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Centile Reference Curves of the SLOfit Physical Fitness Tests for School-Aged Children and Adolescents

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Abstract

Blagus, R, Jurak, G, Starc, G, and Leskošek, B. Centile reference curves of the SLOfit physical fitness tests for school-aged children and adolescents. *J Strength Cond Res* 37(2): 328–336, 2023—The study provides sex- and age-specific centile norms of Slovenian children and youth. Physical fitness was assessed using the SLOfit test battery on population data, including 185,222 children, aged 6–19 years, measured in April and May 2018. Centile curves for both sexes and 12 test items were constructed using the generalized additive models for location, scale, and shape (GAMLSS). Boys generally achieved higher scores in most of the physical fitness tests, except in stand and reach, but this was not consistent throughout childhood and adolescence, nor did it pertain to the entire range of performance. Girls outperformed boys in the arm-plate tapping test throughout childhood; the poorest performing girls outperformed the poorest performing boys in the 600-m run, 60-m dash, backward obstacle course, and standing broad jump. The shapes and trends of physical fitness curves adequately reflect the effects of growth and development on boys' and girls' physical performance. Comparing the existing reference fitness curves showed that Slovenian children and adolescents display higher fitness levels than their peers from other countries. This study provides the most up-to-date sex- and age-specific reference fitness centile curves of Slovenian children, which can be used as benchmark values for health and fitness monitoring and surveillance systems.

Key Words: normative values, muscular fitness, cardiorespiratory fitness, neuromuscular fitness

Introduction

Considerable and predominantly negative changes in secular trends of children's physical fitness and somatic development have been identified in the previous 4 decades (1,16,26,31,37,45,54,59,60,64) with rare exceptions (40). Thus, it is increasingly important to follow individual and population fitness levels to identify adverse trends and implement appropriate early interventions (9,38).

Physical fitness testing can serve as an essential educational tool for the improvement of the physical literacy of children (65), but (equally important) the results of physical fitness tests allow for the identification of children and youth with problems in physical and motor development, which can be effectively addressed with the evidence-based planning of adapted individual approaches and the consequent setting of differentiated learning goals (29). However, the assessment of adequate physical fitness requires sex- and age-specific reference values, against which individual and population physical fitness status can be compared, enables meaningful interpretation of development in children and adolescents, and provides comprehensive feedback to teachers, adolescents, children, parents, and policymakers (28).

In the previous decade, a few physical fitness reference values for children and youth were developed either in the form of test-specific reference centile values or without reference curves (5–8,13–15,17,20–22,25,32,33,39,42,46–48,51,52,54,62). The majority of these reference values and curves are linked to test batteries, which have been used in research projects, on non-representative samples, and were not designed for population surveillance purposes. To date, only a handful of fitness test batteries and protocols have been implemented as national physical fitness surveillance systems for school children in Europe; SLOfit (Slovenia) (29), FITescola (Portugal) (24), NETFIT (Hungary) (11), and Move! (Finland) (27); these represent valuable sources of fitness data, which can be used for research and pedagogical purposes, and informed policymaking in education and public health (30).

This study's primary objective was to obtain and describe the sex- and age-specific physical fitness percentiles for Slovenian children aged 6–19 years, based on the 2018 population data. The Slovenian National SLOfit surveillance system for children and youth's somatic and motor development is one of the world's oldest and best-integrated systems. It has been used to assess the physical fitness of 6- to 19-year olds longitudinally on the population level since 1987 (29).

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (http://journals.lww.com/nsca-jscr).

Journal of Strength and Conditioning Research 37(2)/328–336

Methods

Experimental Approach to the Problem

The SLOfit system is a population-based national surveillance system of children and youth's somatic and motor development in Slovenia. All primary and secondary schools in Slovenia have been using a standardized protocol to gather the population data on 8 fitness tests and 3 anthropometric measurements (Table 1) every April since 1987 (29). In the previous decade, the somatic growth of Slovenian children and youth has stabilized (55), and the 2018 data has been used to create age- and sex-specific growth curves for all tests of the SLOfit test battery.

Subjects

The target population was pupils and students from all Slovenian primary and secondary schools, aged 6–19 years at the time of measurement. The study did not include children and youth with special needs, enrolled in special educational institutions, or children with physical disabilities that prevent them from participating in physical fitness testing. The sample included all students who participated in the SLOfit physical fitness surveillance system in April and May 2018 and had valid scores on at least 1 of the test items comprising the SLOfit test battery (Table 1). The final sample consisted of 213,879 students (108,645 or 50.8% male); of which, 170,742 (79.8%) were from 458 primary schools and 43,137 (20.2%) were from 133 secondary schools. The subjects had no acute or chronic medical conditions that would prevent their safe participation on the day of measurements, and written informed consent was obtained from the parent or guardian to participate in SLOfit. The final sample included 95.3% of all primary school students and 63.3% of all secondary school students in that academic year. The research has been performed under the Declaration of Helsinki. All the aspects of the SLOfit measurement research protocols were reviewed and approved by the National Medical Ethics Committee of the Republic of Slovenia (ID 102/03/15).

