Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Associations of Sports Behavior Risks and Physical Activity Levels with Adolescent Scoliosis and Related Influencing Factors: a school-based cross-sectional study in China

Yuanyuan Cao
Shanghai University of Sport
Xiaohan Li
Shanghai University of Sport
Shaochun Shi
Shanghai Baoshan High School
Yuna Wu
Shanghai Baoshan High School
Mengjia Feng
Shanghai University of Sport
Xu Liu
Shanghai University of Sport
Xinfeng Zheng
Department of Spine Surgery, Xinhua Hospital Affiliated to Shanghai Jiaotong University School of Medicine
Weibing Wu
Shanghai University of Sport
Jun Xia
dx00122@163.com
Shanghai University of Sport

Research Article

Keywords: adolescent, scoliosis, sports behavior risk, physical activity, sedentary behavior, Cobb angle, accelerometer

Posted Date: July 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9990063/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

To examine the associations of adolescent scoliosis with sports behavior risks, physical activity levels, and related influencing factors.

Methods

This school-based cross-sectional study included 9,464 students in grades 4–12 from Shanghai, Xinjiang, and Fujian, China. Scoliosis was confirmed by standing full-spine radiography using Cobb angle ≥ 10°. Demographic characteristics, body morphology, sports behavior risks, IPAQ-based physical activity data, and accelerometer data from a Shanghai subsample were analyzed using univariable analyses and multivariable logistic regression.

Results

A total of 225 students were confirmed with scoliosis, with a detection proportion of 2.38%. Most cases were mild, and Lenke type 1 was the most common classification. Scoliosis was more likely among girls, students in higher grades, and those with lower BMI. Higher risks were associated with unilateral sports and asymmetrical loading, excessive flexibility and large-amplitude movements, insufficient core strength and trunk stability, lower MVPA, and longer sedentary time. Accelerometer data further showed that meeting the 60-min/day MVPA recommendation, higher step counts, cadence, and Axis 1 CPM were associated with a lower likelihood of scoliosis.

Conclusions

Adolescent scoliosis is associated with sex, grade level, BMI, sports behavior risks, and physical activity levels. School-based interventions should focus on high-risk groups, reduce sedentary behavior, promote adequate MVPA, and emphasize core stability, movement control, and symmetrical exercise training.

Clinical trial registration

Clinical trial number: not applicable.

Contributions to the literature

• Provides population-health evidence linking objectively confirmed adolescent scoliosis with sports behavior risks and physical activity patterns.

• Combines school screening, radiographic confirmation, questionnaires, and accelerometer data to characterize modifiable school-based factors.

• Supports school interventions that reduce sedentary time, promote MVPA, and emphasize core stability and symmetrical movement training.

Background

Scoliosis is a three-dimensional spinal deformity commonly diagnosed as a Cobb angle ≥ 10° on standing full-spine radiographs. It often develops or progresses during adolescence, a period of rapid skeletal growth and changes in body morphology and motor ability [1, 2]. If not detected and managed early, scoliosis may affect posture, trunk symmetry, cardiopulmonary function, motor ability, and mental health, and severe cases may require brace treatment or surgery [3–8]. The reported prevalence of adolescent idiopathic scoliosis ranges from 0.47% to 5.2% internationally [9], while the overall prevalence among Chinese adolescents is approximately 1.2%, with increasing screening detection and prevention needs in recent years [10, 11]. Therefore, school-based screening and identification of related factors are important for early detection, risk assessment, and intervention [12].

Previous studies have shown that scoliosis is associated with sex, age, growth and development, and BMI, with higher risks often observed among girls, higher-grade students, and those with lower BMI [13, 14]. Beyond biological and morphological factors, sports behaviors and physical activity patterns may also influence spinal health [15]. Prolonged sedentary behavior, insufficient physical activity, weak core strength, poor trunk stability, and poor posture may increase uneven spinal loading [16–18]. In addition, sports involving unilateral force, asymmetrical loading, excessive flexibility, or large-amplitude movements may affect spinal development during growth [19–29].

