to very high (r = 0.78–0.93) (45).

Modified Push-ups

Participants assumed a prone position with their hands slightly wider than their shoulders, fingers stretched, legs straight and slightly apart, and toes tucked under. Starting with straight arms, legs, and back, participants lowered their body by bending their arms until their chest lightly touched a tennis ball on the floor, and then pushed their body back up to the starting position. Participants completed the maximum number of push-ups (to volitional fatigue without pausing) while keeping a rhythmic pace (set by an audio track) of one repetition every 3 seconds. Participants were stopped when they could not maintain the correct body position or the rhythmic pace. The test-retest reliability of the modified push-up is high to very high (r = 0.60–0.98) (43).

V Sit-and-Reach

While sitting on the measuring pad with their bare feet 30 cm apart and their knees and arms straight, participants slowly reached forward (with their head down) as far as possible without jerking. The end position was held for at least 2 s before the measurement was taken to the nearest 1 cm (up to a maximum of 60 cm). The test was repeated twice with a short break, the result was recorded as the best score from two trials. Performances reaching the toes were recorded as 30 cm, with performances reaching beyond the toes recorded as > 30 cm, and performances failing to reach the toes recorded as < 30 cm. The test-retest reliability of the V sit-and-reach is very high (r = 0.98) (46).

Statistical Analyses

Sex- and age-specific normative percentiles were developed using LMSchartmaker Pro v2.43 (Institute of Child Health, London, UK) using the Lambda Mu Sigma (LMS) method (34). The LMS method fits smooth percentile curves to reference data by summarizing the changing distribution of three sex- and age-specific curves representing the skewness (L, expressed as a Box-Cox power), the median (M), and the coefficient of variation (S). Using penalized likelihood, the curves were fitted as cubic splines using non-linear regression, with the extent of smoothing required expressed in terms of smoothing parameters or equivalent degrees of freedom (47). The 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th percentiles were calculated for each anthropometric and performance test. Sex- and age-related differences in means were expressed as standardized (Cohen's) effect sizes (ES) (48). Positive ES indicated higher fitness for boys compared to girls, and negative ES indicated lower fitness for boys compared to girls. ES of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with ES < 0.2 considered to be negligible (48).

RESULTS

Sex- and age-specific normative percentile values (P_{10}, P_{20}, P_{30}, P_{40}, P_{50}, P_{60}, P_{70}, P_{80}, and P_{90}) for anthropometric (height, body mass, BMI, sum of skinfolds, and percent body fat) are presented in Supplementary Materials S1–S5. Tables 1 to 3 show the sex- and age-specific normative percentile values for performance tests (20mSRT, modified push-ups, and V sit-and-reach). Normative percentile values for estimated $\dot{V}O_{2peak}$ (S6) and LMS summary statistics for anthropometric and performance tests (S7 and S8) are presented as additional supplementary.

Height, body mass, and BMI typically increased with age from 12 to 16 years before stabilizing, while the sum of skinfolds declined with age for boys and remained stable for girls (Fig. 2). From age 13 onwards, the sex-related difference increased with age with large differences (boys > girls) found from age 14 and 16 for height and body mass, respectively (Fig. 3). For BMI, the sex-related difference (boys < girls) declined from age 12 to 15 years and then changed direction (boys > girls) and increased thereafter. Boys were leaner (i.e., lower sum of skinfolds) than girls throughout adolescence, with the sex gap increasing with age.

Boys' cardiorespiratory endurance and muscular strength/endurance performance increased with age, whereas girls' performance increased from age 12 to 16 years before stabilizing. Flexibility remained stable for both boys and girls throughout adolescence. The sex-related differences were large, substantially increasing with age especially after age 15 for cardiorespiratory endurance (boys > girls), slightly increasing with age for muscular strength/endurance performance (boys > girls), and slightly decreasing with age for flexibility (boys < girls).

