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Research article

Normative Reference Values and International Comparisons for the 20-Metre Shuttle Run Test: Analysis of 69,960 Test Results among Chinese Children and Youth

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Abstract
There is increasing evidence that cardiorespiratory endurance (CRE) is declining among Chinese children and youth. The 20-meter shuttle run test (20-m SRT) is considered the most effective and widely used field-based measurement of CRE for children and youth worldwide. However, there have been few attempts to set 20-m SRT norms for Chinese children and youth. We aimed to develop sex- and age-specific 20-m SRT norms for Chinese children and youth, and compare them with international standards. Participants were 69,960 healthy children and youth aged 9-17 years from six geographical areas of China, selected using a stratified cluster random sampling method. Sex- and age-specific 20-m SRT percentiles and curves were extracted for four common 20-m SRT metrics (laps, completed stages/minutes, speed at the last complete stage, estimated peak oxygen uptake). We also estimated the prevalence of healthy CRE according to the interim international cut-points (42 $mL.kg^{-1}min^{-1}$ for boys, 35 $mL\cdot kg^{-1}min^{-1}$ for girls). Chinese boys consistently outperformed girls, while more girls (86.4%) exhibited healthy CRE than boys (67.1%). Younger children and youth were more likely to meet the standards compared with the older, regardless of sex. Chinese children and youth underperformed international norms by 0.85% for boys and 3.1% for girls. The performance indicator (z-score) of Chinese children and youth was -0.01, indicating that 20-m SRT performance was worse than the international mean. The sex differences were also higher for international than Chinese students. This study provided national sex- and age-specific 20-m SRT Chinese norms, offering a valuable tool for screening, monitoring and identifying target groups for future interventions and early prevention of cardiovascular risk factors.

Keywords: Cardiorespiratory endurance, laps, completed stages/minutes, the speed at the last complete stage, estimated peak oxygen uptake, prevalence.

Introduction

As an important indicator of health in children and youth, cardiorespiratory endurance (CRE) reflects the ability to deliver and use oxygen to generate energy for muscle activity during exercise (Armstrong et al., 2011; Institute of Medicine, 2012). CRE has been inversely associated with body fat (Andersen et al., 2008), metabolic syndrome (Brage et al., 2004), arterial compliance (Reed et al., 2005), cardiovascular disease risk (Ortega et al., 2008), cancer, and mental health disorders (Ruiz et al., 2009a). CRE can be used to provide insight into the synergistic capabilities of various bodily systems and organs involved in performing physical activity and exercise (Ortega et al., 2008). Additionally, CRE can track these capabilities relatively well from childhood to adulthood (Malina, 2001; Ortega et al., 2013).

The 20-meter shuttle run test (20-m SRT) (Tomkinson and Olds, 2007; Catley and Tomkinson, 2013) is considered the most effective field-based measurement of CRE for children and youth and is the most widely used method for this purpose worldwide. Although the 20-m SRT cannot provide specific information about the function or contribution of specific systems, and its scoring method involves subjectivity (Cooper Institute for Aerobics Research, 1992), it is an effective measure of peak oxygen uptake (VO_{2peak}), because VO_{2peak} is achieved at the completion of maximal performance (Tomkinson et al., 2019). Moreover, the 20-m SRT can authentically imitate typical activities performed by youth and has moderate-to-high criterion-related validity ($r_p = 0.78$, 95% confidence interval [CI] [0.72-0.85]) for estimating VO_{2peak} (Mayorga-Vega et al., 2015). Besides, a previous study of the 20-m SRT reported a test-retest reliability coefficient of 0.89 for children (Leger et al., 1988). Together with its low cost, simplicity, and ability to test large groups of children simultaneously (Melo et al., 2011; Ruiz et al., 2009b; Tomkinson and Olds, 2008), the 20-m SRT can provide an excellent tool for population-based health surveillance and monitoring.

Several reference standards have been set to classify the CRE levels and to identify the individual's clinical metabolic risk status. Tomkinson et al. (2017) established international sex- and age-specific 20-m SRT norms for health and fitness screening, profiling, monitoring and surveillance based on 1,142,026 children and youth from 50 countries. Besides, 20-m SRT norms have been published for Europe (Tomkinson et al., 2017), North America (Carrel et al., 2012), Oceania (Catley and Tomkinson, 2013) and England (Sandercock et al., 2008), whereas limited 20-m SRT data are available for Asian youth. There have been a small number of studies in East Asian populations from Mainland China (Wang et al., 2011; Zou et al., 2019), Hong Kong (Barnett et al., 1993), Japan (Yang et al., 2019), the Philippines (Gonzalez-Suarez et al., 2013), and South Korea (Stickland et al., 2003). However, besides

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Japanese studies utilizing large annual national fitness surveillance data, there are only a small number of recent studies of young people in other Asian countries, which tend to have small sample sizes and narrow age ranges. Zou et al. (2012) obtained 20-m SRT data from 4687 subjects in Shanghai to compare 20-m SRT performance among normal weight, overweight and obese children and youth. A total of 676 schoolchildren in Wuhan, Hubei province was also tested with the 20-m SRT to estimate CRE in a study on the relationship between body fat and CRE (Wang et al., 2011). However, these data were geographically limited to only one large Chinese city and are not representative of the Chinese population. In a previous study, we developed sex- and age-specific 20-m SRT norms for Chinese Han children and youth aged 7-18 years old, but minority groups were not considered (Sun et al., 2015).