Current studies have mainly focused on prevalence, radiographic features, and demographic factors, while fewer have examined scoliosis in relation to sports behavior risks, subjective physical activity, and objective activity indicators. Questionnaires such as the IPAQ can assess physical activity and sedentary behavior but may be affected by recall bias [30–32]. Accelerometers provide objective data on sedentary time, activity intensity, step counts, and movement patterns [33, 34]. Combining these methods may provide a more comprehensive understanding of sports behavior-related factors associated with scoliosis.

Therefore, this study recruited students in grades 4–12 from Shanghai, Xinjiang, and Fujian, China. Scoliosis was identified through school-based screening and radiographic confirmation using Cobb angle ≥ 10°. Sports behavior questionnaires, IPAQ data, and accelerometer data from a Shanghai subsample were used to examine associations between scoliosis and sports behaviors, sedentary behavior, and physical activity levels, aiming to provide evidence for early screening, risk identification, school-based physical education interventions, and spinal health promotion.

Methods

Study Design and Participants

This school-based cross-sectional study was conducted from September 2024 to August 2025 in Shanghai, Xinjiang, and Fujian, China. It included scoliosis screening, radiographic assessment, physical fitness testing, and a survey of sports behavior-related factors among students in grades 4–12. Written informed consent to participate was obtained from all participating students and their parents or legal guardians before enrollment. The study was approved by the Ethics Review Committee of Shanghai University of Sport (No. 102772024RT110). A multistage stratified cluster sampling method was used. Schools were selected based on school type, grade structure, regional representativeness, and field feasibility. Within selected schools, students were stratified by grade, and class-level cluster sampling was performed.

The inclusion criteria were as follows: (1) students enrolled in grades 4 to 12 at selected schools in Shanghai, Xinjiang, or Fujian; (2) provision of informed consent by both the students and their guardians; (3) ability to cooperate with school-based on-site scoliosis screening; and (4) ability to complete basic demographic information, the sports behavior questionnaire, the physical activity questionnaire, and physical fitness testing. The exclusion criteria were as follows: (1) students who were not from the study regions, selected schools, or target grades; (2) students who were unable to complete scoliosis screening because of physical disability, acute injury, severe disease, or other physical conditions; (3) students who were unable to cooperate with the on-site examination, physical fitness testing, or questionnaire survey; and (4) students with a history of spinal surgery, brace treatment, or ongoing systematic treatment related to scoliosis.

After data consistency and logical checks, duplicate, invalid, inconsistent, out-of-range records and records with missing key variables or indeterminable outcomes were removed. Finally, 9,464 students were included in the full-sample analysis. Among them, 287 had Cobb angle data, and 225 were diagnosed with scoliosis based on Cobb angle ≥ 10°. The participant flow and data collection process are shown in Fig. 1.

School-Based Screening and Radiographic Confirmation

All participants underwent school-based scoliosis screening following a standardized protocol, including general physical examination, Adam's forward bend test, ATR measurement, and an exercise test. Physical signs included asymmetry of the shoulders, scapulae, waist concavities, iliac crests, or deviation of the spinous process line. Any abnormality was considered a positive physical sign. ATR was measured during Adam's forward bend test, with ATR ≥ 5° defined as positive. Students with positive physical signs or ATR ≥ 5° underwent an exercise test, and those with post-exercise ATR ≥ 5° were classified as positive in the initial screening. Students positive in the initial screening received secondary screening using the same procedures. Those with negative physical signs and ATR results were classified as screening negative, whereas students with persistent abnormalities and post-exercise ATR ≥ 5° were classified as positive in secondary screening. On-site screening results were categorized as no scoliosis, poor posture, grade I scoliosis, grade II scoliosis, or grade III scoliosis. ATR values of 5°≤ATR < 7°, 7°≤ATR < 10°, and ATR ≥ 10° corresponded to grade I, grade II, and grade III scoliosis, respectively.