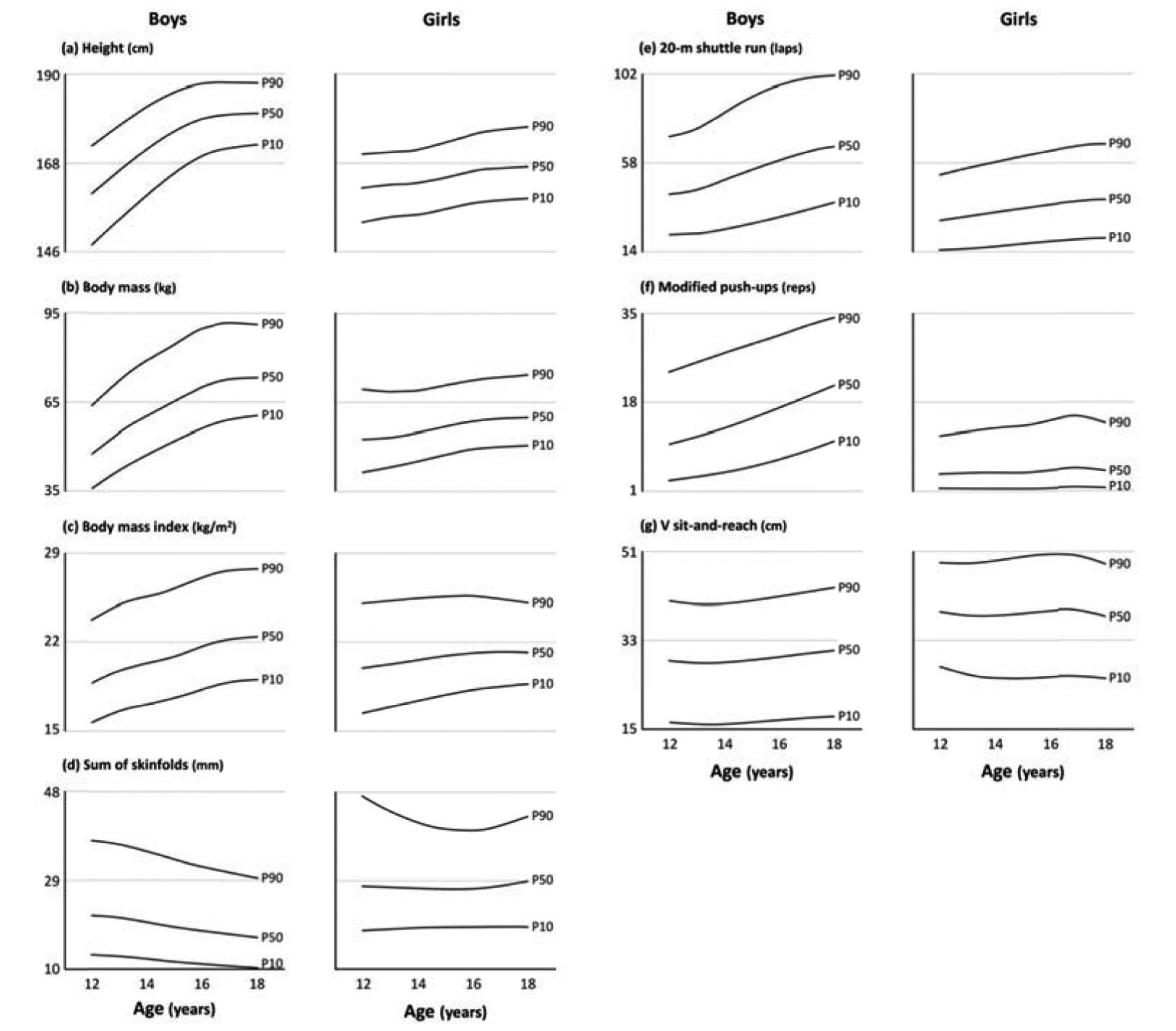

Fig. 2. *Smoothed sex- and age-specific percentile curves (P_{10}, P_{50} and P_{90}).*