There is strong evidence for a worldwide decline in aerobic performance in children since the 1950s (Tomkinson and Olds, 2007). Besides, one previous study reported a particularly marked decline in the maximal long-distance running performance of Asian children and youth (Tomkinson et al., 2012). Dong et al. (2019) reported that the forced vital capacity of Chinese children and youth significantly declined from 2362.2 mL to 2210.0 mL over time from 1985 to 2014. The times taken to run 1000 m and 800 m increased by 37.1 s and 30.7 s, respectively, from 1985-2014 (Gan et al., 2019). As an indicator of VO_{2peak}, 20-m SRT should be measured to monitor CRE, providing insight into the current and future health status of Chinese children and youth. Unfortunately, there are still no 20-m SRT norms for Chinese children and youth, and it is unclear how Chinese students compare with their international peers.

The current study hypothesized that CRE among Chinese children and youth would be lower than international standards. By recruiting 69,960 children and youth aged 9-17 years, the primary aim of the present study was to develop sex- and age-specific 20-m SRT norms for Chinese children and youth. The secondary aim was to estimate the percentage of individuals with healthy CRE among Chinese children and youth, and conduct comparisons with international norms.

Methods

Data sources and ethical considerations

In 2015-2016, a cross-sectional survey called “Development of new methods and evaluation standards for the physical health of children and youth in China” was conducted. This project aimed to develop new assessment methods and evaluation standards for the physical health of Chinese children and youth. It was approved by the Human Experiment Ethics Committee of East China Normal University (approval No. HR2016/12055). Informed consent was obtained from schools, teachers, students, and parents. Participants were informed about the investigation objectives and requirements before data were collected. All participants’ names were digitally coded to avoid the release of personal information.

Participants

There are six main geographical areas in China (East China, North China, Central-South China, Northeast China, Northwest China, Southwest China). Considering population weighting, geographical location and gross domestic product per capita, corresponding cities were selected from 27 of the 31 provinces of Mainland China across the six areas in 2015-2016. In each city, primary and middle schools with students aged 7-18 years were selected from urban and rural areas. A stratified random cluster sampling method was then used to select classes in selected schools. Finally, 93,755 healthy children and youth (without serious physical or mental illness, physical disability, or intellectual disability) aged 7-18 years were recruited. A total of 92,477 participants aged 7-18 years were eventually included, after excluding 1,278 participants (1.36%) because of a lack of demographic information (n = 674, 0.72%), a lack of information on 20-m SRT laps (n = 226, 0.28%) or extreme values (n = 338, 0.36%), defined as sex- and age- 20-m SRT Z score > 3 or < - 3 standard deviations (SD). Data for 69,960 children and youth aged 9-17 years were extracted for use in the present study. These participants included boys (51.2%, 47.6% - 53.3% for each age group) and girls (48.8%), Han (92%) and minority nationalities (8%), consistent with the sixth census of China in 2010 (China Statistics Press., 2010), urban students (49.7%) and rural students (50.3%).

Questionnaire and 20-m SRT test

A self-administered questionnaire covering demographic indicators, family status, living habits, and mental health was administered to participating children and youth, from which only demographic information was obtained for the present study. Questionnaires were completed over a 40-min period in the classroom in the presence of graduate students majoring in human sports science.

The FitnessGram protocol was used to conduct the 20-m SRT test (Cooper Institute for Aerobics Research, 1992). The test was conducted on rubberized school playgrounds or covered stadiums, in which two lines 20-m apart were drawn. The required equipment consisted of an audio player and the beep test audio recordings. Approximately 40 students from the same class were divided into two groups by sex, with approximately 15-20 individuals in each group, according to the actual number of boys and girls in the class. Each test was conducted by a team of four postgraduate students majoring in sports and human science who were trained according to FITNESSGRAM recommendations (Cooper Institute for Aerobics Research, 1992) before beginning the assessments. After participants had adequately warmed up and viewed an instructional 20-m SRT video recorded in advance, participants were asked to continually run between the two lines 20-m apart, turning when signaled by the recorded beeps. For this reason, the test is also often called the “beep” or “bleep” test. Participants started at a speed of 8.0 $km.h^{-1}$. After approximately one minute, at the end of the first stage on the cassette called “stage 1”, a sound indicated an increase in speed to 9.0 $km.h^{-1}$. Thereafter, the speed was increased by 0.5 $km.h^{-1}$ each minute. Children ran in time with a series of audible signals for as long as possible until they could no longer run the 20-m distance in time with the audio signal (on two consecutive occasions) or when they stopped because of volitional fatigue. The last lap completed (not necessarily the level stopped at) was recorded as the result.