Based on previous evidence that ATR thresholds of 5°–7° are commonly used for referral, and that ATR ≥ 7° may reduce false positives and excessive referrals [12, 35–37], students with ATR ≥ 7° in this study were referred for standing full-spine radiographic examination. Cobb angles were measured by trained professionals, and the main curve angle and Lenke classification were recorded. When multiple structural curves were present, the largest Cobb angle was used. Radiographically confirmed scoliosis was defined as Cobb angle ≥ 10°. Students with Cobb angle ≥ 10° were assigned to the confirmed scoliosis group, while those with Cobb angle < 10° or below the radiographic referral threshold were assigned to the non-confirmed group. Because universal radiographic examination was not performed, Cobb angle ≥ 10° in this study represents radiographically confirmed detection through the school-based screening and referral pathway, rather than prevalence under universal radiographic examination.

Measurement of Body Morphology and Physical Function

On-site measurements included height, weight, body fat percentage, and grip strength. Height and weight were measured by trained staff using standardized equipment, and body mass index (BMI) was calculated using the following formula: BMI = weight (kg)/height² (m²) [38]. Body fat percentage was measured using a body composition analyzer (InBody 270, Biospace Co., Ltd., Seoul, Korea) [39]. Grip strength was measured using a mechanical handgrip dynamometer (T.K.K. 5001, Takei Scientific Instruments Co., Ltd., Niigata, Japan), including left-hand grip strength and right-hand grip strength, and the bilateral grip strength difference was calculated [40]. All measurements were conducted according to standardized procedures to minimize measurement errors across different regions and examiners.

Questionnaire Survey of Sports Behavior Factors

Sports Behavior Risks Related to Spinal Health

The Sports Behavior Risk Questionnaire Related to Spinal Health for Primary and Secondary School Students, developed by the research team, was used to assess spinal health-related sports behaviors. Items were developed based on literature review, relevant screening standards, previous studies, and characteristics of physical activity and sports participation among students [41–43]. The questionnaire was revised after two rounds of Delphi expert consultation involving 15 experts from fields including child and adolescent health, school physical education, spinal health, sports medicine, athletic training, and epidemiology [44].

The final questionnaire included 24 items across eight dimensions: insufficient regular exercise, unreasonable training load, unilateral sports and asymmetrical loading, excessive flexibility and large-amplitude movements, insufficient core strength and trunk stability, inadequate movement technique and motor control, low back discomfort related to sports behavior, and insufficient training protection. Each item was scored on a 5-point scale, with higher scores indicating greater sports behavior risk exposure. Dimension scores ranged from 3 to 15, and the total score ranged from 24 to 120. Total scores were classified as low risk (≤ 56), moderate risk (57–88), or high risk (≥ 89). The Cronbach's α coefficient was 0.854, indicating good internal consistency [45].

IPAQ-Based Physical Activity Assessment

The short form of the International Physical Activity Questionnaire (IPAQ-SF) was used to assess vigorous-intensity activity, moderate-intensity activity, walking, and sedentary behavior over the previous 7 days. Total weekly physical activity was calculated as MET-min/week according to the IPAQ-SF protocol. Derived indicators included MVPA time, weekday sedentary time, achievement of ≥ 600 MET-min/week, meeting the 60-min/day physical activity recommendation for adolescents, and physical activity level classification [32, 41]. To reduce collinearity, only representative IPAQ-SF-derived variables were included in multivariable analyses.

Accelerometer Measurement

A subset of students from Shanghai wore a triaxial accelerometer (ActiGraph wGT3X-BT, ActiGraph LLC, Pensacola, FL, USA) to objectively measure physical activity, sedentary behavior, and activity intensity. Students were instructed to wear the device continuously for 7 days, except during bathing, swimming, or other inappropriate situations. Valid wear was defined as ≥ 4 days of records and total wear time ≥ 2400 min.

Accelerometer data were cleaned using standardized software or algorithms, excluding non-wear time and abnormal records. Extracted indicators included wear time, sedentary behavior time, physical activity time at different intensities, total and average daily MVPA, MVPA proportion, achievement of the 60-min/day activity recommendation, step count, cadence, Vector Magnitude CPM, Axis 1 CPM, and number of epochs [46–48].

In Shanghai, 426 students had at least one accelerometer record, and 321 met the valid wear criteria, including 191 students with Cobb angle < 10° or without confirmed scoliosis and 130 with Cobb angle ≥ 10°. Accelerometer analysis was conducted as a Shanghai subsample analysis. To reduce the influence of wear time, each indicator was entered separately into logistic regression models adjusted for sex, age, BMI, and wear time. Epoch count was used only to describe recording status because of its strong correlation with wear time.