(a) height, (b), body mass, (c) body mass index, (d) sum of skinfolds, (e) 20-m shuttle run, (f) modified push-ups, and (g) V sit-and-reach

Table 1. *20-m shuttle run (laps) percentile values by sex and age*

	Age (year)	n	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}
Boys	12.0–12.9	26	22	28	33	38	43	48	53	61	71
	13.0–13.9	104	23	30	35	40	45	50	56	64	75
	14.0–14.9	99	26	33	39	44	50	56	62	71	83
	15.0–15.9	33	28	36	43	49	55	61	68	77	91
	16.0–16.9	71	32	40	47	53	59	66	73	83	96
	17.0–17.9	116	35	44	51	57	64	70	78	87	100
	18.0–18.9	113	39	47	54	60	66	73	80	88	101
Girls	12.0–12.9	40	14	19	23	26	30	33	38	44	52
	13.0–13.9	127	16	20	24	28	32	36	40	46	56
	14.0–14.9	73	17	22	26	30	34	38	43	49	58
	15.0–15.9	17	18	23	27	31	36	40	45	51	61
	16.0–16.9	36	19	25	29	33	38	42	47	54	64
	17.0–17.9	139	20	26	30	35	39	44	49	56	67
	18.0–18.9	93	21	27	31	36	40	45	50	57	67

Table 2. *Modified push-ups (reps) percentile values by sex and age*

	Age (year)	n	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}
Boys	12.0–12.9	26	3	5	6	8	10	12	15	18	24
	13.0–13.9	107	4	6	8	9	11	14	16	20	25
	14.0–14.9	104	5	7	9	11	13	16	18	22	27
	15.0–15.9	33	6	8	11	13	15	17	20	24	29
	16.0–16.9	73	7	10	12	15	17	19	22	26	31
	17.0–17.9	115	9	12	14	17	19	21	24	28	33
	18.0–18.9	118	10	14	16	19	21	24	26	29	34
Girls	12.0–12.9	41	1	2	3	3	4	5	6	8	12
	13.0–13.9	127	1	2	3	3	4	5	7	9	12
	14.0–14.9	80	1	2	3	4	5	6	7	9	13
	15.0–15.9	17	1	2	3	4	5	6	7	10	14
	16.0–16.9	36	1	2	3	4	5	6	8	10	14
	17.0–17.9	149	2	2	3	4	5	6	8	11	15
	18.0–18.9	99	1	2	3	4	5	6	8	10	15

Table 3. *V sit-and-reach (cm) percentile values by sex and age*

	Age (year)	n	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}
Boys	12.0–12.9	26	16.1	20.6	23.7	26.3	28.8	31.2	33.7	36.7	40.8
	13.0–13.9	106	15.9	20.3	23.4	26.0	28.4	30.8	33.3	36.3	40.3
	14.0–14.9	105	16.0	20.4	23.5	26.1	28.5	30.8	33.4	36.3	40.3
	15.0–15.9	33	16.2	20.7	23.8	26.5	28.9	31.3	33.9	36.8	40.8
	16.0–16.9	74	16.6	21.2	24.4	27.1	29.6	32.0	34.6	37.7	41.8
	17.0–17.9	117	17.1	21.8	25.0	27.8	30.3	32.8	35.5	38.6	42.8
	18.0–18.9	119	17.5	22.2	25.5	28.3	30.9	33.5	36.2	39.3	43.7
Girls	12.0–12.9	41	27.4	31.5	34.3	36.6	38.7	40.7	42.9	45.3	48.6
	13.0–13.9	129	26.0	30.4	33.4	35.9	38.1	40.3	42.5	45.1	48.6
	14.0–14.9	81	25.2	30.0	33.2	35.8	38.1	40.4	42.8	45.5	49.1
	15.0–15.9	17	25.1	30.0	33.4	36.1	38.5	40.9	43.3	46.1	49.8
	16.0–16.9	36	25.5	30.4	33.7	36.5	38.9	41.3	43.8	46.6	50.3
	17.0–17.9	152	25.7	30.5	33.8	36.5	38.9	41.2	43.6	46.4	50.1
	18.0–18.9	100	25.2	29.7	32.8	35.4	37.7	39.9	42.2	44.8	48.3