Procedures

Physical education (PE) teachers perform the annual SLOfit testing in schools with the support of classroom teachers. Faculty of Sport, University of Ljubljana, is the only institution in Slovenia that educates physical education teachers who are thoroughly trained for the task in various courses during their study. All the schools follow the same testing protocol and use standard equipment. The results are sent to the Laboratory for Diagnostics of Somatic and Motor Development at the Faculty of Sport, University of Ljubljana. The main SLOfit administrator uses specially designed software to check the data for logical errors separately for each item of the SLOfit test battery and communicates the eventual needs for corrections to teachers.

As the method used for constructing the centile curves is sensitive to outliers (potentially leading to convergence issues), multivariate outliers were identified and removed after this initial data cleansing. For each physical fitness measure (hereafter referred to as "the test"), a multivariate regression model was fitted, including the test as the dependent variable and all other anthropometric and physical fitness measures, as well as age and gender, as independent variables. Studentized residuals were obtained, and then 0.1% of the subjects with the smallest and 0.1% with the largest studentized residuals were removed from further analysis. To ensure the representativeness of the studied sample, weights were computed via iterative poststratification (also known as iterative proportional fitting) (35) to match the sample joint distributions by age, gender, and region to population data. Population data were obtained from the Statistical Office of the Republic of Slovenia (3). When necessary, the sample weights were trimmed (trimming the weights outside the [0.3, 3] interval) to avoid substantial sampling variances (35).

Table 1

Somatic and physical fitness measures in the SLOfit test battery.

Test	Abbreviation	Component
Body height (cm)	BH	Somatic characteristic
Body mass (kg)	BW	Somatic characteristic
Body mass index (kg·m^{-2})	BMI	Somatic characteristic
Triceps skinfold (mm)	TSF	Somatic characteristic
600-m run (s)	R600	Cardiorespiratory fitness component
60-second sit-ups (reps)	SU60	Muscular fitness component
Bent-arm hang (s)	BAH	Muscular fitness component
Stand-and-reach (cm)	SAR	Flexibility
20-second arm-plate tapping (reps)	APT	Neuromuscular fitness component
Standing broad jump (cm)	SBJ	Muscular fitness component
Backwards obstacle course (s)	BOC	Neuromuscular fitness component
60-m dash (s)	D60	Neuromuscular fitness component

Statistical Analyses

Centile curves and reference values were obtained using Generalized Additive Models for Location, Scale and Shape (GAMLSS) (43). Several continuous distributions (Box-Cox Cole and Green [BCCG], Box-Cox power exponential [BCPE], Box-Cox-t [BCT], generalized inverse Gaussian) or discrete distributions (Negative Binomial type I, Delaporte, Burr type XII [BURR]) were fitted to the data as appropriate, optimizing the degrees of freedom (DF) for P-splines fit for all parameters of the respective distributions using Schwarz Bayesian criterion (SBC) (50). Appropriate link functions were used for the parameters. Box-Cox Cole and Green is routinely used in the Lambda Mu Sigma (LMS) method (10). Box-Cox power exponential and BCT are extensions of LMS, adding an extra parameter, ν, to allow modeling (positive or negative) kurtosis (with $\nu = 2$ BCPE and BCCG [LMS] coincide). The best-fitted model was selected based on SBC, observation of worm plot (61), Q-statistics calculations (44), and estimated and empirical centiles comparison. In all the models, $\lambda = 0.5$ was used for the power transformation of age. Separate analyses were performed for boys and girls. Many zeros were present in the data for bent-arm hang (BAH). Here, we used a zero-adjusted mixed distribution, which has a point probability at zero but has a continuous distribution (BCCG, BCPE, and BCT). Degrees of freedoms for P-splines fit for the extra parameter were optimized, as described previously. The analysis was performed using the R language for statistical computing (R version 3.6.3, R Foundation for Statistical Computing, Vienna, Austria); GAMLSS were fitted using the R packages gamlss and gamlss.inf (34).

The best-fitted models with the optimal DFs for the P-splines fit for all parameters of the respective distributions and SBC for each gender are reported in Supplemental Digital Content (see Table 1, Supplemental Digital Content 1, http://links.lww.com/JSCR/A326). We report also the proportion of boys and girls below the estimated centiles for the best-fitted model (see Table 2, Supplemental Digital Content 1, http://links.lww.com/JSCR/A326). Considering sample weights, we divided the sample into 1-year age groups, truncated to