It should be noted that this research was conducted during 2015–2016 and took place over one year. Thus, a deviation may be caused by climate differences between summer and winter, which is a common limitation among large data studies. However, we conducted the test in covered stadiums in winter wherever possible, and allowed participants to adequately warm-up to reduce the impact of environmental conditions such as temperature and weather.

Data analysis

The last birthday of each participant was used as the criterion for calculating age. Completed stages/minutes and speed at the last complete stage ($km.h^{-1}$) were calculated according to laps. Estimated peak oxygen uptake (VO_{2peak}, $mL.kg^{-1}min^{-1}$) was calculated using an equation developed by Leger et al. (1988) based on the number of laps. This is a widely used and internationally recognized method for estimating VO_{2peak}:

$$VO_{2peak}\ (mL\cdot kg^{-1}\cdot min^{-1}) = 31.025 + 3.238 \times S - 3.248 \times Age + 0.1536 \times S \times Age$$

S: the running speed at the last completed stage ($km.h^{-1}$); Age: age at the last birthday.

The lambda, mu and sigma method (LMS) summarizes the changing distribution in reference centile curves by three curves representing the median, coefficient of variation and skewness (Cole and Green, 1992). LMS has become the main method for developing growth evaluation and nutrition screening criteria worldwide because it can provide a convenient “black box” for fitting smooth reference centile curves (Cole and Green, 1992; Fenton and Sauve, 2007; Guedes et al., 2010; Hagiwara et al., 2014). We used the LMS method to establish sex- and age-specific 20-m SRT percentiles and curves for Chinese children and youth for four 20-m SRT metrics (laps, completed stages/minutes, the speed at the last complete stage and VO_{2peak}). Smooth centile curves were fitted to obtain sex- and age-specific 20-m SRT norms of Chinese children and youth by combining the changing distribution of three sex- and age-specific curves representing skewness (L, expressed as a Box-Cox power transformation), median (M) and coefficient of variation (S). We obtained cubic splines using non-linear regression. Smoothing parameters or equivalent degrees of freedom were used to express the extent of smoothing required. These analyses were performed using the LMS Chart maker Pro version 2.43 (Institute of Child Health, London) (Pan and Cole, 2010). The effective degrees of freedom for 20-m SRT speed in the present study were 1 (L curve), 4 (M curve) and 3 (S curve) for boys, and 1 (L curve), 3 (M curve) and 3 (S curve) for girls.

The percentages of children and youth with healthy CRE were estimated using the interim international cut-points (42 $mL\cdot kg^{-1}\cdot min^{-1}$ for boys, 35 $mL\cdot kg^{-1}\cdot min^{-1}$ for girls) (Ruiz et al., 2016). Healthy CRE (%) was calculated by the number of participants that met the criterion-referenced standards over the total number of participants. Z scores of VO_{2peak} were calculated as a students’ VO_{2peak} value minus the mean, divided by the SD for that child’s age and sex in the international 20-m SRT performance norms. We used this Z score as a performance indicator to rank Chinese participants against their international peers from 50 other countries (Lang et al., 2018). The sex-specific difference in estimated VO_{2peak} ($mL.kg^{-1}min^{-1}$) at each age (9-17 years) was calculated. Positive differences indicated better performance for both boys than girls. The speed at the last completed stage was compared between Chinese children and youth, and international standards. The level of statistical significance was set at 0.05 and all analyses were conducted using SPSS version 25.0 (IBM, Armonk, NY, USA).

Results

Tabulated centiles from 5% to 95% were used to present norms for four common 20-m SRT metrics (Table 1 for laps, Table 2 for completed stages/minutes, Table 3 for speed at the last complete stage and Table 4 for estimated VO_{2peak}).

Table 1. 20-m SRT (number of laps) centiles by age and sex for 69,960 Chinese children and youth aged 9–17 years.

	Age(yr)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Boy	9	8	10	13	15	18	20	23	26	29	35	40
	10	9	12	15	18	21	23	26	30	34	41	47
	11	11	14	18	21	24	27	30	34	39	47	53
	12	13	16	20	24	28	31	35	39	45	53	61
	13	14	18	23	27	31	35	40	45	51	60	69
	14	16	20	26	30	35	39	44	49	56	67	76
	15	17	22	28	33	37	42	47	53	60	72	82
	16	19	23	29	35	40	44	50	56	64	75	86
	17	19	24	31	36	41	46	52	58	66	78	89
Girls	9	8	10	13	15	17	19	21	24	27	32	37
	10	10	12	14	17	19	21	24	27	31	36	42
	11	11	13	16	19	21	24	26	30	34	40	46
	12	12	14	17	20	23	26	29	32	36	43	50
	13	12	15	19	22	24	27	30	34	39	46	52
	14	13	16	20	23	26	29	32	35	40	48	55
	15	14	16	20	23	26	29	33	37	41	49	56
	16	14	17	21	24	27	30	33	37	42	50	57
	17	14	17	21	24	27	31	34	38	43	50	58

Ages shown represent age at last birthday (e.g. 9 = 9.0–9.99).