DISCUSSION

We presented updated sex- and age-specific health-related fitness normative-referenced percentile values for Czech youth aged 12–18 years. These normative values can assist with the interpretation of fitness test results by comparing Czech youth scores relative to the reference population. Given that low physical fitness is significantly associated with current and future health (3–10), and high physical fitness is significantly associated with better sports/athletic performance (49–51), our normative values may be useful for fitness and public health screening and surveillance. Such normative-referenced values also add to a growing body of international (19), regional (20), and country-specific health-related fitness norms (21–29) for youth.

Our results are broadly consistent with other studies that have presented health-related fitness normative values for youth (21–29). Typically, boys have higher cardiorespiratory and muscular fitness performance compared to girls, with age-related improvements larger for boys, resulting in a widening sex gap with age (20). On the other hand, girls tend to have higher flexibility compared to boys, with small age-related improvements and a slight closing of the sex gap throughout adolescence (20). In contrast, we found little age-related change in flexibility among Czech youth. Moreover, Czech youth compare favourably to their age- and sex-matched international peers (19). For 20mSRT performance – the only fitness performance test we could directly compare to other norms studies – Czech youth were above average. This favourable result could be the results of international data being older (based on 20mSRT data collected between 1981 and 2014), or because the best performing countries are from central-northern Europe (52). Compared to their age- and sex-matched European peers, Czech boys are average and Czech girls are below average (20).

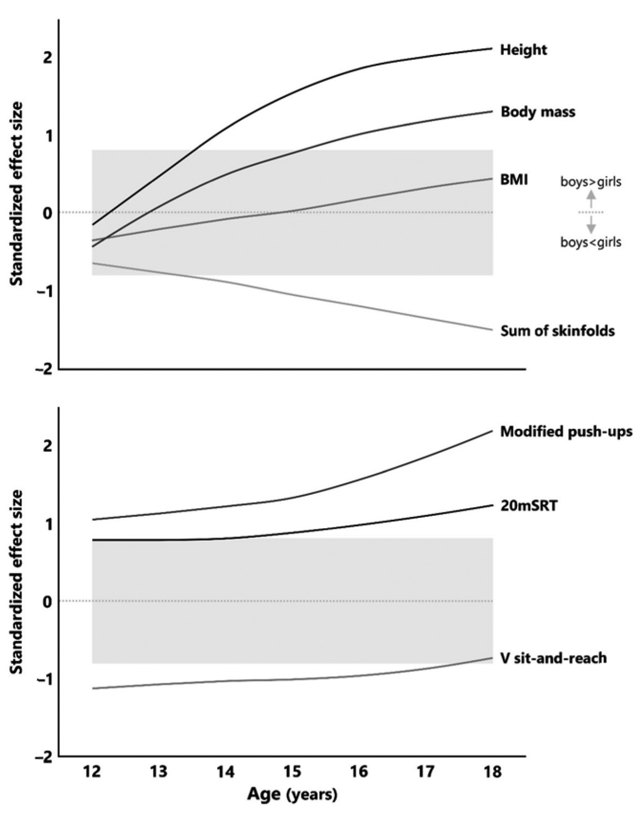

Fig. 3. *Standardized sex-specific differences in mean health-related fitness for Czech youth aged 12–18 years.*

The limits of the grey zone represent the threshold for a large effect size (0.8 or –0.8). Positive effects indicated higher values for boys compared to girls, and negative effects indicated lower values for boys compared to girls.
20mSRT – 20-m shuttle run test; BMI – body mass index