Data Management and Quality Control

During data management, consistency and logical checks were performed on the original database. Among 10,159 field records from screening, physical fitness testing, questionnaires, and radiographic assessment, 9,464 students were included after excluding duplicate, invalid, inconsistent, out-of-range records and those with missing key variables or indeterminable outcomes, yielding a valid response rate of 93.2%. The primary outcome was defined by radiographic Cobb angle, with Cobb angle ≥ 10° classified as scoliosis and Cobb angle < 10° as non-scoliosis. Radiographic characteristics included Cobb angle magnitude and Lenke classification; curve location and direction were excluded because they were derived from ATR screening or surface assessment.

Data from different sources were quality-controlled based on value ranges, logical relationships, derived-indicator consistency, and completeness. The accelerometer sub-analysis included only Shanghai students with valid wear, defined as ≥ 4 days and total wear time ≥ 2400 min. Participants with missing key variables were excluded. Missing non-key variables were handled by available-case analysis for descriptive and group comparisons and complete-case analysis for logistic regression. To avoid collinearity, highly correlated questionnaire, IPAQ, or accelerometer indicators were not entered simultaneously; accelerometer indicators were modeled separately with adjustment for sex, age, BMI, and wear time.

Statistical Analysis

Following STROBE guidelines, analyses were conducted using SPSS 28.0 and R 4.4.0. All tests were two-sided with $\alpha = 0.05$. Radiographic scoliosis was defined as Cobb angle ≥ 10° and coded as 1, while Cobb angle < 10° was coded as 0. Continuous variables were reported as mean ± SD or M (P25, P75), and categorical variables as n (%). Group comparisons used χ^2 or Fisher's exact tests, ANOVA or Kruskal–Wallis H tests, independent-samples t tests, or Mann–Whitney U tests, as appropriate. Radiographic characteristics of students with Cobb angle ≥ 10° were described by Cobb angle category and Lenke classification. Curve location and direction were excluded because they were derived from ATR screening or surface assessment. Multivariable binary logistic regression was used to examine associated factors. Model 1 included region, sex, school stage, and BMI; Model 2 added eight sports behavior dimensions; and Model 3 added IPAQ14 MVPA time and IPAQ7 weekday sedentary time. Results were expressed as adjusted ORs and 95% CIs. The accelerometer sub-analysis included valid Shanghai samples only, defined as ≥ 4 wear days and total wear time ≥ 2400 min. Each accelerometer indicator was analyzed in separate logistic regression models adjusted for sex, age, BMI, and wear time. Average steps were calculated per valid wear day, and cadence was expressed as steps/min.

Results

Radiographic Characteristics of Students with Scoliosis

Among the 9,464 students included in the analysis, 225 were radiographically confirmed as having scoliosis with a Cobb angle ≥ 10° through the school-based screening and referral pathway, yielding an overall detection proportion of 2.38%. The detection proportions in Shanghai, Xinjiang, and Fujian were 2.59% (130/5,021), 2.33% (50/2,146), and 1.96% (45/2,297), respectively, with no significant regional difference (P = 0.256). This proportion reflects

radiographically confirmed cases identified through the screening and referral pathway, rather than prevalence under universal radiographic examination. Among the 225 confirmed students, the mean Cobb angle was 17.97 ± 4.52°. Most students had mild scoliosis, with 153 (68.0%) having a Cobb angle of 10° to < 20°, 69 (30.7%) having 20° to < 30°, and 3 (1.3%) having ≥ 30°. Lenke type 1 was the most common classification (50.2%), followed by types 2 (20.9%), 5 (12.4%), and 3 (10.2%). By region, the mean Cobb angles were 16.97 ± 4.06° in Shanghai, 18.88 ± 4.67° in Xinjiang, and 19.83 ± 4.88° in Fujian. Cobb angle category distribution differed significantly among regions (P = 0.01), whereas Lenke classification did not (P = 0.99). No significant differences in Cobb angle categories or Lenke classification were observed by sex or grade. Overall, mild scoliosis predominated, and Lenke type 1 was the most frequent classification among confirmed students. The detailed distributions are presented in Table 1.