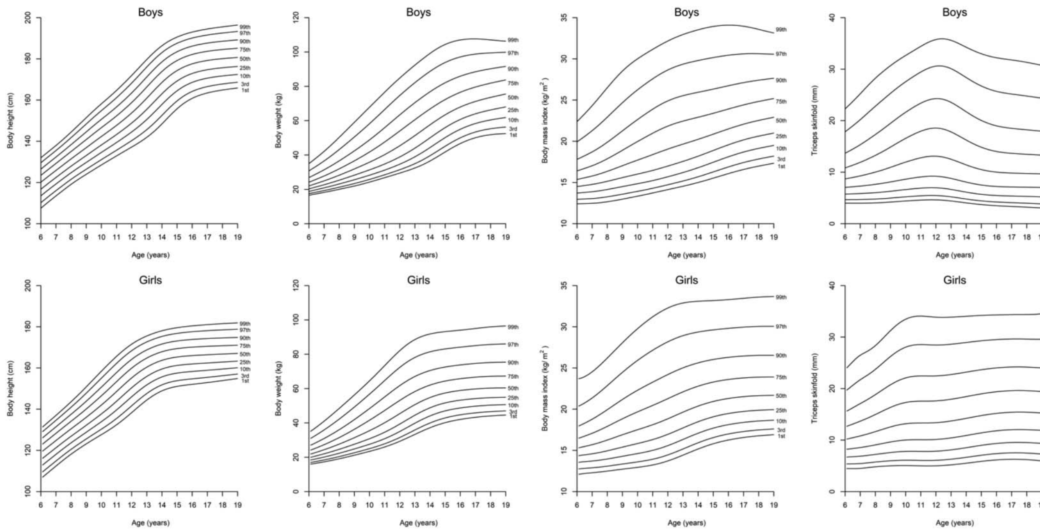

Figure 1. Smoothed reference curves for the 1st, 3rd, 10th, 25th, 50th, 75th, 90th, 97th, and 99th centiles of BH, BW, BMI, and TSF in 6- to 19-year-old Slovenian boys and girls.

integers, computed empirical centiles for each group, and compare the empirical and predicted centiles for boys and girls, respectively (see Figures 1 and 2, Supplemental Digital Content 1, http://links.lww.com/JSCR/A326). We can conclude that the fit is generally reasonable by comparing the empirical and predicted centiles, observing the worm plots, and examining the Q-statistics.

Results

Centile curves for the 1st, 3rd, 10th, 25th, 50th, 75th, 90th, 97th, and 99th centiles for somatic characteristics and physical fitness tests are shown in Figures 1–3, whereas the reference values for all centiles are shown in Supplemental digital Content 1 (see Tables 3–14, http://links.lww.com/JSCR/A326).

Lower centiles indicate better performance for the time-related tests, backward obstacle course, 600-m run, and 60-m dash. Therefore, the centiles must be interpreted in an ascending way (i.e., the 1st centile means the best performance, and the 99th centile means the poorest performance).

Looking at triceps skinfold, one observes a steady increase for both boys and girls up to age 12 and 10 years, respectively; however, the values start decreasing afterward in boys (especially with higher centiles) but not in girls; for whom (although it is less pronounced in younger ages), an increase is also observed in older ages. When considering physical fitness measures, one observes uniform and steady improvements in older boys over the centiles. There is also a noticeable deviation from the trend at around 12 years, at which the improvement with increasing age is not as significant as observed in other ages or as observed for in the case of BAH, the performance even decreases in higher centiles, or in the case of the standing broad jump, for which this is observed in the lower centiles. Consistent improvement across the centiles with increasing age can be observed in girls up to around 12 years.

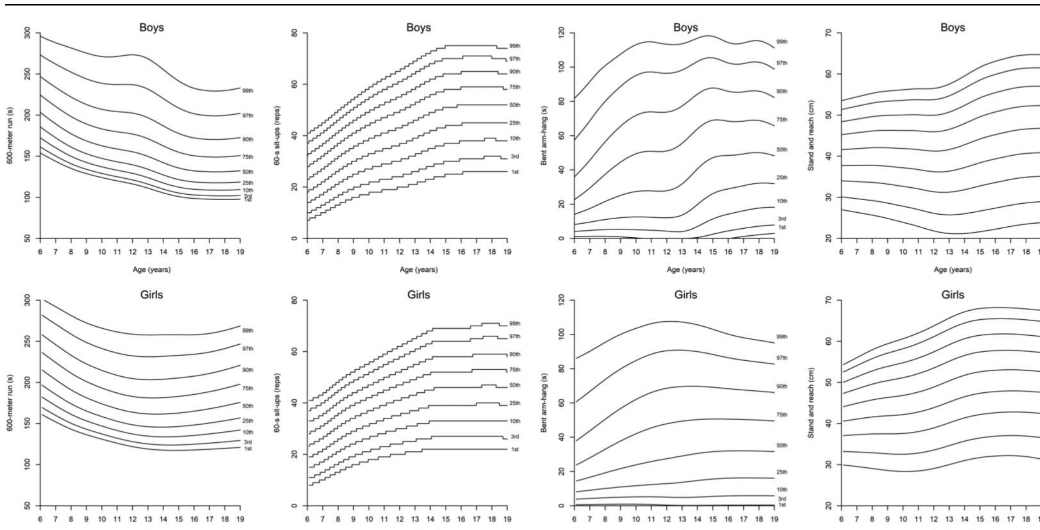

Figure 2. Smoothed reference curves for the 1st, 3rd, 10th, 25th, 50th, 75th, 90th, 97th, and 99th centiles of R600, SU60, BAH, and SAR in 6- to 19-year-old Slovenian boys and girls.