We decided to develop new Czech normative-referenced percentile values, principally because existing normative values were outdated and not available for all tests. For example, despite the fact that national testing of physical fitness in youth has a long history in the Czech Republic (dating back to 1923) (30–33), the last national fitness normative values were published in 1995 (33). Given recent (post-2000) international declines in several health-related fitness components (e.g., cardiorespiratory endurance (12), muscular power (13), muscular endurance (14), our normative values probably correspond better to the health-related fitness of today's Czech youth. Our percentiles could be used to interpret fitness test results using a quintile framework as in previous studies (19, 20). For instance, youth below the 20th percentile can be considered as having "very low" health-related fitness; between the 20th and 40th percentiles, "low" fitness; between the 40th and 60th percentiles, "moderate" fitness; between the 60th and 80th percentiles, "high" fitness; and above the 80th percentile, "very high" fitness. In the absence of universal health-related criterion-referenced cut-points for fitness among youth (53, 54), we support the recommendation of the U.S. National Academy of Medicine (formerly called the Institute of Medicine) (55) for interim cut-points being derived from the bottom quintile (the 20th percentile) based on sex- and age-specific percentile values. Future studies should examine whether such interim cut-points significantly discriminate between youth with high and low health risk. Similarly, our percentiles may be used to identify youth with very high fitness performance for athlete recruitment/selection (56).

Our normative percentiles can help support healthy behaviours through population surveillance systems such as the INDARES, which compares the physical fitness results (as well as physical activity, active transportation, and body composition results) of registered users to existing norms, using it to provide feedback and advice for improvement. The INDARES provides a potential opportunity for other countries to engage in a similar cost-effective public health surveillance strategy. Developed by the Palacký University Olomouc Faculty of Physical Culture in 2006, the INDARES has 63,915 registered users (as of 5 May, 2022), of which 18.1% (11,567) were aged between 11 and 20 years. The physical fitness module** provides detailed descriptions of each fitness test including online instructional videos, immediate written and visual feedback after entering test results, and the ability to report results at both the individual and school class levels. Our normative values will be integrated into the INDARES as 'reference data' and will help provide more accurate feedback to registered youth users. With the revised, more accurate standards, there is the potential for greater expansion within physical education classes or sports/athletic clubs.

This study has several strengths. First, we provided the most up-to-date health-related fitness normative-referenced values for Czech youth aged 12–18 years. Second, because we recruited youth from 32 schools across eight cities representing all historical Czech lands, our normative percentiles are broadly representative of Czech youth. Third, health-related fitness was objectively measured using standard operating procedures and was supervised by a single, experienced researcher. Fourth, we used the LMS method to develop smoothed sex- and age-specific percentiles, from which we quantified sex- and age-related differences as standardized effect sizes.

However, because participation at the individual level was voluntary, it is possible that youth with low fitness levels chose not to participate in fitness testing, resulting in normative values unrepresentative of the population. We therefore conducted a sensitivity analysis and found negligible (ES < 0.2) body size differences between those who did and did not participate in fitness testing, which suggests that our normative-referenced percentiles were unbiased. Another limitation is that schools were only selected from larger cities (the smallest city involved in our study has over 14,000 inhabitants). This could play a role as the literature shows possible differences in physical fitness between youth from urban and rural areas. Our developmental changes in health-related fitness were also limited by the cross-sectional research design. While a longitudinal research design would have been more appropriate for a developmental analysis, it was impractical given our large sample. It was also impractical to assess the biological age of all participants, therefore, only calendar age was recorded. Future studies should examine the maturational differences in health-related fitness among youth. Importantly, several sex-age groups had less than 50 participants, which should not have biased our normative values, but did reduce our confidence in them. Finally, despite being scalable alterna-

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tives of laboratory-based criterion measures, field tests of fitness are affected by factors other than underlying construct fitness.

CONCLUSIONS

This study presents the most up-to-date sex- and age-specific health-related fitness normative-referenced percentile values for Czech youth. We recommend our normative percentiles be used to interpret fitness test results by identifying Czech youth with high or low scores relative to our reference values, or to track age-related changes against our percentile bands. Our normative values may have utility for fitness and public health screening and surveillance. For example, they can inform public health surveillance systems, such as the INDARES, to identify youth with low fitness who might benefit from intervention. Future research should aim to develop health-related criterion-referenced standards for fitness among youth.