Table 2. **20-m SRT (number of completed stages/minutes) centiles by age and sex for 69,960 Chinese children and youth aged 9–17 years.**

	Age(yr)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Boy	9	1.54	1.85	2.26	2.59	2.88	3.18	3.48	3.83	4.25	4.88	5.43
	10	1.72	2.07	2.53	2.90	3.23	3.56	3.90	4.29	4.76	5.46	6.08
	11	1.93	2.32	2.83	3.24	3.61	3.97	4.35	4.78	5.31	6.08	6.77
	12	2.16	2.59	3.16	3.61	4.02	4.42	4.85	5.32	5.90	6.76	7.52
	13	2.40	2.87	3.50	3.99	4.44	4.88	5.34	5.86	6.50	7.44	8.27
	14	2.61	3.12	3.80	4.33	4.81	5.29	5.78	6.34	7.02	8.04	8.92
	15	2.79	3.33	4.04	4.60	5.11	5.61	6.13	6.71	7.43	8.50	9.43
	16	2.93	3.48	4.22	4.80	5.32	5.84	6.38	6.98	7.73	8.82	9.78
	17	3.03	3.60	4.36	4.95	5.48	6.01	6.56	7.17	7.93	9.05	10.02
Girls	9	1.59	1.86	2.21	2.50	2.76	3.02	3.29	3.61	4.00	4.59	5.12
	10	1.75	2.04	2.43	2.74	3.03	3.31	3.61	3.96	4.39	5.03	5.61
	11	1.90	2.21	2.63	2.97	3.27	3.58	3.90	4.27	4.73	5.42	6.04
	12	2.04	2.37	2.81	3.17	3.49	3.81	4.16	4.54	5.03	5.76	6.41
	13	2.16	2.50	2.97	3.33	3.67	4.01	4.36	4.76	5.27	6.02	6.70
	14	2.25	2.61	3.08	3.46	3.80	4.15	4.51	4.92	5.43	6.20	6.89
	15	2.32	2.68	3.16	3.54	3.89	4.24	4.61	5.02	5.54	6.31	7.01
	16	2.37	2.73	3.22	3.60	3.95	4.30	4.67	5.08	5.60	6.38	7.07
	17	2.40	2.76	3.25	3.63	3.99	4.34	4.71	5.13	5.65	6.43	7.13

Table 3. **20-m SRT (speed at the last complete stage/km.h^{-1}) centiles by age and sex for 69,960 Chinese children and youth aged 9–17 years.**

	Age(yr)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Boy	9	8.73	8.91	9.13	9.30	9.45	9.60	9.75	9.92	10.12	10.42	10.68
	10	8.83	9.02	9.27	9.46	9.63	9.79	9.96	10.14	10.37	10.71	11.01
	11	8.95	9.16	9.43	9.63	9.82	9.99	10.18	10.39	10.64	11.02	11.36
	12	9.08	9.31	9.60	9.82	10.02	10.22	10.42	10.65	10.93	11.35	11.72
	13	9.22	9.46	9.78	10.02	10.23	10.44	10.66	10.91	11.22	11.68	12.09
	14	9.34	9.60	9.93	10.19	10.42	10.64	10.88	11.15	11.48	11.98	12.42
	15	9.43	9.70	10.05	10.32	10.56	10.80	11.05	11.34	11.69	12.22	12.70
	16	9.49	9.77	10.13	10.41	10.67	10.92	11.18	11.48	11.85	12.41	12.92
	17	9.52	9.81	10.18	10.47	10.74	11.00	11.27	11.59	11.98	12.57	13.11
Girls	9	8.79	8.93	9.12	9.26	9.39	9.51	9.65	9.80	9.98	10.27	10.53
	10	8.88	9.03	9.23	9.38	9.52	9.65	9.80	9.96	10.17	10.48	10.76
	11	8.96	9.12	9.33	9.49	9.64	9.78	9.94	10.11	10.33	10.67	10.98
	12	9.03	9.20	9.42	9.59	9.74	9.89	10.06	10.24	10.47	10.83	11.16
	13	9.10	9.27	9.49	9.67	9.83	9.99	10.16	10.35	10.59	10.97	11.32
	14	9.15	9.32	9.55	9.73	9.90	10.06	10.23	10.43	10.68	11.07	11.43
	15	9.18	9.36	9.59	9.78	9.94	10.11	10.29	10.49	10.75	11.14	11.52
	16	9.20	9.38	9.62	9.81	9.98	10.14	10.32	10.53	10.79	11.20	11.58
	17	9.21	9.40	9.64	9.82	10.00	10.17	10.35	10.56	10.83	11.24	11.63

Table 4. **20-m SRT (VO_{2max}, mL.kg^{-1}min^{-1}) centiles by age and sex for 69,960 Chinese children and youth aged 9–17 years.**