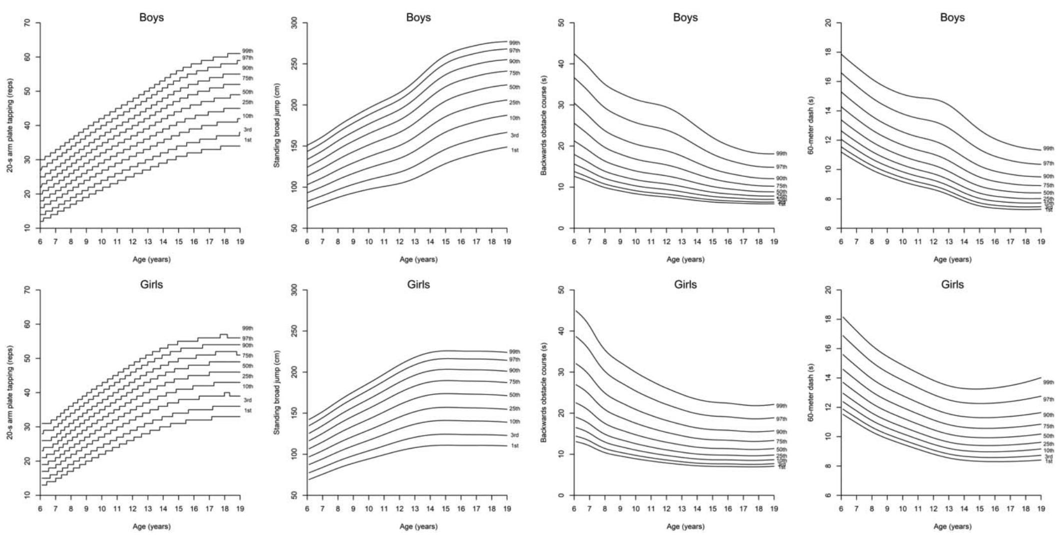

Figure 3. Smoothed reference curves for the 1st, 3rd, 10th, 25th, 50th, 75th, 90th, 97th, and 99th centiles of APT, SBJ, BOC, and D60 in 6- to 19-year-old Slovenian boys and girls.

Afterward, the results remain similar or slightly decline with increasing age, as observed in the 600-m dash and 600-m run (more evident in higher centiles for both tests).

Centile curves for the 1st, 3rd, 10th, 25th, 50th, 75th, 90th, 97th, and 99th centiles of somatic characteristics and physical fitness tests for boys and girls are shown in Figure 4. Comparing the somatic characteristics between boys and girls, one observes that the boys were, in general, taller (the exception being children between 9 and 14 years; among whom [depending on the centile], the girls were taller than boys uniformly over the centiles) and heavier (the exception being children around 10 to 14 years; among whom, boys had lower values in lower centiles); they had larger body mass index and lower triceps skinfold than girls had (the exception being children around 10 to 14 years; among whom, boys had higher values in higher centiles).

Uniformly and across the centiles and ages, girls performed better than boys in the stand-and-reach test with the difference increasing up to 12 to 15 years (depending on the centiles, with differences in lower centiles increasing until later ages) and decreasing afterward. Comparing the differences across the centiles, one can observe much more significant differences in younger and older children than middle-aged children (especially between 10 and 12 years).

Boys performed better than girls in standing broad jump, with a constant difference up to age 10 years, observable uniformly over the centiles and ages. Afterward, the difference decreased, reaching its lowest value at around 12 years before increasing rapidly. Boys also performed better than girls in the backward obstacle course, 600-m dash and 600-m run, but not uniformly over all centiles and age groups. In age groups between 8 and 16 years, girls performed better than boys in higher centiles (with the range being more extensive in higher centiles). In the BAH test, boys also achieved higher results than girls except for the youngest children: girls performed better in certain centiles. The difference decreased (uniformly over the centiles) at around 12 years but then increased rapidly at older ages.

Girls performed similarly or even better than boys in 20-second arm plate tapping uniformly over the centiles up to around 14 years. Nevertheless, boys outperformed girls in older ages, with the difference being especially pronounced in the higher centiles.

The difference between boys and girls increased with age for 60-second sit-ups, with boys outperforming girls. The only exception was observable in the lowest centile where girls performed similarly or even better than boys up to around 13 years of age when the situation was reversed.

Discussion

The present study provides data on population age- and sex-specific physical fitness centile references in healthy Slovenian children and youth aged between 6 and 19 years. Our findings confirm the growth of the majority of components of physical fitness throughout childhood across the centiles and a somewhat less accelerated growth or plateauing in adolescence, which is similar to prevailing evidence (57). Since the existing fitness reference curves from other studies are based on heterogeneous physical fitness tests, not included in the SLOfit test battery, the direct comparison of the centile curves is mostly impossible, but it is possible to compare the developmental trends of the tests and curve shapes, covering the same fitness components: neuromuscular, muscular or cardiorespiratory ones, and flexibility.