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Conflicts of Interest
None declared

Authors' Contributions
LR and GRT – concept and design; LR and MV – data collection; LR – data collection supervision; LR and GRT – final dataset, data analysis and interpretation; LR – draft manuscript with GRT and JJL collaboration. All authors contributed to the interpretation of results, editing and critical reviewing of the final manuscript, and approved the final manuscript.

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Electronic Supplementary Materials
The dataset analysed during the study is available in the Figshare repository (https://doi.org/10.6084/m9.figshare.19945802). This article contains supplementary material available at https://doi.org/10.21101/cejph.a7645.

REFERENCES

1. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100(2):126-31.
2. Pate RR. The evolving definition of physical fitness. Quest. 1988;40(3):174-9.
3. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Int J Behav Nutr Phys Act. 2010;7(1):40. doi: 10.1186/1479-5868-7-40.
4. Bermejo-Cantarero A, Álvarez-Bueno C, Martínez-Vizcaino V, Redondo-Tébar A, Pozuelo-Carrascosa DP, Sánchez-López M. Relationship between both cardiorespiratory and muscular fitness and health-related quality of life in children and adolescents: a systematic review and meta-analysis of observational studies. Health Qual Life Outcomes. 2021;19:127. doi: 10.1186/s12955-021-01766-0.
5. Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. Sport Med. 2014;44(9):1209-23.
6. Blair SN, Cheng Y, Holder JS. Is physical activity or physical fitness more important in defining health benefits? Med Sci Sports Exerc. 2001;33(6 Suppl):S379-99; discussion S419-20.
7. 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. Sport Med. 2019;49(7):1079-94.
8. Garciá-Hermoso A, Ramírez-Vélez R, Garciá-Alonso Y, Alonso-Martínez AM, Izquierdo M. Association of cardiorespiratory fitness levels during youth with health risk later in life: a systematic review and meta-analysis. JAMA Pediatr. 2020;174(10):952-60.
9. Ruiz JR, Castro-Piñero J, Artero EG, Ortega FB, Sjöström M, Suni J, et al. Predictive validity of health-related fitness in youth: a systematic review. Br J Sports Med. 2009;43(12):909-23.
10. García-Hermoso A, Izquierdo M, Ramírez-Vélez R. Tracking of physical fitness levels from childhood and adolescence to adulthood: a systematic review and meta-analysis. Transl Pediatr. 2022;11(4):474-86.
11. Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes. 2008;32(1):1-11.
12. Tomkinson GR, Lang JJ, Tremblay MS. Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014. Br J Sports Med. 2019;53(8):478-86.
13. Tomkinson GR, Kaster T, Dooley FL, Fitzgerald JS, Annandale M, Ferrar K, et al. Temporal trends in the standing broad jump performance of 10,940,801 children and adolescents between 1960 and 2017. Sport Med. 2021;51(3):531-48.
14. Kaster T, Dooley FL, Fitzgerald JS, Walch TJ, Annandale M, Ferrar K, et al. Temporal trends in the sit-ups performance of 9,939,289 children and adolescents between 1964 and 2017. J Sports Sci. 2020;38(16):1913-23.
15. Dooley FL, Kaster T, Fitzgerald JS, Walch TJ, Annandale M, Ferrar K, et al. A systematic analysis of temporal trends in the handgrip strength of 2,216,320 children and adolescents between 1967 and 2017. Sport Med. 2020;50(6):1129-44.
16. Lang JJ, Tomkinson GR, Janssen I, Ruiz JR, Ortega FB, Léger L, et al. Making a case for cardiorespiratory fitness surveillance among children and youth. Exerc Sport Sci Rev. 2018;46(2):66-75.
17. Chmelík F, Frömel K, Křen F, Stelzer J, Engelová L, Kudláček M, et al. The verification of the usability of the online Indares.com system in collecting data on physical activity – pilot study. Acta Univ Palacki Olomuc Gymnica. 2008;38(4):59-66.
18. Hoffman J. Norms for fitness, performance, and health. 1st ed. Champaign: Human Kinetics; 2006.
19. Tomkinson GR, Lang JJ, Tremblay MS, Dale M, LeBlanc AG, Belanger K, 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(21):1545-54.
20. Tomkinson GR, Carver KD, Atkinson F, Daniell ND, Lewis LK, Fitzgerald JS, 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. 2017;52(22):1445-56.
21. Catley MJ, Tomkinson GR. Normative health-related fitness values for children: analysis of 85347 test results on 9–17-year-old Australians since 1985. Br J Sports Med. 2013;47(2):98-108.
22. Hoffmann MD, Colley RC, Doyon CY, Wong SL, Tomkinson GR, Lang JJ. Normative-referenced percentile values for physical fitness among Canadians. Heal Reports. 2019;30(10):14-22.
23. Tambalis KD, Panagiotakos DB, Psarra G, Daskalakis S, Kavouras SA, Geladas N, 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(6):736-46.
24. Vanhelst J, Labreuche J, Béghin L, Drumez E, Fardy PS, Chapelot D, et al. Physical fitness reference standards in French youth: The BOUGE program. J Strength Cond Res. 2017;31(6):1709-18.
25. Vanhelst J, Ternynck C, Ovigneur H, Deschamps T. Normative health-related fitness values for French children: The Diagnoform programme. Scand J Med Sci Sport. 2020;30(4):690-9.
26. 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(4):340-51.