	Age(yr)	P_5	P_{10}	P_{20}	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}	P_{90}	P_{95}
Boy	9	42.0	42.9	44.0	44.8	45.6	46.3	47.0	47.8	48.7	50.0	51.2
	10	40.5	41.5	42.8	43.7	44.6	45.4	46.2	47.1	48.2	49.8	51.1
	11	39.2	40.3	41.7	42.8	43.7	44.7	45.6	46.6	47.9	49.7	51.3
	12	38.0	39.3	40.8	42.0	43.1	44.1	45.1	46.3	47.7	49.8	51.6
	13	36.9	38.3	40.0	41.3	42.4	43.6	44.7	46.0	47.6	50.0	52.1
	14	35.8	37.2	39.0	40.5	41.7	43.0	44.3	45.7	47.5	50.1	52.4
	15	34.5	36.0	38.0	39.5	40.9	42.2	43.6	45.2	47.1	50.0	52.6
	16	33.1	34.7	36.7	38.3	39.8	41.2	42.7	44.4	46.5	49.6	52.5
	17	31.6	33.2	35.4	37.1	38.6	40.1	41.7	43.5	45.7	49.1	52.2
Girls	9	42.3	43.0	43.9	44.7	45.3	45.9	46.5	47.2	48.1	49.3	50.4
	10	40.8	41.6	42.6	43.4	44.1	44.8	45.5	46.3	47.3	48.7	50.0
	11	39.3	40.2	41.3	42.2	42.9	43.7	44.4	45.3	46.4	48.0	49.4
	12	37.8	38.8	39.9	40.8	41.7	42.5	43.3	44.2	45.4	47.2	48.8
	13	36.3	37.3	38.5	39.5	40.3	41.2	42.1	43.1	44.4	46.3	48.1
	14	34.8	35.7	37.0	38.0	38.9	39.8	40.7	41.8	43.2	45.3	47.2
	15	33.1	34.1	35.4	36.5	37.4	38.3	39.3	40.4	41.9	44.1	46.2
	16	31.5	32.5	33.8	34.8	35.8	36.8	37.8	39.0	40.5	42.9	45.1
	17	29.8	30.8	32.1	33.2	34.2	35.2	36.2	37.5	39.0	41.5	43.9