The 20-second arm plate tapping results showed accelerated improvement until 15 years in boys and girls for the neuromuscular fitness components. The constant improvement of speed and coordination of alternate arm movement in childhood is consistent with the trends among Spanish children (22) and other European children and adolescents until 17 years (58). Our findings also cover late adolescence until 19 years and show that after 17 years, the results of this test continue to improve among boys, although with less pronounced acceleration than before, while the results plateau across the centiles in girls. The backward obstacle course results, which indicate the agility and coordination of whole-body movement, were improving throughout the entire childhood and adolescence in boys, with a slight deceleration between 10 and 12 years, when boys were experiencing the accelerated growth of height and subcutaneous fat. Still, they started plateauing around 15 years in girls. Although this test is specific for the SLOfit test battery, the comparison of the centile curves of this test with the centile curves of other tests of agility and speed shows that the curves are similar to the curves of the star agility run (20), 4 × 10 m shuttle-run (14,21,58), and 5-10-5 shuttle run (53). Compared with the European curves of the

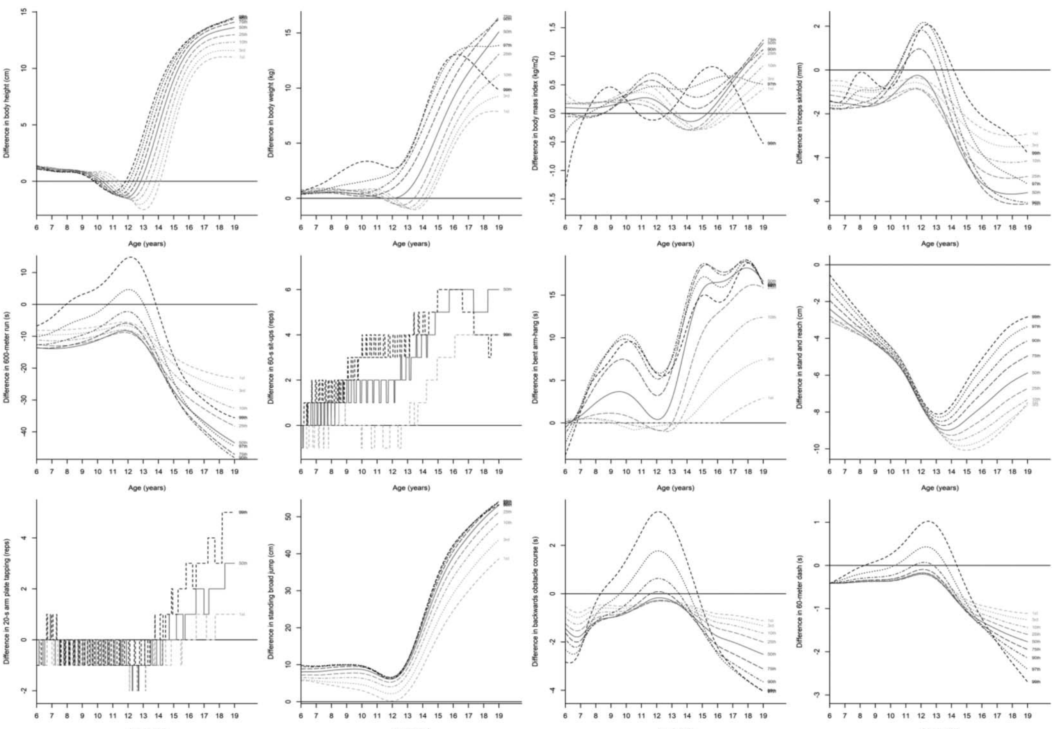

Figure 4. Differences in the smoothed reference curves for the 1st, 3rd, 10th, 25th, 50th, 75th, 90th, 97th, and 99th centiles of somatic characteristics and physical fitness tests between 6- and 19-year-old Slovenian boys and girls. Girl's results are used as a reference point. For APT and SU60, only the 1st, 50th, and 99th centiles are shown to clarify the presentation.

4 × 10 m shuttle run test (58), the plateauing in agility and speed in girls started at 12 years. In contrast, the Slovenian girls experienced the plateauing 3 years later. The 60-m dash curves also resemble the trends observed in other tests of speed, such as the 5-second sprinting test (63), 50-m dash test (8,15), or 50-yard dash test (14). In boys, sprinting speed increased throughout childhood and adolescence with slight deceleration between 11 and 13 years, which was also observed in Polish boys (15) and (in Slovenian data) coinciding with the growth acceleration of triceps skinfold in this age period. The presented curves of triceps skinfold thickness and 60-m dash show that increased fat mass, naturally accumulated before the pubertal growth spurt, coincides with a temporary decrease of the pace of sprinting speed development. In girls, sprinting speed plateauing started at 14 years, which was previously observed in Polish (15) and Australian (8) girls, who also have reference values available for the late adolescence period. Comparing the values of the Slovenian 50th centile with Australian and Polish 50th centile at 12 years, the sprinting speed on a 10-m longer distance was 0.29 and 0.36 m·s^{-1} higher in Slovenian boys and girls, respectively.