27. Santos R, Mota J, Santos DA, Silva AM, Baptista F, Sardinha LB. Physical fitness percentiles for Portuguese children and adolescents aged 10–18 years. J Sports Sci. 2014;32(16):1510-8.
28. Gulías-González R, Sánchez-López M, Olivas-Bravo Á, Solera-Martínez M, Martínez-Vizcaíno V. Physical fitness in Spanish schoolchildren aged 6-12 years: reference values of the battery EUROFIT and associated cardiovascular risk. J Sch Health. 2014;84(10):625-35.
29. Sandercock G, Voss C, Cohen D, Taylor M, Stasinopoulos DM. Centile curves and normative values for the twenty metre shuttle-run test in English schoolchildren. J Sports Sci. 2012;30(7):679-87.
30. Roubal E, Roubal J. [Physical maturity of secondary school students as measured in 1923]. Anthropologie. 1925;3(1):45-58. Czech.
31. Pávek F. [Physical performance of 7- to 19-year-old youth of the Czechoslovak Socialist Republic]. Prague: Olympia; 1977. Czech
32. Moravec R, Havlíček I, Kasa J, Ramacsay L, Scholzová A, Šelingerová M, et al. [Physical, functional development and physical performance of 7–18 years old youth in the Czech and Slovak Federative Republic]. Bratislava: Slovšport; 1990. Slovak.
33. Měkota K, Kovář R, Chytráčková J, Kohoutek M, Gajda V, Moravec R. UNIFITTEST (6–60). Tests and norms of motor performance and physical fitness in youth and adult age. Acta Univ Palacki Olomuc Gymnica. 1995;25(1 Suppl):S7-108.
34. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. Stat Med. 1992;11(10):1305-19.
35. Cain KL, Salmon J, Conway TL, Cerin E, Hinckson E, Mitáš J, et al. International Physical Activity and Built Environment Study of adolescents: IPEN Adolescent design, protocol and measures. BMJ Open. 2021;11(1):e046636. doi: 10.1136/bmjopen-2020-046636.
36. Mitáš J, Dygrýn J, Rubín L, Křen F, Vorlíček M, Nykodým J, et al. [Multifactorial research on built environment, active lifestyle and physical fitness in Czech adolescents: Design and methods of the study]. Tělesná Kult. 2018;41(1):17-24. Czech.
37. Rubín L, Mitáš J, Dygrýn J, Vorlíček M, Nykodým J, Řepka E, et al. [Physical activity and physical fitness of Czech adolescents in the context of the urban environment]. Olomouc: Palacký university Olomouc; 2018. Czech
38. Voss LD, Bailey BJ. Equipping the community to measure children's height: the reliability of portable instruments. Arch Dis Child. 1994;70(6):469-71.
39. Groffik D, Fromel K, Badura P. Composition of weekly physical activity in adolescents by level of physical activity. BMC Public Health. 2020;20:562. doi: 10.1186/s12889-020-08711-8.
40. Bonham MP, Dordevic AL, Ware RS, Brennan L, Truby H. Evaluation of a commercially delivered weight management program for adolescents. J Pediatr. 2017;185:73-80.
