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Relationship between cardiorespiratory fitness and latitude in children and adolescents: Results from a cross-sectional survey in China

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ABSTRACT

Background: This study assessed the correlation between latitude and the cardiorespiratory fitness (CRF) of children and adolescents.
Methods: In 16 provinces and autonomous regions in China, 25,941 children and adolescents aged 10–18 were included. CRF was measured using the 20 m shuttle run test (20 m SRT) and estimated peak oxygen uptake (VO_{2peak}). One-way ANOVA and multiple regression analysis were used to explore the correlation between CRF and latitude in children and adolescents.
Results: The VO_{2peak} values of the low (south), middle, and high (north) latitude groups for boys were 43.1, 43.1, and 40.7 mL/kg/min, respectively, and 40.0, 40.0, and 38.5 mL/kg/min for girls, respectively. After adjusting for confounding factors, the regression coefficients (β) between VO_{2peak}-Z and both latitude-Z and (latitude-Z)^2 for boys were −0.151 and −0.043, respectively. For girls, they were −0.142 and −0.020, respectively. The Partial correlation coefficient (*r*) for latitude-Z and (latitude-Z)^2 were −0.14 and −0.04 for boys, and −0.13 and −0.02 for girls, respectively.
Conclusion: The CRF among children and adolescents in high latitude regions is significantly lower than that in middle and low latitude region, and it generally shows a “parabolic” trend between Latitude-Z and VO_{2peak}-Z.

Introduction

As the core component of children’s and adolescents’ physical health,[1] cardiorespiratory fitness (CRF) is an important standard used for measuring the health of children and adolescents, and is one of the indicators used for predicting adult health.[2,3] Low CRF is related to the incidence of cardiovascular diseases, diabetes, and other diseases, which can be used as a predictor of disease occurrence and is directly related to mortality.[4–6] Low CRF ranks first among all the factors affecting all-cause mortality, surpassing risk factors such as hypertension, smoking, high cholesterol, and obesity.[7]

CRF is influenced by many factors, and especially by the regional environment factor. A study[8] on 1,142,026 children and adolescents aged 9–17 years from 50 countries reported regional variations in CRF. Children and adolescents in Africa and Central-Northern Europe have the highest 20 m shuttle run test (20 m SRT) performance, whereas those in South America have the lowest 20 m SRT performance. In European countries, children and adolescents in northern and central countries have better CRF than their southern counterparts. A study of the CRF of children and adolescents aged 9–13 years in Canada, Kenya, and Mexico demonstrated that Kenyan teenagers in the tropical monsoon region had the highest CRF, whereas Canadian children in Northern North America had the lowest.[9] The CRF development of children and adolescents in

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different parts of a country also varies. Sun et al. discovered that children and adolescents in Northeast and Southwest China had lower CRF than in other regions.[10] Other studies reported that the gap between children's CRF in Eastern and Western China has gradually narrowed.[11]

Most of previous studies compared the differences in CRF among children and adolescents in different countries or regions. The results of studies on CRF of children and adolescents at different latitudes are still inconsistent, and little is known about the differences and temporal trends in the CRF of children and adolescents at different latitudes in the same country. China is located in the east of Asia and has a vast territory, with a 49-latitude difference from south to north. It spans five climatic zones: tropical, subtropical, warm temperate, middle temperate, and cold temperate. The terrain and climate are complex and diverse. The huge geographic latitude span results in huge differences in sunshine time, temperature, barometric pressure, and precipitation in different regions. This inevitably influences the lifestyle, dietary structure, and physical activity of children and adolescents,[12–14] causing regional differences in children's and adolescents' CRF.[10] Therefore, we aimed to analyze the correlation between natural environmental factors and the CRF of children and adolescents aged 10–18 years in China to provide a scientific basis for improving the physical health of children and adolescents.

Materials and methods

Participants and sampling

Data for the present study were drawn from the "Formulation of new methods and evaluation criteria for the physical health of children and adolescents in China", which was a cross-section survey of the physical health of Chinese children and adolescents conducted in 2015–2016. Considering population weighting and geographical location, we used the proportion of each indicator in the 2010 Sixth National Census Main Data Bulletin[15] to conduct sampling. Based on the population ratio of about 1.52:1 in the north and south, about 1:1 in urban and rural areas, and about 1:1 for boys and girls, corresponding cities were selected from 16 (Heilongjiang, Jilin, Xinjiang, Shanxi, Hebei, Henan, Jiangxi, Jiangsu, Shanghai, Zhejiang, Sichuan, Yunnan, Guizhou, Fujian, and Hainan) of 31 provinces in Mainland China. About 100 boys and girls aged 10–18 years in each province were selected using the random case method. After excluding invalid data and extreme values, a total of 25,941 healthy children and adolescents (without physical disability or serious illness, mental illness; Boys = 12,864, girls = 13,077) were extracted for the current study (Table 1). Written informed consent from parents and every participant has been obtained.