The produced centile curves for muscular fitness components also confirmed the previously identified developmental trends. The standing broad jump test is the most widely used test of explosive strength, and the directions of centile curves based on Slovenian data were similar to the ones from previous studies in other countries (8,11,14,15,18,21,22,25,39,42,52,56,58,63). The curves followed a similar pattern as the 60-m dash curves, with boys showing slight deceleration between 11 and 13 years and girls plateauing after 14 years. However, the difference in centile values between children and youth from Slovenia and other countries was considerable. Comparing the 50th centile of 10-year olds from our population and the samples above, it is found that the values of 10-year-old Slovenian boys and girls in standing broad jump were 19 and 23 cm higher at this centile than in other national reference curves, respectively. At the 50th centile of 10-year olds in Slovenia, the sprinting speed also exceeded the 50th centile of different national curves at 11 years. Although Slovenian boys were outperforming girls of this age in standing broad jump by approximately 8 cm, the results of 10-year-old Slovenian girls at 50th centile were higher than that in the same centile of boys from the aforementioned national curves by 4–23 cm. This confirms the extraordinary progress of girls' motor development in Slovenia in the past 2 decades because of high-quality and emancipatory school physical education (40). The centile curves of the 60-second sit-up test, measuring abdominal muscle strength, shows progressive development throughout childhood, but the curves start plateauing at 14 years in boys and girls. The childhood trends are consistent with the existing centile curves of 30-second sit-up test in childhood and early adolescence (22), although, in the existing curves, the plateauing of the results occurs around 14 years in boys and between ages 11 and 12 years in girls (21,56); however, in our case, the results of boys started plateauing later at 15 years in boys and at 14 years in girls. In the European 30-second sit-up test reference curves (58), the plateauing was not observed in boys, but it started at 11 years in girls. The Slovenian 60-second sit-up curves are very similar to the Polish (15) 30-second sit-up curves in boys because both show plateauing after age 14 years. Still, in girls, the results of the Polish population seem to plateau around 10 years, which is 4 years earlier than in Slovenian girls. Similarly, the existing 180-second sit-up test curves show plateauing after 14 years in boys and after 13 years in girls (8). The curves of the curl-up test, which also measures abdominal muscle strength, do not show any plateauing, but they show a decelerating trend in girls after 12 years and in boys after 14 years (49). Although less pronounced than in standing broad jump, and not directly comparable, it seems that the sit-up test values of the 50th centile in Slovenian boys and girls are higher than in other national curves. Specifically, if we compare the 50th centile curve of the aforementioned 30-second sit-up curves at 14 years (when plateauing of the curve starts in Slovenian population) with the same curve of the Slovenian 60-second sit-ups, and simply double the results of the 50th centiles 30-second sit-up curves from other countries, Slovenian centile of boys is 4.5 repetitions higher and Slovenian centile of girls 7.6 repetitions higher. The BAH centile curves of Slovenian boys and girls differ considerably from the existing centile curves from other countries (21,22,58), which also vary greatly among themselves but are similar to the centile curves of the Polish population (15). The difference in the shapes of our reference curves and the existing reference curves, based on the EUROFIT version of the BAH, is probably linked also to the fact that this pronated grip version of the test is too demanding for many children, which results in a large proportion of children who score zero, which has been evidenced in other studies (21,22).

The Slovenian population's endurance strength of arms and shoulders progressed steadily until 11 years in boys and girls. Still, it decelerated in girls until 14 years, after which it started declining in higher and plateauing in lower centiles. In boys, a temporary decline occurred between 11 and 13 years but continued to progress until 15 years, when it started plateauing or declining in the highest centiles. The temporal decrease in the BAH in boys fits perfectly with the period of the most significant acceleration of triceps skinfold thickness, which logically results in a more significant fat burden and the consequent decline of the test results. Such trends, although less pronounced, are visible also on the Polish (15) and Spanish (22) reference curves but are completely absent from the European (58) and Macedonian (21) ones. In girls, the European reference curves (58) demonstrate a plateauing trend of BAH results throughout childhood and adolescence, which was not the case in Slovenian reference curves or other published reference curves (15,21,22). Although the BAH test in the SLOfit test battery is performed with a supinated grip, which is different from EUROFIT version of the test, which uses the more demanding pronated grip version, the difference in 50th centile values between Slovenian and other international curves was very pronounced. Even if we speculate the pronated grip version to be 50% more demanding and reduce the results of the Slovenian boys and girls by half, the values at 50th centile of Slovenian boys and girls is 44 and 62% higher than in the international curves.