Table 1
Distribution of Cobb Angle and Lenke Classification Characteristics among Students with Scoliosis

Group	Category	N	Cobb angle (°)	10° to < 20°	20° to < 30°	≥ 30°	P value	Lenke type 1	Lenke type 2	Lenke type 3	Lenke type 4	Lenke type 5	Lenke type 6	P val
Overall	Total	225	17.97 ± 4.52	153(68.0)	69(30.7)	3(1.3)		113(50.2)	47(20.9)	23(10.2)	7(3.1)	28(12.4)	7(3.1)	
Region	Shanghai	130	16.97 ± 4.06	99(76.2)	29(22.3)	2(1.5)	0.01	65(50.0)	28(21.5)	14(10.8)	3(2.3)	16(12.3)	4(3.1)	0.9
	Xinjiang	50	18.88 ± 4.67	32(64.0)	17(34.0)	1(2.0)		24(48.0)	12(24.0)	4(8.0)	2(4.0)	6(12.0)	2(4.0)	
	Fujian	45	19.83 ± 4.88	22(48.9)	23(51.1)	0(0.0)		24(53.3)	7(15.6)	5(11.1)	2(4.4)	6(13.3)	1(2.2)	
Sex	Male	75	17.58 ± 3.97	55(73.3)	20(26.7)	0(0.0)	0.28	39(52.0)	16(21.3)	6(8.0)	2(2.7)	11(14.7)	1(1.3)	0.8
	Female	150	18.16 ± 4.76	98(65.3)	49(32.7)	3(2.0)		74(49.3)	31(20.7)	17(11.3)	5(3.3)	17(11.3)	6(4.0)	
Grade	4	6	14.76 ± 2.36	6(100.0)	0(0.0)	0(0.0)	0.3	2(33.3)	2(33.3)	1(16.7)	0(0.0)	1(16.7)	0(0.0)	0.6
	5	12	16.13 ± 3.63	11(91.7)	1(8.3)	0(0.0)		7(58.3)	2(16.7)	0(0.0)	1(8.3)	2(16.7)	0(0.0)	
	6	38	16.56 ± 4.43	30(78.9)	7(18.4)	1(2.6)		19(50.0)	8(21.1)	4(10.5)	1(2.6)	6(15.8)	0(0.0)	
	7	40	17.10 ± 3.91	29(72.5)	11(27.5)	0(0.0)		22(55.0)	8(20.0)	5(12.5)	1(2.5)	3(7.5)	1(2.5)	
	8	21	18.91 ± 5.79	13(61.9)	7(33.3)	1(4.8)		7(33.3)	8(38.1)	3(14.3)	0(0.0)	2(9.5)	1(4.8)	
	9	23	18.96 ± 4.53	14(60.9)	9(39.1)	0(0.0)		11(47.8)	2(8.7)	3(13.0)	1(4.3)	4(17.4)	2(8.7)	
	10	28	18.72 ± 4.71	17(60.7)	10(35.7)	1(3.6)		15(53.6)	5(17.9)	3(10.7)	2(7.1)	3(10.7)	0(0.0)	
	11	27	19.15 ± 4.41	15(55.6)	12(44.4)	0(0.0)		10(37.0)	8(29.6)	2(7.4)	1(3.7)	6(22.2)	0(0.0)	
	12	30	19.07 ± 4.17	18(60.0)	12(40.0)	0(0.0)		20(66.7)	4(13.3)	2(6.7)	0(0.0)	1(3.3)	3(10.0)	

Note: Only students with radiographically confirmed scoliosis with a Cobb angle ≥ 10° were included. Cobb angle is presented as mean ± standard deviation, and Cobb angle categories and Lenke classifications are presented as n (%). Percentages indicate proportions within each subgroup. Cobb angle categories were defined as 10° to < 20°, 20° to < 30°, and ≥ 30°. Between-group comparisons were performed using the χ^2 test or Fisher's exact test.