Table 1
Sex distribution of children and adolescents aged 10–18 years in China.

Age (year)	Boys N(%)	Girls N(%)	Total N(%)
10	1414(11.0)	1454(11.1)	2868(11.1)
11	1491(11.6)	1448(11.1)	2939(11.3)
12	1433(11.1)	1423(10.9)	2856(11.0)
13	1498(11.6)	1459(11.2)	2957(11.4)
14	1421(11.0)	1468(11.2)	2889(11.1)
15	1492(11.6)	1446(11.1)	2938(11.3)
16	1420(11.0)	1482(11.3)	2902(11.2)
17	1421(11.0)	1492(11.4)	2913(11.2)
18	1274(9.9)	1405(10.7)	2679(10.3)
Total	12864(100)	13077(100)	25941(100)

20 m SRT and questionnaire

The 20 m SRT adopts the test method developed by the Cooper Institute.[16] The method is as follows: After the warm-up, the participants start from the starting line, which is placed 20 m from the second line, and run to the opposite end of the line following the rhythm of the music. The initial speed is 8 km/h, which increases to 9 km/h in the second minute, and then the running speed increased by 0.5 km/h every consecutive minute. The test is stopped when the participants feel too tired to continue, or when they fail to reach the end line twice in a row before the sound. Each time 20 m is completed, it is recorded as 1 lap. The total round trip laps are recorded as the final result.

The children and adolescents participating in the study were given a self-reported questionnaire covering demographic indicators, lifestyle, and mental sub-health, from which the students' location, moderate-to-vigorous physical activity (MVPA) and individual socioeconomic status (SES) information was obtained for the current study. The family income was divided into low (less than 2000), middle (2001–5000), upper middle (5001–8000) and high (above 8000) based on the GNI per capita in China.[17] Parental education was divided into primary school, junior high school, senior high school, college or bachelor degree. Parental occupation included, for example, civil servant or teacher, worker, clerk, businessman, farmer and others. The father or mother with the highest level of education and the highest occupational classification score was selected as the representative of the parents' education and occupation. The Occupational classification was recorded according to the International Standard Economic Status Index (ISEI).[18] MVPA (moderate-to-vigorous physical activity) frequency (except physical education) was divided into never, 1–2 times per month, 1–2 times per week, and more than 3 times per week. GDP per capita in cities where children and adolescents live was obtained from the respective statistical yearbooks of China's provinces.[19]

Based on the geographical research[20] and the actual distribution of the research samples, we divided the samples into three latitudes for regional comparison. Low latitudes (south) were defined as below 30° N, middle latitudes were defined as 30°–40° N, and high latitudes (north) were defined as above 40°N.

Anthropometric measurements

The test for measuring height and weight take use of the standardized equipment at schools. All the participants were required to wear a T-shirt and thin trousers, without shoes. Height (recorded to the nearest 0.1 cm) and weight (recorded to the nearest 0.1 kg) were used to calculate the BMI (Body mass index), which was calculated as weight (kg)/height $(m)^2$.

Evaluation criteria for nutrition

The evaluation criteria for nutrition was based on the 2007 WHO report on growth reference 5–19 years (BMI-for-age), and examined the presence of underweight (BMI was minus 2Z-Score), overweight (BMI above or equal to 1Z-Score) and obesity (BMI above 2Z-Score).[21]

Ethical consideration

This research was approved by the East China Normal University Committee on Human Research Protection (approval No. HR2016/12055). Informed consent was obtained from teachers, students, and parents.

Statistical analyses

The estimated VO_{2peak} of each student was calculated according to the formula reported by Leger[22]: $VO_{2peak} = 31.025 + 3.238 \times S - 3.248 \times age + 0.1536 \times S \times age$, where S is the speed at the last completed stage of participants. The first level, S = 8, From the second level, $S = 8 + 0.5 \times 20$ m SRT completed stage. Latitude and VO_{2peak} Z-scores were calculated by sex and age, respectively. The Z-score was calculated as Z-score = (measured value − mean value)/standard deviation.