The stand-and-reach reference curves resemble the existing references (15,20,39) as well as the sit-and-reach (8,14,22,25,33,56,58) and modified-backsaver-sit-and-reach (49) reference curves. Girls outperformed boys throughout childhood and adolescence, and the sex differences were also observable in the curves' trends. Although girls were experiencing constant improvement of the test results throughout childhood and adolescence, the boys were experiencing a typical declining trend until 13 years, when the positive trend prevailed until the end of adolescence. The pronounced decline in boys between 11 and 13 years corresponded to the pronounced increase of triceps skinfold thickness in this period, which indicated the pubertal growth spurt. A direct comparison of the 50th centile of Slovenian 10-year-old boys and girls with the aforementioned existing stand-and-reach references of their peers from Germany (20,39) and Poland (15) show on average approximately 9% greater flexibility of Slovenian children at this centile. When adjusting the aforementioned sit-and-reach reference curves to the stand-and-reach curves, the 50th centile of Slovenian boys and girls is approximately 5 and 10% higher than in other international curves.

The cardiorespiratory component of physical fitness in SLOfit is assessed by the reference curves of the 600-m run, which can be compared with the reference of the 20-m shuttle run test (8,15,25,33,56,58), Cooper test (15), 1-mile run/walk test (14), and 9-minute run (20) or treadmill exercise test (17,39). In boys, the results of the 600-m run were progressively improving until 11 years, when the trend slightly decelerated until 13 years. The decelerating period in boys was parallel to the most significant acceleration of triceps skinfold thickness. The acceleration 600-m run results increased again between 13 and 17 years, after which the curve plateaued. In other studies, we also acknowledged similar plateauing of aerobic endurance in this period (15). In contrast, in other cases, the plateauing started a year or more earlier (17,33,42,49,56) or was not observable at all (25,39,56). In girls, a constant improvement of 600-m run scores was visible until 13 years, when the curve plateaued until 15 years, but the scores started to deteriorate until 19 years. In other studies, girls' aerobic endurance reference curves' plateauing started earlier (15,20,25,33,42,58,62) and similarly deteriorated toward late adolescence (15,17), whereas in some cases, the deterioration of aerobic endurance reference curves in girls was observable already from age 6 onward (22). In other cases, however, girls' aerobic endurance curves' plateauing occurred only in late adolescence (39,49) or was not observable at all (8).

In comparison to all other existing physical fitness reference curves, our analysis also compares differences in the values behind the reference centile curves between boys and girls. The mere observation of differences in body height reveals the difference in timing of puberty with girl's growth spurt occurring approximately a year and a half before boy's growth spurt, creating a 2-year window until 13 years in which the girls were typically taller and, in the lowest centiles, also heavier than boys. Between 10 and 14 years, the triceps skinfold thickness in the above-50th centile was also higher in boys than in girls, which brought the centile curves of boys and girls in some tests very close. This fact confirms the idea that growth and maturation impact physical fitness levels and their development in youth (36). In the 600-m run, the girls with the poorest cardiorespiratory endurance in the 99th and 97th centiles outperformed the boys with the most inferior results. In contrast, the difference in results shrunk to less than 10 seconds in all centiles. Growth in peak $\dot{V}O_2$ exhibits an apparent growth spurt in both sexes during adolescence, but the earlier onset of pubertal development in girls brings the peak $\dot{V}O_2$ of girls closer to boys' values than ever before or after (19).

Similarly, the girls outperformed boys in 20-second arm-plate tapping, but this was reversed after most boys entered puberty at 14 years. Girls' earlier maturation may lead to an estrogen-mediated delay in dendritic pruning (12). With the increasing estrogenic levels in pubertal girls, eliminating redundant synapses is slowed down, making girls' movement regulation less effective than boys. Boys, in contrast, enter puberty 1 to 2 years later than girls and experience considerable increases in testosterone levels at that time. Testosterone positively impacts the corticomotor connections and thus increases the number of neutrons in the visual system (4), giving boys an advantage in movement regulation after entering puberty.

The exact physiological mechanisms also moderated the observed diminishing sex-related difference in the 60-m dash between 12 and 13 years. In that period, the difference in achieved time between boys and girls shrunk across the centiles to less than 0.5 seconds, although in the highest 3 centiles, the slowest girls were outperforming the slowest boys between 8 and 15 years.

Although the boys generally outperformed girls in standing broad jump throughout childhood, this difference almost disappeared at 12 years in the lowest centiles, making the poorest performing girls equal to the poorest performing boys. After this period, however, because of the pubertal hormonal changes (with the increased gaining of muscle mass among boys and fat mass among girls) (57), the difference in the standing broad jump results rapidly grew from 0 to 8 cm difference at 12 years to 30–50 cm difference at 19 years.

The most apparent effect of somatic growth on the difference in performance between boys and girls was observable in the BAH test. At 6 years, there were almost no sex-related differences in the results of this test yet. Still, boys started outperforming girls until 10 years, when girls were experiencing the most significant increases of triceps skinfold thickness. After 10 years, the triceps skinfold thickness in girls plateaued, and no additional fat mass was gained afterward, but the boys reached the peak of triceps skinfold growth at 12 years, which pushed their BAH test results very close to the level of girls of the same age. After 13 years, when the fat mass in boys started declining, and the fat mass of girls stabilized, the boys began outperforming girls.