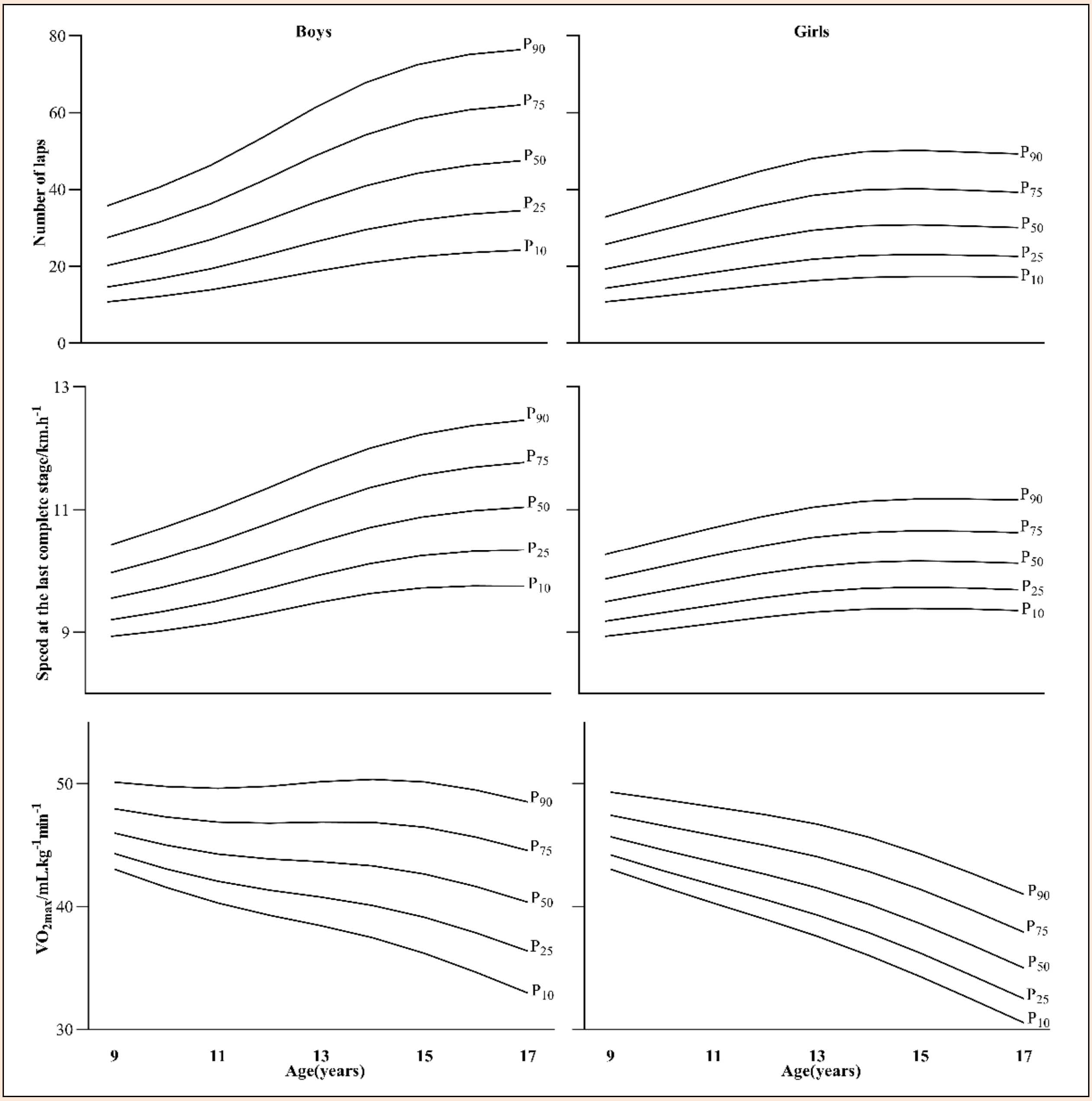

Figure 1. **Smoothed centile curves for 20-m SRT metrics for Chinese children and youth.**

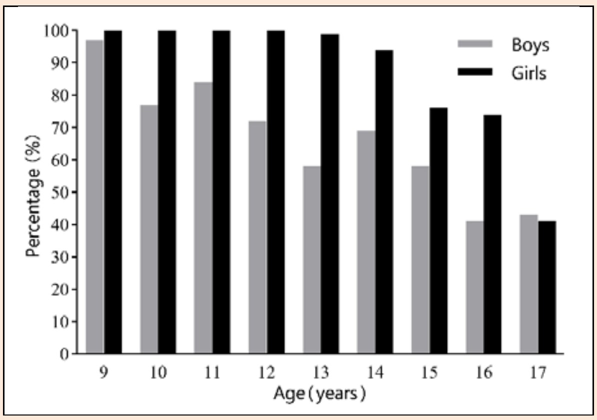

Figure 2. **Percentage of Chinese children and youth aged 9–17 years meeting the interim international cut-points of 42 mL·kg^{-1}·min^{-1} for boys and 35 mL·kg^{-1}·min^{-1} for girls.**

The smoothed centile curves for 20-m SRT laps, the speed at the last stage and estimated VO_{2peak} are presented in Figure 1. The number of laps increased with age. For example, the P_{50} of the number of laps increased from 20 to 46 for boys and increased from 19 to 31 for girls aged between 9 and 17 years old. Similar trends were found in completed stages/minutes and speed at the last complete stage, whereas estimated VO_{2peak} (mL·kg^{-1}·min^{-1}) decreased by 13.4% for boys and 23.3% girls as age increased from 9–17 years old, taking P_{50} as an example.

Figure 2 shows the percentage of Chinese children and youth aged 9–17 years meeting the interim international cut-points (42 mL·kg^{-1}·min^{-1} for boys, 35 mL·kg^{-1}·min^{-1} for girls) (Ruiz et al., 2016). Overall, 67.1% of boys and 86.4% of girls had healthy CRE. The percentages of girls with healthy CRE were higher than that of boys in each age group, except at 17 years old, in which boys' CRE was slightly higher. All girls aged 9–12 years met the standards, then decreased to 41.9% by 17 years of age. Although there were slight fluctuations, the results revealed an age gradient for boys, in which the highest and lowest prevalence rates were exhibited at 9 years old (97.2%) and 16 years old (41.3%) respectively. Younger children were more likely to meet the standards compared with older children, regardless of sex.

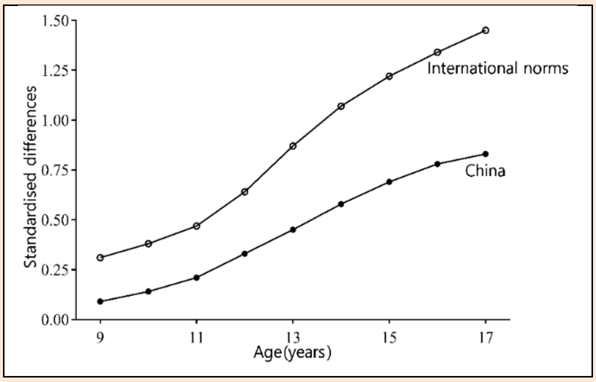

Figure 3. Standardized differences in speed at the last completed stage (km.h^{-1}) between age-matched boys and girls for Chinese children and youth compared with international values.

Table 5 showed the comparisons on 20-m SRT (speed at the last completed stage, km.h^{-1}) performance between Chinese children and youth and international standards. Except for the 9-10 years age groups, Chinese girls outperformed international norms in all age groups, with the largest positive performance difference of 0.37 km·h^{-1} at 13 years old. Chinese boys underperformed the international norms, with differences ranging from 0.12 km·h^{-1} at 12 years old, to 0.35 km·h^{-1} at 9 years old. All of these differences in speed between Chinese children and youth and international standards were significant. The performance indicator (z-score) for Chinese children and youth was -0.01, which was the same as that reported in Australia (z-score = -0.01), higher than that reported in the USA (z-score = -0.47) and Italy (z-score = -0.09), and lower than that reported in Japan (z-score = 0.98) and Canada (z-score = 0.32). The negative z-scores indicated that 20-m SRT performance was worse than the international mean.