Children and adolescents were categorized into three age groups: 10–12 years is upper primary school age, 13–15 years is junior middle school age, and 16–18 years is high school age. Chi-square test was used to analyze the individual characteristic information of children and adolescents in different latitudes. One-way ANOVA was used to explore the differences in VO_{2peak} between participants in different latitude groups.

The multiple regression model was used to analyze the relationship between latitude and the VO_{2peak} of children and adolescents of different genders. The partial correlation coefficient (r) and the regression coefficients (β) were used to comment on the strength of association between variables. According to Cohen's standard,[23] the correlation coefficient (r) of ±0.1, ±0.3, ±0.5 corresponds to small, moderate, and large effect sizes, respectively. All analyses were conducted using IBM SPSS statistics 23.0 (IBM, Armonk, NY, USA).

Results

Descriptive characteristics of children and adolescents in different latitudes

Table 2 shows the individual characteristics of children and adolescents in different latitudes. The differences in family income, parental education level, parental occupation and the nutritional status were statistically significant in different latitudes ($p < 0.001$). The difference in MVPA frequency (except Physical Education) prevalence of boys was not statistically significant ($p = 0.168$). The difference of MVPA frequency prevalence of girls was statistically significant ($p < 0.001$). In low, middle and high latitudes, 12.7%, 7.9% and 12.2% of boys' family income was less than 2000 yuan, and 15.0%, 7.2% and 13.7% of girls' family income were respectively. The proportion of children and adolescents with lower family income in mid-latitude group is lower than that in low-latitude and high-latitude groups. The prevalence of overweight and obesity in high latitude areas were 19.5%, 12.1% for boys and 13.1%, 3.4% for girls, respectively, which were higher than those in middle and low latitudes groups.

Distribution of means and SDs of VO_{2peak} in different-aged children and adolescents at different latitudes

Table 3 shows that the VO_{2peak} of boys at high latitudes was lower than those at middle and low latitudes (Table 2). We found significant differences in all age groups ($p < 0.05$). For boys aged 12–14 years, the VO_{2peak} of the middle latitude group was significantly lower than that of low latitude group ($p < 0.05$). For boys aged 15–18 years, the VO_{2peak} at middle latitudes was significantly higher than that in the low latitude group ($p < 0.05$).

Table 4 shows that the VO_{2peak} of girls in high latitude regions of all ages was always the lowest except the age of 10 years, where we found significant differences ($p < 0.05$). For girls aged 12–14 and 16 years, the VO_{2peak} of the middle latitude adolescents was significantly lower than that of low latitude adolescents ($p < 0.05$). For girls aged 17–18 years, the VO_{2peak} of middle latitude adolescents was significantly higher than that of low latitude adolescents ($p < 0.05$).

Table 2
Descriptive characteristics of children and adolescents in different latitudes.

	Boys				Girls			
	low	middle	high	p	low	middle	high	p
family income (RMB)								
<2000	12.7%	7.9%	12.2%	<0.001	15.0%	7.2%	13.7%	<0.001
2001-5000	35.1%	34.8%	39.6%		38.0%	41.8%	42.8%	
5001-8000	26.3%	31.8%	30.2%		26.0%	31.1%	28.6%	
≥8000	25.9%	25.5%	18.0%		21.0%	19.8%	14.9%	
parental education								
primary school	7.5%	4.1%	4.6%	<0.001	7.9%	3.6%	5.3%	<0.001
junior high school	31.2%	30.4%	28.3%		33.3%	32.5%	29.3%	
senior high school	34.0%	40.8%	39.5%		33.5%	41.4%	36.9%	
College or bachelor degree	27.3%	24.7%	27.6%		25.3%	22.5%	28.5%	
parental occupation								
civil servant or teacher	18.1%	15.3%	18.3%	<0.001	15.9%	13.6%	17.4%	<0.001
worker	12.6%	14.8%	12.1%		11.5%	13.9%	10.2%	
clerk	19.3%	26.2%	18.3%		19.9%	27.5%	17.8%	
businessman	18.6%	19.2%	17.4%		17.6%	18.3%	15.3%	
farmer	11.2%	6.6%	8.1%		14.1%	7.3%	11.6%	
others	20.1%	17.9%	25.8%		21.0%	19.4%	27.6%	
nutrition status (BMI)								
underweight	6.3%	4.8%	6.9%	<0.001	5.4%	3.6%	6.0%	<0.001
normal weight	71.1%	68.6%	61.4%		83.8%	82.5%	77.6%	
overweight	14.8%	17.8%	19.5%		8.5%	10.8%	13.1%	
obesity	7.8%	8.8%	12.1%		2.3%	3.1%	3.4%	
MVPA frequency (except PE)								
never	8.2%	7.9%	8.7%	0.168	10.7%	7.9%	11.6%	<0.001
1-2 times/month	26.2%	26.3%	28.2%		41.3%	36.6%	39.2%	
1-2 times/week	35.1%	34.7%	34.6%		32.9%	32.5%	33.0%	
≥3 times/week	30.5%	31.1%	28.5%		15.1%	23.0%	16.2%	
Per Capita GDP# (Mean ± SD, ten thousand yuan)	5.8 ± 2.6	7.4 ± 2.2	5.7 ± 2.0	<0.001	5.7 ± 2.6	7.3 ± 2.2	5.6 ± 2.0	<0.001