Univariable Analysis of Sports Behavior-Related Factors in Students with Scoliosis

Students were grouped according to radiographically confirmed scoliosis, defined as a Cobb angle ≥ 10°. No significant difference in regional distribution was observed between the Cobb angle ≥ 10° group and the non-radiographically confirmed group (P = 0.256). However, sex, grade, and body morphology distributions differed significantly between the two groups (all P < 0.001). The detection proportion was higher among girls than boys (3.33% vs. 1.51%) and increased with higher grade levels. Underweight students had the highest detection proportion (8.48%), followed by those with normal weight (2.35%), overweight (0.82%), and obesity (0.32%).

For physical indicators, the Cobb angle ≥ 10° group had higher age and height but lower weight, body fat percentage, and BMI than the non-radiographically confirmed group. No significant differences were found in grip strength-related indicators. The sports behavior questionnaire showed higher scores in the Cobb angle ≥ 10° group for unilateral sports and asymmetrical loading, excessive flexibility and large-amplitude movements, insufficient core strength and trunk stability, and low back discomfort related to sports behavior, as well as higher total and mean scores.

Regarding physical activity, activity level classification was associated with Cobb angle ≥ 10° (P = 0.030). Students meeting the recommendation of 60 minutes of daily physical activity had a lower detection proportion than those who did not (0.81% vs. 2.56%, P < 0.001), whereas no significant difference was

observed for achieving ≥ 600 MET-min/week. Continuous analyses showed that the Cobb angle ≥ 10° group had fewer days of moderate-intensity physical activity, lower vigorous-intensity MET, moderate-intensity MET, total physical activity MET, and MVPA time, as well as longer weekday sedentary time. Overall, students with Cobb angle ≥ 10° were characterized by lower BMI, greater exposure to sports behavior-related risks, longer sedentary time, and lower physical activity levels. The complete univariable results are presented in Table 2.

Table 2
Univariable Analysis of Basic Characteristics and Sports Behavior-Related Factors among Students Stratified by Cobb Angle Group

Factor	Option	Non-radiographically confirmed group	Cobb angle ≥ 10° group	Statistic	P value
Region	Shanghai	4891 (97.41)	130 (2.59)	χ^2=2.72	0.256
Region	Xinjiang	2096 (97.67)	50 (2.33)		
Region	Fujian	2252 (98.04)	45 (1.96)		
Sex	Male	4888 (98.49)	75 (1.51)	χ^2=32.96	< 0.001
Sex	Female	4351 (96.67)	150 (3.33)		
School stage	Primary school	3666 (98.50)	56 (1.50)	χ^2=24.33	< 0.001
School stage	Junior high school	3168 (97.42)	84 (2.58)		
School stage	Senior high school	2405 (96.59)	85 (3.41)		
Body morphology	Underweight	658 (91.52)	61 (8.48)	χ^2=147.77	< 0.001
Body morphology	Normal weight	6203 (97.65)	149 (2.35)		
Body morphology	Overweight	1445 (99.18)	12 (0.82)		
Body morphology	Obesity	933 (99.68)	3 (0.32)		
Risk level	Low risk	2079 (98.86)	24 (1.14)	χ^2=19.82	< 0.001
Risk level	Moderate risk	6843 (97.22)	196 (2.78)		
Risk level	High risk	317 (98.45)	5 (1.55)		
Physical activity level classification	Low	1427 (97.67)	34 (2.33)	χ^2=7.04	0.03
Physical activity level classification	Moderate	6980 (97.46)	182 (2.54)		
Physical activity level classification	High	832 (98.93)	9 (1.07)		
Achieved ≥ 600 MET-min/week	No	1486 (97.57)	37 (2.43)	χ^2=0.00	0.957
Achieved ≥ 600 MET-min/week	Yes	7753 (97.63)	188 (2.37)		
Estimated achievement of adolescent 60 min/day recommendation	No	8261 (97.44)	217 (2.56)	χ^2=10.89	< 0.001
Estimated achievement of adolescent 60 min/day recommendation	Yes	978 (99.19)	8 (0.81)		
Age	Mean ± SD	13.20 ± 2.58	14.01 ± 2.48	U = 844613.50	< 0.001
Height (cm)	Mean ± SD	157.27 ± 11.36	160.07 ± 10.16	U = 898014.50	< 0.001
Weight (kg)	Mean ± SD	51.72 ± 14.06	49.52 ± 11.66	U = 1124062.50	0.037
Body fat (%)	Mean ± SD	21.89 ± 5.85	21.05 ± 5.42	U = 1123267.00	0.038
BMI	Mean ± SD	20.67 ± 4.01	19.10 ± 3.01	U = 1270307.50	< 0.001
Left grip strength (kg)	Mean ± SD	23.18 ± 8.14	23.14 ± 7.78	U = 1029076.50	0.799
Right grip strength (kg)	Mean ± SD	24.49 ± 8.62	24.46 ± 8.28	U = 1027724.00	0.773
Grip strength difference (kg)	Mean ± SD	1.31 ± 1.22	1.32 ± 1.30	U = 1019014.00	0.615
Insufficient regular exercise score	Mean ± SD	7.30 ± 2.03	7.45 ± 1.99	U = 974354.50	0.104
Unreasonable training load score	Mean ± SD	8.47 ± 2.10	8.59 ± 1.97	U = 999568.50	0.32
Unilateral sports and asymmetrical loading score	Mean ± SD	7.91 ± 2.05	8.37 ± 1.90	U = 896804.00	< 0.001
Excessive flexibility and large-amplitude movements score	Mean ± SD	8.19 ± 2.07	8.74 ± 2.06	U = 875308.50	< 0.001
Insufficient core strength and trunk stability score	Mean ± SD	8.29 ± 2.09	8.75 ± 1.91	U = 899336.50	< 0.001
Inadequate movement technique and motor control score	Mean ± SD	8.44 ± 2.07	8.50 ± 1.91	U = 1004650.50	0.386