In the 60-second sit-ups, there were no significant initial differences between boys and girls at 6 years, but boys gradually outperformed girls from 7 year onward. Until 13 years, the difference stabilized at 2 extra repetitions per minute in boys. After most boys enter puberty around 12 years, consequent changes in body size, composition, and increases in anabolic hormones may partly explain gains in performance (41) with boys having greater strength per unit of body size than girls (3).

The earlier maturation of girls is also visible in the backward obstacle course test results. Initially, boys perform better than girls, but between 11 and 13 years, the slowest girls typically outperform the slowest boys. This is especially pronounced in the 99th centile in which girls' dominance is visible from 8 to 16 years. At 16 years, the differences between boys and girls are on the same level as they were at the age of 6 years, but boys' performance then improves further until the end of adolescence.

Flexibility is the only component of physical fitness in which girls have been consistently outperforming boys throughout childhood and adolescence (8,14,15,20–22,33,39,42,49,56,58,62). In our study, the initial difference in stand-and-reach test results between boys and girls at 6 years was the smallest but then grew rapidly until 14 years. At that age, the boys were still adapting to the effects of their pubertal peak height velocity, whereas the girls had already adjusted to their attained body height. In the following years, boys quickly adapt to their growth changes because of decelerated height attainment and decreased flexibility differences compared with girls. Because of growing estrogen levels, girls start to gain fat mass during puberty and (as a result) their tissue density is lower than in boys, who are typically gaining muscle mass and reducing fat mass in this period, which may be the biological reason for better flexibility in girls (36), but (other than these physiological factors) cultural and behavioral aspects that advocate greater acceptance of flexibility than muscle strength in girls may also account for the observed sex differences (23).

Comparing the Slovenian reference centile curves with the existing reference curves from other countries revealed that the trends and shapes of the obtained curves follow the established patterns but that the results of Slovenian children and adolescents for corresponding percentiles are higher than in their peers from other countries. The shapes and trends of physical fitness curves imply that physical fitness development is associated with somatic development, reflecting the dependence of physical performance on growth and development. For example, the maturation-related increase of subcutaneous fat was accompanied by declining results in the 60-m dash, BAH, or 600-m run. Importantly, by producing the curves of centile differences, we were able to show that the superior physical performance of boys is neither constant nor does it pertain to the entire range of performance. The girls proved to be outperforming boys in the speed of alternate arm movement throughout childhood until 14 years. In contrast, the poorest performing girls were shown to be beating the poorest performing boys in aerobic endurance, speed, and coordination in late childhood and early adolescence. At around 12 years, girls' physical performance came very close to boys' endurance, speed, explosive strength, muscular endurance, and coordination; however, in flexibility, girls were outperforming boys throughout childhood and adolescence.

This study's main strength is using recent population data obtained through standardized physical fitness assessment with standardized measuring equipment. Although it is based on cross-sectional data, the inclusion of almost the entire population ensures the presence of various growth and developmental patterns and, in this sense, compensates for ignoring the individual variations that could be obtained through cohort design, as suggested to be desired by some other researchers (20). The study includes a large age span, from 6 to 19 years, which was only rarely achieved in similar studies (15), and it covers multiple components of muscular, neuromuscular, cardiorespiratory fitness and flexibility. Although the SLOfit measurements are conducted in school settings by physical education teachers, this is not necessarily a limitation because all physical education teachers in Slovenia are educated by 1 institution (Faculty of Sport) because they are thoroughly educated in SLOfit measurements through multiple courses and because they are conducting the measurements regularly throughout their career. The accuracy of the data is assured by both legislative demands and by the central processing of the data with specialized software and procedures that ensure the data quality level comparable to measurements, conducted by specially trained research teams.

Practical Applications

This study's primary objective was to develop the sex- and age-specific physical fitness reference percentile curves of the SLOfit test battery for Slovenian children and adolescents aged 6–19 years, using the GAMLSS method. The obtained reference curves can be used in clinical and educational settings for the identification of children with low levels of physical fitness, in surveillance of individual somatic and motor development, and in the monitoring of the effects of intervention programs or sport training. Since children in Slovenia belong to one of the physically most active populations globally (2), these reference values can serve as important criteria for the evaluation of the existing reference curves from other countries and for the assessment of developmental deficiencies of contemporary populations' physical fitness.

Acknowledgments

The data gathering through the SLOfit system was supported by the Ministry of Education, Science, and Sport of the Republic of Slovenia. The research program P5-0142, Bio-Psycho-Social Context of Kinesiology, and the research project J5-1797, SLOfit Lifelong, both funded by the Slovenian Research Agency, provided funding of the analysis. The authors thank all Slovenian schools and teachers for their dedicated professional work in coordinating and implementing SLOfit measurements. Laboratory: Laboratory for the diagnostics of somatic and motor development, Institute of Sport, Faculty of Sport, University of Ljubljana.

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