Note: #: One-Way ANOVA; MVPA: Moderate-to-vigorous physical activity; PE: physical education.

Table 3
Estimated peak oxygen uptake (VO_{2peak}) of Chinese boys aged 10–18 years in different latitudes categories(mL/kg/min).

Age (year)	low		middle		high		Pairwise Comparison
	N	Mean(SD)	N	Mean(SD)	N	Mean(SD)	$p < 0.05$
10	590	45.7(3.2)	514	45.3(3.4)	310	44.8(3.6)	A > C, B > C
11	576	44.5(3.3)	590	44.3(3.7)	325	42.9(3.2)	A > C, B > C
12	545	45.2(4.4)	614	43.5(4.1)	274	42.2(3.7)	A > B, B > C, A > C
13	551	45.7(5.1)	633	43.8(4.7)	314	42.4(4.5)	A > B, B > C, A > C
14	507	45.4(4.8)	622	44.5(4.9)	292	42.0(4.6)	A > B, B > C, A > C
15	664	42.8(5.7)	506	43.9(5.2)	322	40.6(4.6)	A < B, B > C, A > C
16	635	40.6(6.0)	490	42.4(5.2)	295	38.6(4.6)	A < B, B > C, A > C
17	570	39.3(5.8)	525	40.5(5.6)	326	36.5(5.5)	A < B, B > C, A > C
18	389	37.2(5.2)	545	39.1(6.0)	340	36.2(6.2)	A < B, B > C, A > C
Total	5027	43.1(5.7)	5039	43.1(5.2)	2798	40.6(5.4)	A > C, B > C

Note: A, VO_{2peak} for children and adolescents in low latitude regions; B, VO_{2peak} for children and adolescents in middle latitude regions; C, VO_{2peak} for children and adolescents in high latitude regions.

Table 4
VO_{2peak} of Chinese girls aged 10–18 years in different latitudes categories (mL/kg/min).

Age (year)	low		middle		high		Pairwise Comparison
	N	Mean(SD)	N	Mean(SD)	N	Mean(SD)	$p < 0.05$
10	588	44.8(3.2)	543	44.8(3.2)	323	45.1(3.1)	
11	567	43.7(2.8)	557	43.8(3.6)	324	42.9(2.9)	A > C, B > C
12	564	43.8(3.5)	595	42.6(3.7)	264	41.5(2.9)	A > B, B > C, A > C
13	531	43.1(4.5)	644	42.3(4.0)	284	40.5(3.5)	A > B, B > C, A > C
14	613	41.5(4.1)	568	40.7(3.7)	287	38.9(3.3)	A > B, B > C, A > C
15	657	38.9(3.8)	495	38.6(3.7)	294	37.7(3.5)	A > C, B > C
16	631	36.8(3.9)	550	36.3(3.3)	301	34.8(3.6)	A > B, B > C, A > C
17	653	34.8(3.4)	556	35.4(3.6)	283	32.6(3.7)	A < B, B > C, A > C
18	526	32.7(3.6)	575	34.7(5.8)	304	31.2(4.9)	A < B, B > C, A > C
Total	5330	40.0(5.5)	5083	40.0(5.3)	2664	38.4(5.7)	A > C, B > C

Note: A, VO_{2peak} for children and adolescents in low latitude regions; B, VO_{2peak} for children and adolescents in middle latitude regions; C, VO_{2peak} for children and adolescents in high latitude regions.

VO_{2peak} Z-Scores' distribution for boys and girls in different latitude regions

Fig. 1 shows the VO_{2peak} Z-score distribution of boys and girls in different latitudes regions. Fig. 1 shows that the VO_{2peak} Z-scores of boys and girls in high latitude regions are more distributed between the left and low divisions, indicating that the CRF of children and adolescents in high latitudes is lower than those in middle and low latitude regions.