Figure 3 shows the standardized differences in speed at the last completed stage (km·h^{-1}) between age-matched boys and girls for Chinese children and youth compared with international values. All of the standardized differences values were positive, indicating that boys had higher speed at the last completed stage than girls in each age group for international and Chinese students. The sex differences were higher for international than Chinese students with the biggest differences at 9 years old (244%) and the smallest differences at 16 years old (72%).

Table 5. Comparison on 20mSRT (speed at the last completed stage, km.h^{-1}) performance between Chinese children and youth and international standard.

		China			International[1]			t	P
	Age(yr)	N	Mean	SD	N	Mean	SD		
Boy	9	3876	9.68	0.64	101532	10.03	0.85	-25.45	＜0.01
	10	4160	9.80	0.67	81538	10.13	0.92	-23.08	＜0.01
	11	4149	9.97	0.69	79660	10.25	1.00	-17.89	＜0.01
	12	3868	10.24	0.81	70266	10.47	1.11	-12.45	＜0.01
	13	3815	10.60	0.92	72913	10.73	1.21	-6.71	＜0.01
	14	3826	10.83	0.96	65317	10.97	1.28	-6.51	＜0.01
	15	4200	11.00	1.00	53287	11.12	1.33	-5.74	＜0.01
	16	4273	11.02	1.03	35490	11.27	1.37	-11.48	＜0.01
	17	3632	11.10	1.03	29123	11.41	1.42	-12.88	＜0.01
	Total	35799			589126				
Girls	9	3753	9.60	43.9	98166	9.71	0.70	-9.33	＜0.01
	10	3704	9.70	42.6	81415	9.75	0.77	-3.57	＜0.01
	11	3640	9.85	41.3	78029	9.79	0.83	4.32	＜0.01
	12	3553	10.00	39.9	69497	9.83	0.88	11.51	＜0.01
	13	3451	10.23	38.5	92491	9.86	0.91	23.40	＜0.01
	14	3601	10.25	37.0	55035	9.89	0.93	22.52	＜0.01
	15	4075	10.25	35.4	43730	9.91	0.94	22.43	＜0.01
	16	4386	10.17	33.8	34978	9.93	0.95	16.40	＜0.01
	17	3998	10.21	32.1	29559	9.96	0.97	16.04	＜0.01
	Total	34161			552900				

The ages shown represent age at last birthday (e.g. 17=17.00–17.99). [1]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. Published Online First: 20 May 2016.

Discussion

The present study developed sex- and age-specific 20-m SRT norms for Chinese children and youth, and conducted comparisons with international standards. Regional, national and international 20-m SRT norms have previously been developed to effectively evaluate children's aerobic test performance (Gahche et al., 2017; Sandercock et al., 2008; Tomkinson et al., 2017; 2019). For example, Tomkinson and colleagues provided the most comprehensive and up-to-date set of international sex- and age-specific norms for 20-m SRT based on 1,142,026 children and youth aged 9-17 years from 50 countries in 2017 (Tomkinson et al., 2017).

Indicators such as the Gini coefficient, Human Development Index (HDI) and urbanization rate are often used to evaluate socioeconomic status. The Gini index is used to measure population distribution of wealth, a commonly used measure of inequality (The World Bank, 2015; 2018). It has been previously reported that income inequality acts as a social stressor, and is associated with worse health, such as an elevated risk of cardiovascular disease (Pickett and Wilkinson, 2015). The study also indicated that income inequality is a moderate to strong negative correlate of CRE in children and youth, regardless of country development status (Lang et al., 2018). China's Gini coefficient (38.9) is higher than the international average (36.9) (The World Bank, 2015), providing one potential explanation for the low CRE observed among Chinese children and youth. As a broad measure of human capital and potential, the HDI in developing countries is a strong negative correlate of 20-m SRT performance in children and youth (r_s = -0.56), including China (Lang et al., 2018). The 2011 Human Development Report showed that China's HDI was 0.687, slightly higher than the worldwide average (0.682)(United Nations Development Programme, 2011). In the current study, the CRE of Chinese children and youth were found to be lower than international norms. It has been reported that urbanization, characterized by lower energy requirements, is a moderate negative correlate of 20-m SRT performance in developing countries (r_s = -0.45). China has experienced rapid economic development with the implementation of policies of reforms and the opening up of China since 1978 and China's urbanization rate reached 59.58% by the end of 2018, higher than the worldwide average (55.27%) (The World Bank, 2018), possibly contributing to the low CRE among Chinese children and youth.