Note: Categorical variables are presented as n (%), and continuous variables are presented as mean ± standard deviation. Categorical variables were compared using the χ^2 test or Fisher's exact test, and continuous variables were compared using the Mann–Whitney U test. Radiographically confirmed scoliosis was defined as a Cobb angle ≥ 10°.

Factor	Option	Non-radiographically confirmed group	Cobb angle ≥ 10° group	Statistic	P value
Low back discomfort related to sports behavior score	Mean ± SD	8.28 ± 2.09	8.58 ± 1.84	U = 931713.00	0.007
Insufficient training protection score	Mean ± SD	8.36 ± 2.09	8.41 ± 1.95	U = 1015095.50	0.544
Questionnaire total score	Mean ± SD	65.23 ± 11.15	67.40 ± 9.48	U = 890067.00	< 0.001
Questionnaire mean score	Mean ± SD	2.72 ± 0.46	2.81 ± 0.39	U = 890067.00	< 0.001
Days of vigorous physical activity in the past 7 days (d)	Mean ± SD	1.53 ± 1.37	1.33 ± 1.24	U = 1116151.00	0.051
Daily duration of vigorous physical activity (min)	Mean ± SD	21.61 ± 17.99	19.47 ± 18.10	U = 1115432.50	0.057
Days of moderate-intensity physical activity in the past 7 days (d)	Mean ± SD	2.94 ± 1.64	2.44 ± 1.14	U = 1211615.50	< 0.001
Daily duration of moderate-intensity physical activity (min)	Mean ± SD	32.39 ± 17.98	31.20 ± 15.94	U = 1070025.00	0.448
Days of walking for at least 10 minutes in the past 7 days (d)	Mean ± SD	4.80 ± 1.33	4.72 ± 1.27	U = 1086061.50	0.236
Daily walking duration (min)	Mean ± SD	37.20 ± 14.10	36.47 ± 13.35	U = 1058255.00	0.639
Weekday daily sedentary time (min)	Mean ± SD	425.15 ± 98.20	460.53 ± 86.76	U = 834627.00	< 0.001
Vigorous MET-min/week	Mean ± SD	409.50 ± 514.58	338.67 ± 424.92	U = 1119100.00	0.046
Moderate MET-min/week	Mean ± SD	443.55 ± 390.45	341.24 ± 260.13	U = 1150648.00	0.006
Walking MET-min/week	Mean ± SD	602.48 ± 310.92	573.91 ± 277.36	U = 1079220.50	0.325
Total physical activity MET-min/week	Mean ± SD	1455.53 ± 963.13	1253.82 ± 723.43	U = 1132851.50	0.021
Moderate-to-vigorous physical activity MVPA (min/week)	Mean ± SD	183.71 ± 162.14	145.87 ± 121.46	U = 1145236.50	0.009