Fig. 2 shows that in the three age groups, with the increase in age, the VO_{2peak} of both boys and girls show a downward trend, and the decline at middle latitudes was less than those in the low and high latitudes.

Regression analysis of the variation in VO_{2peak} with latitude in children and adolescents in different age groups

Table 5 is the multiple regression model of the relationship between latitude-Z and VO_{2peak} Z-scores. As shown in Tables 2 and 3, in some age groups, VO_{2peak} shows a trend of first rising and then falling among different latitude groups. Based on this, the hypothesis of quadratic function relationship between VO_{2peak}-Z and latitude-Z is proposed. Therefore, latitude-Z and (latitude-Z)^2 are brought into the regression model.

Model[1] is a regression model with VO_{2peak}-Z as the dependent variable and latitude-Z and (latitude-Z)^2 as independent variables only adjusted for age; Model[2] adjusted for age, parental education, parental occupation, family income and Per Capita GDP; Model[3]

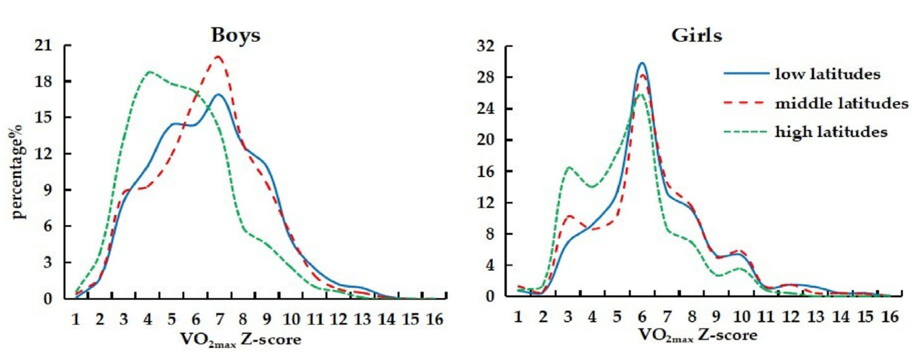

Fig. 1. Distribution of cardiorespiratory fitness (CRF) in children and adolescents in different latitude regions.

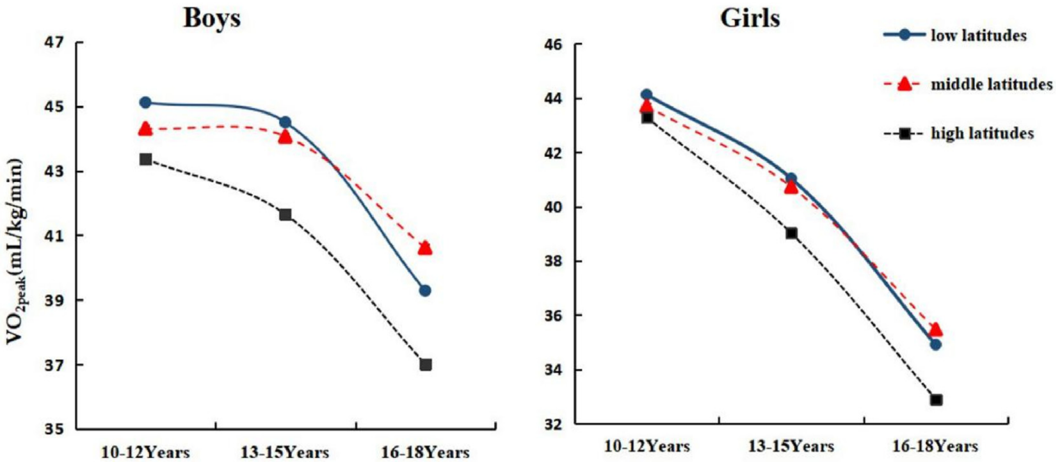

Fig. 2. The variation in CRF of children and adolescents in different latitude regions in different age groups.