41. The Cooper Institute. FitnessGram administration manual. 5th ed. Champaign: Human Kinetics; 2017.
42. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, et al. Skinfold equations for estimation of body fatness in children and youth. Hum Biol. 1988;60(5):709-23.
43. Plowman SA, Meredith MD, editors. Fitnessgram/Activitygram reference guide. 4th ed. Dallas: The Cooper Institute; 2013.
44. Nevill AM, Ramsbottom R, Sandercock G, Bocachica-González CE, Ramírez-Vélez R, Tomkinson G. Developing a new curvilinear allometric model to improve the fit and validity of the 20-m shuttle tun test as a predictor of cardiorespiratory fitness in adults and youth. Sport Med. 2021;51(7):1581-9.
45. Tomkinson GR, Lang JJ, Blanchard J, Léger LA, Tremblay MS. The 20-m shuttle run: assessment and interpretation of data in relation to youth aerobic fitness and health. Pediatr Exerc Sci. 2019;31(2):152-63.
46. Cuberek R, Machová I, Lipenská M. Reliability of V sit-and-reach test used for flexibility self-assessment in females. Acta Univ Palacki Olomuc Gymnica. 2013;43(1):35-9.
47. Pan H, Cole T. User's guide to LMSchartmaker. Swindon: Medical Research Council; 2011.
48. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Mahwah: Lawrence Erlbaum Associates; 1988.
49. Armstrong N, Tomkinson GR, Ekelund U. Aerobic fitness and its relationship to sport, exercise training and habitual physical activity during youth. Br J Sports Med. 2011;45(11):849-58.
50. Johnston K, Wattie N, Schorer J, Baker J. Talent identification in sport: a systematic review. Sport Med. 2018;48(1):97-109.
51. Till K, Morris R, Emmonds S, Jones B, Cobley S. Enhancing the evaluation and interpretation of fitness testing data within youth athletes. Strength Cond J. 2018;40(5):24-33.
52. Lang JJ, Tremblay MS, Léger L, Olds T, Tomkinson GR. 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(4):276. doi: 10.1136/bjsports-2016-096224.
53. Fraser BJ, Rollo S, Sampson M, Magnussen CG, Lang JJ, Tremblay MS, et al. Health-related criterion-referenced cut-points for musculoskeletal fitness among youth: a systematic review. Sport Med. 2021;51(12):2629-46.
54. Rollo S, Fraser BJ, Seguin N, Sampson M, Lang JJ, Tomkinson GR, et al. Health-related criterion-referenced cut-points for cardiorespiratory fitness among youth: a systematic review. Sport Med. 2022;52(1):101-22.
55. Pate R, Oria M, Pillsbury L, editors. Fitness measures and health outcomes in youth. Washington, DC: National Academies Press; 2012.
56. Henriques-Neto D, Hetherington-Rauth M, Magalhães JP, Correia I, Júdice PB, Sardinha LB. Physical fitness tests as an indicator of potential athletes in a large sample of youth. Clin Physiol Funct Imaging. 2022;42(2):88-95.

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