Several previous studies have reported that the relationship between body mass index (BMI) and CRE exhibits an inverted U-shaped curve (Bi et al., 2019; Huang and Malina, 2007; Li et al., 2017; Zhao et al., 2017). One previous study reported that the prevalence of overweight status and obesity among children and youth in developed countries tended to be stable, whereas that in developing countries is growing rapidly, including China (US Preventive Services Task Force, 2017). According to the 2017 Report on Childhood Obesity in China, the prevalence of overweight status among Chinese school-aged children increased from 2.1% in 1985 to 12.2% in 2014, and the prevalence of obesity increased from 0.5% to 7.3% in the same period (Zhang and Ma, 2017). Therefore, the increasing prevalence of overweight and obesity among Chinese children and youth may be an important contributor to their low CRE.

A previous study revealed that compared with students who used passive transport, those English school students who walked (OR = 1.31 for girls and 1.20 for boys) and cycled (OR = 9.99 for girls and 1.31 for boys) to school were more likely to be classed as fit, corresponding to high CRE (Voss and Sandercock, 2010). Similar findings have been reported from Colombia (Amaya, 2017; Ramirez-Velez et al., 2017) and China (Yang et al., 2017), indicating a positive relationship between CRE and active modes of traveling to school (e.g., walking or cycling). However, a survey conducted by Sun et al. (2015) revealed that only 50.9% of Chinese high school students cycled or walked to and from school, which was lower than the proportion in some other countries (Voss and Sandercock, 2010), potentially contributing to the lower CRE among children in China.

A study by Sandercock et al. (2010) reported that a higher CRE level was associated with a higher frequency of eating breakfast among British boys. Thivel et al. (2013) reached the same conclusion based on research among French children and youth. According to the China Health and Nutrition Survey conducted by the Chinese Center for Disease Control, Chinese children and youth exhibit various unhealthy eating habits, such as skipping breakfast and consuming high-sugar drinks, as well as consuming high-salt and high-fat diets (Yu et al., 2018; Cai et al., 2013; Hu et al., 2010; Liu et al., 2011). Therefore, eating habits may be another factor contributing to low CRE levels among Chinese children and youth.

Sedentary behavior may also be a factor influencing the CRE levels of Chinese children and youth. An investigation by Gahche et al. (2017) reported that children and youth aged 6-11 years in the United States engaging in more than 2 hours of screen time per day tended to have low CRE levels. According to the 2018 Physical Activity Guidelines for Americans (Piercy et al., 2018), excessive screen time was associated with increased risk of death, and is also negatively correlated with CRE. The proportion of Chinese children and youth engaging in more than 2 hours of screen time per day is reported to have reached 58.5% (Fu, 2013), which may also partially explain the low CRE levels observed in the current study.

The present study involved several strengths and limitations that should be considered. Importantly, the current study obtained 20-m SRT data for 69,960 children and youth from six geographical areas of China, constituting the largest national CRE database to date. To our knowledge, this study is the first survey of 20-m SRT norms in China to conduct systematic comparisons with international standards. An important limitation of this study was that we did not consider biological maturity. However, although biological maturity might impact CRE, particularly in girls, the norms were age- and sex-specific, which may have reduced the influence of growth and development in adolescence to some extent. Besides, this was a cross-sectional study, and a longitudinal cohort study will be needed to better understand the age- and sex-based differences in CRE among children and youth in China.

Conclusion

Because of the advantages of the method in terms of suitability for simultaneous large group testing, simplicity, convenience, low-cost and reasonable level of validity, the 20-m SRT is the most widely used measure of CRE worldwide, providing an excellent marker of current and future health of populations (Mahar et al., 2011; Wilkinson et al., 1999). Firstly, based on 20-m SRT performance data for 69,960 Chinese children and youth, the current study provided national sex- and age-specific norms for children and youth. These data can help to identify target groups requiring future intervention. For example, children and youth with very high CRE may be candidates for recruitment into elite sporting or athletic development programs. In contrast, for children and youth with very low CRE, appropriate fitness goals should be set to promote positive health-related fitness behavior and monitor longitudinal changes. Secondly, the current study estimated the prevalence of children and youth with healthy CRE according to the interim international cut-points (42 mL.kg^{-1}min^{-1} for boys, 35 mL.kg^{-1}min^{-1} for girls)(Ruiz et al., 2016), offering a valuable tool for screening, monitoring and early prevention of cardiovascular risk factors. Thirdly, the CRE of Chinese children and youth is lower than international standards and corresponding intervention strategies aimed at improving CRE levels should be considered in both school and family environments.

Unfortunately, despite its many advantages, and the Education Department of the Chinese Government has not yet adopted the 20-m SRT as a nationwide test. Therefore, we propose that it would be valuable for Chinese government departments to formulate policies to promote 20-m SRT projects for the whole country and conduct regular tests to evaluate CRE among children and youth. This would also support horizontal international comparisons.

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Key points

- Provided national sex- and age-specific 20-m SRT Chinese norms, offering a valuable tool for screening, monitoring and identify target groups for future interventions and early prevention of cardiovascular risk factors.
- Estimated the prevalence of healthy CRE and performed comparisons with international standards.

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