Table 5
Multiple regression model of the relationship between latitude-Z and VO_{2peak}-Z for children and adolescents.

variable		Model[1]			Model[2]			Model[3]			Model[4]			Model		
		β	r	*P*	β	r	*P*	β	r	*P*	β	r	*P*	β	r	*P*
Boys	latitude-Z	−0.166	−0.16	0.000	−0.171	−0.16	0.000	−0.160	−0.15	0.000	−0.157	−0.15	0.000	−0.151	−0.14	0.000
	(latitude-Z)^2	−0.058	−0.06	0.000	−0.036	−0.03	0.000	−0.035	−0.03	0.000	−0.038	−0.04	0.000	−0.043	−0.04	0.000
	family income				0.049	0.04	0.000	0.053	0.05	0.000	0.042	0.04	0.000	0.042	0.04	0.000
	parental education				−0.024	−0.02	0.032	−0.018	−0.01	0.110	−0.022	−0.02	0.051	−0.020	−0.02	0.075
	parental occupation				0.002	0.00	0.667	0.001	0.00	0.874	−0.001	−0.00	0.906	−0.001	0.00	0.808
	Per Capita GDP				0.011	0.02	0.009	0.015	0.03	0.001	0.013	0.03	0.003	0.007	0.01	0.132
	BMI							−0.034	−0.13	0.000	−0.032	−0.13	0.000	−0.032	−0.13	0.000
	MVPA										0.109	0.10	0.000	0.107	0.10	0.000
	season of data collection													−0.087	−0.04	0.000
Girls 2	latitude-Z	−0.139	−0.13	0.000	−0.142	−0.13	0.000	−0.135	−0.13	0.000	−0.136	−0.13	0.000	−0.142	−0.13	0.000
	(latitude-Z)^2	−0.036	−0.04	0.000	−0.026	−0.02	0.007	−0.028	−0.03	0.004	−0.026	−0.02	0.007	−0.020	−0.02	0.038
	family income				0.023	0.02	0.032	0.023	0.02	0.033	0.020	0.02	0.062	0.018	0.01	0.099
	parental education				−0.013	−0.02	0.243	−0.015	−0.01	0.203	−0.017	−0.01	0.132	−0.019	−0.01	0.102
	parental occupation				−0.003	−0.01	0.566	−0.004	−0.01	0.465	−0.003	−0.01	0.534	−0.002	−0.00	0.708
	Per Capita GDP				0.004	0.01	0.317	0.006	0.01	0.168	0.004	0.01	0.341	0.011	0.02	0.015
	BMI							−0.027	−0.09	0.000	−0.027	−0.09	0.000	−0.027	−0.09	0.000
	MVPA										0.092	0.08	0.000	0.092	0.08	0.000
	season of data collection													0.100	0.05	0.000

Note: Model[1] only adjusted for age; Model[2] adjusted for age, parental education, parental occupation, family income and Per Capita GDP; Model[3] adjusted for age, parental education, parental occupation, family income, Per Capita GDP, BMI; Model[4] adjusted for age, parental education, parental occupation, family income, Per Capita GDP, BMI and MVPA frequency; Model[5] adjusted for age, parental education, parental occupation, family income, Per Capita GDP, BMI, MVPA frequency and season of data collection.

adjusted for age, parental education, parental occupation, family income, Per Capita GDP and BMI; Model[4] adjusted for age, parental education, parental occupation, family income, Per Capita GDP, BMI and MVPA frequency; Model[5] adjusted for age, parental education, parental occupation, family income, Per Capita GDP, BMI, MVPA frequency and season of data collection.

In Model[1]- Model[5], the regression coefficients (β) during VO_{2peak}-Z and latitude-Z, (latitude-Z)^2, family income, BMI, MVPA, season of data collection were statistically significant among boys ($p < 0.05$), and the β during VO_{2peak}-Z and latitude-Z, (latitude-Z)^2, Per Capita GDP, BMI, MVPA, season of data collection were statistically significant among girls. In Model[1]- Model[5], the β of VO_{2peak}-Z and latitude-Z range from −0.171 to −0.135, and the r of VO_{2peak}-Z and latitude-Z range from −0.16 to −0.13 ($p < 0.001$). The effect sizes were all small. The β of VO_{2peak}-Z and (latitude-Z)^2 in Model[1]- Model[5] ranged from −0.058 to −0.020, and the r of VO_{2peak}-Z and (latitude-Z)^2 in Model[1]- Model[5] ranged from −0.06 to −0.02 ($p < 0.05$).

After adjusting various influencing factors in Model[5], the results showed that the β of latitude-Z and (latitude-Z)^2 were −0.151 and −0.043 in boys, and −0.142 and −0.020 in girls, respectively. The r of latitude-Z and (latitude-Z)^2 were −0.144 and −0.039 in boys, and −0.132 and −0.018 in girls, respectively ($p < 0.05$). The relationship between latitude-Z and VO_{2peak}-Z of children and adolescents of different genders was shown in Fig. 3.

Fig. 3 showed the relationship between latitude-Z and VO_{2peak}-Z in children and adolescents of different genders. Both boys and girls' VO_{2peak} showed a "parabolic" trend. Among them, the VO_{2peak}-Z of girls showed a slight increase first and then decreased, while the VO_{2peak}-Z for boys increased first and then decreased rapidly as the latitude increased. The parabolic curve of girls is more gentle than that of boys.

Discussion

The present study demonstrated that the CRF of children and adolescents in high latitude regions is significantly lower than that in low and middle latitude region. In model[5], the partial correlation

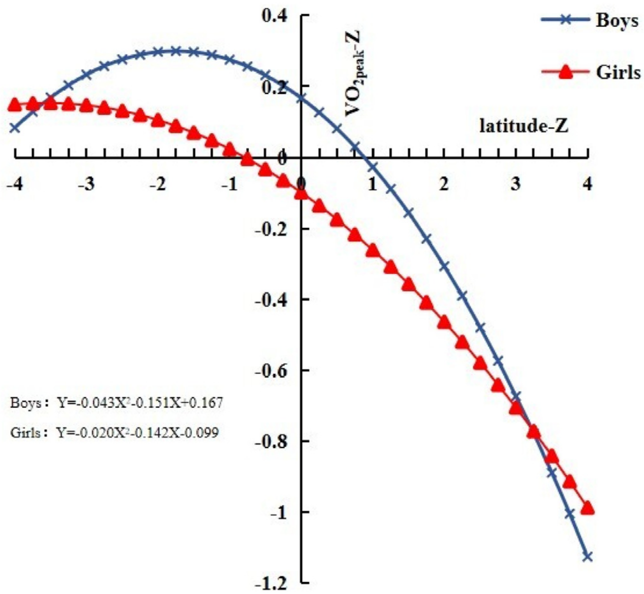

Fig. 3. Relationship between latitude-Z and VO_{2peak}-Z in children and adolescents of different genders.

coefficients (r) between Latitude-Z and VO_{2peak}-Z were larger than those for other confounding factors ($r_{Boys} = -0.144$, $r_{Girls} = -0.132$). There was a negative correlation between Latitude-Z and VO_{2peak}-Z ($p < 0.001$). After adjusting for all confounding factors, it generally show a "parabolic" trend between Latitude-Z and VO_{2peak}-Z. In other words, CRF showed a trend of slight rise and then rapid decline with the increase of latitude. Latitude was negatively correlated with CRF after adjusting for BMI, MVPA, SES and other confounding factors, and may be related to altitude, temperature and precipitation in different latitudes.[10,24,25] Similar trends have been found in studies of child and adolescent CRF in other countries. Héroux et al.[9] found the intercountry difference in children aged 9–13 years among Canada, Mexico and Kenya. Canada is a high-latitude country between 41 and 83°N, The city of Guadalaha in Mexico is at 20.4°N, and Kenya is a low-latitude country straddled the equator. In three countries, Canadian children (The boys and girls were 41.3 and 38.3 mL/kg/min, respectively) in high-latitude had lower CRF scores than their counterparts in Mexico (The boys and girls were 47.1 and 46.4 mL/kg/min, respectively) and Kenya (The boys and girls were 50.2 and 46.7 mL/kg/min, respectively) at low and middle latitude. There was no significant difference in CRF between Mexican girls and Kenyan girls. The trend of CRF among three different latitude countries is basically consistent with the results of this study. However, there may be an issue of comparability because of differences in assessment measures and equations used to estimate CRF among studies. In addition, convenience sampling was used in Mexico and Kenya and the sample size was in miniature which limited the representativeness of the results.

Differences in CRF among children and adolescents at different latitudes were also confirmed within other countries.[26,27] The distribution of CRF for Chilean adolescents in the southern hemisphere is varied at different latitudes. The prevalence of unhealthy CRF[28] is higher in northern regions (low latitudes) and southern regions (high latitudes) than in central regions.[29] The CRF of adolescents in high latitudes is higher than that in low latitudes, which is similar to the results of Lang[8] and colleagues CRF study of children and adolescents in developed countries. After comparing the 20 m SRT performance of children and adolescents in 50 countries, Lang et al. found that the CRF of children and adolescents showed different trends in developed and developing countries. In developing countries, children and adolescents in areas with higher temperatures have higher CRF than those in areas with lower temperatures.[8] As a developing country, China showed the same trend, that is, the CRF of children and adolescents in high latitude regions with lower temperatures is lower than in low latitude regions with higher temperatures. It is worth noticing that in the Lang et al.'s study, there was a clear latitude gradient in CRF in Europe and other developed countries. Children and adolescents in Central-Northern countries performed better on the 20 m SRT than their Southern contemporaries. The CRF of children and adolescents in countries such as Estonia, Iceland, Norway, and Denmark is much higher than that of southern countries such as Greece, Portugal and Italy. These findings are conflicting and difficult to interpret. The reason is that the author suggested it may be due to the negative physiological effects of exercise at warm and humid temperatures, or the difference in PA caused by the widespread popularity of ice-snow sports among Nordic children and adolescents,[30] which is worthy of further exploration. It is worth noting that the study involved 177 studies covering a time span from 1985 to 2015, while in recent decades, CRF of children and adolescents in most countries showed a downward trend over time.[31–33] The study did not adjust the time trends, which could have influenced the results.

Similar to the above research, the CRF of children and adolescents in high-latitude developed countries is often better than that in low-latitude countries. Children and adolescents in Portugal's Porto (42°N) has better CRF than their peers in Maputo, the capital of Mozambique (25°S).[34] British children and adolescents have higher CRF than their Tanzanian counterparts.[35] The authors of the above studies often attribute these findings to the outcome of a higher SES in association with a better nutritional environment in developed country, as well as higher levels of self-reported physical activity. However, other confounding factors such as BMI and time of data collection have not been controlled in the above studies, so it is not clear whether the differences in CRF among children and adolescents in different countries are related to geographical factors such as latitude.

Another study found that children and adolescents in high-latitude Norway had similar CRF as peers in low-latitude Tanzania.[36] In this reach, the CRF estimated from an bicycle protocol test. However, about two-thirds of the Tanzanian children were not able to ride a conventional bicycle. The Tanzanian children reached significantly higher estimated VO_{2peak} in the 20 m SRT compared with the bicycle protocol test. The VO_{2peak} probably underestimated in Tanzanian children.

Strengths and limitations

Although most studies have compared CRF between children and adolescents in different regions and countries, some studies have a small sample size and are not representative, and most studies have failed to control the influence of confounding factors, so they cannot confidently conclude whether geographical factors such as latitude are independently associated with CRF. This study is one of the few that provides evidence for an independent association between latitude and CRF using a representative sample of children and adolescents. This study can help to identify target groups requiring future intervention.

There are also some study limitations to note. First, the present study did not investigated children and adolescents' physical activity by objective measurement. Second, this study used a cross-sectional design and can not determine causality. Therefore, cohort studies and PA surveys should be conducted in children and adolescents of different latitude regions in the future.

Conclusions

The present study investigated and analyzed the relationship between CRF and latitude in Chinese children and adolescents. Findings from this study confirm the belief that children and adolescents at high latitudes have lower CRF than those at middle and low latitudes. After adjusting for confounding factors, we observed a "parabolic" trend between Latitude-Z and VO_{2peak}-Z. An independent association between latitude and CRF was confirmed among Chinese children and adolescents. However, whether this association can be confirmed in other countries, the trend of correlation between latitude and CRF in the southern hemisphere and developed countries still needs further empirical research. The CRF among developed countries in Europe shows a trend opposite to the results of this study, the reasons of which should receive further investigation. In addition, effective strategies should be implemented to improve the CRF of children and adolescents in high latitude regions. Whether the CRF can be improved in high latitude areas by building indoor sports venues and promoting north winter ice-snow sports on campus is also one of the future research direction.

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CRediT authorship contribution statement

Ting Zhang: Approval of the version of the manuscript to be published (the names of all authors must be listed), Writing - original draft, Formal analysis, Conceptualization. **Xiaojian Yin:** Approval of the version of the manuscript to be published (the names of all authors must be listed), Writing - review & editing, Conceptualization. **Xiaofang Yang:** Approval of the version of the manuscript to be published (the names of all authors must be listed), Writing - review & editing. **Cunjian Bi:** Approval of the version of the manuscript to be published (the names of all authors must be listed), Writing - original draft, Data curation. **Yuqiang Li:** Approval of the version of the manuscript to be published (the names of all authors must be listed), Data curation. **Yi Sun:** Approval of the version of the manuscript to be published (the names of all authors must be listed), Formal analysis, Data curation. **Ming Li:** Approval of the version of the manuscript to be published (the names of all authors must be listed). **Feng Zhang:** Approval of the version of the manuscript to be published (the names of all authors must be listed), Data curation. **Yuan Liu:** Data curation, Approval of the version of the manuscript to be published (the names of all authors must be listed).

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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