Note: Categorical variables are presented as n (%), and continuous variables are presented as mean ± standard deviation. Categorical variables were compared using the χ^2 test or Fisher's exact test, and continuous variables were compared using the Mann–Whitney U test. Radiographically confirmed scoliosis was defined as a Cobb angle ≥ 10°.

Multivariable Analysis of Sports Behavior-Related Factors in Students with Scoliosis

Multivariable logistic regression was performed using Cobb angle ≥ 10° as the dependent variable. In Model 1, which included region, sex, grade, and BMI, region was not significantly associated with Cobb angle ≥ 10°. Female sex, higher grade level, and lower BMI were independently associated with a higher likelihood of Cobb angle ≥ 10°. Girls had a higher likelihood than boys (aOR = 2.117, 95% CI: 1.597–2.807, P < 0.001). Each one-grade increase was associated with increased likelihood of detection (aOR = 1.286, 95% CI: 1.210–1.365, P < 0.001), whereas higher BMI was associated with lower likelihood (aOR = 0.829, 95% CI: 0.791–0.870, P < 0.001).

After further adjustment for the eight sports behavior dimensions in Model 2, the associations of sex, grade, and BMI remained stable. Higher scores for unilateral sports and asymmetrical loading, excessive flexibility and large-amplitude movements, and insufficient core strength and trunk stability were associated with a higher likelihood of Cobb angle ≥ 10°, with aORs of 1.100, 1.128, and 1.086, respectively (all P < 0.05). Other sports behavior dimensions were not significantly associated with Cobb angle ≥ 10°.

In Model 3, after including IPAQ-derived MVPA time and weekday daily sedentary time, sex, grade, and BMI remained stable associated factors. Each 10-min/week increase in MVPA was associated with a lower likelihood of Cobb angle ≥ 10° (aOR = 0.987, 95% CI: 0.975–0.999, P = 0.040), whereas each 10-min/day increase in weekday sedentary time was associated with a higher likelihood (aOR = 1.021, 95% CI: 1.002–1.041, P = 0.029).

Overall, female sex, higher grade level, lower BMI, higher scores in selected sports behavior risk dimensions, lower MVPA, and longer sedentary time were associated with Cobb angle ≥ 10°. The multivariable regression results are presented in Table 3, and the corresponding model fit indices are shown in Table 4.

Table 3
Multivariable Logistic Regression Analysis of Sports Behavior-Related Factors Associated with Cobb Angle ≥ 10°

Variable	Model 1: Basic model	Model 1: P value	Model 2: Behavior dimension model	Model 2: P value	Model 3: Physical activity model	Model 3: P value
	OR (95% CI)		OR (95% CI)		OR (95% CI)	
Region: Xinjiang vs. Shanghai	0.982 (0.692–1.393)	0.92	0.951 (0.670–1.351)	0.78	1.371 (0.899–2.090)	0.143
Region: Fujian vs. Shanghai	0.753 (0.531–1.069)	0.112	0.734 (0.516–1.043)	0.084	0.938 (0.639–1.375)	0.742
Sex: Female vs. Male	2.117 (1.597–2.807)	< 0.001	2.147 (1.618–2.849)	< 0.001	1.912 (1.434–2.551)	< 0.001
Grade	1.286 (1.210–1.365)	< 0.001	1.279 (1.204–1.360)	< 0.001	1.208 (1.122–1.301)	< 0.001
BMI	0.829 (0.791–0.870)	< 0.001	0.827 (0.789–0.868)	< 0.001	0.824 (0.786–0.864)	< 0.001
Insufficient regular exercise score			0.972 (0.899–1.052)	0.485		
Unreasonable training load score			0.965 (0.894–1.042)	0.363		
Unilateral sports and asymmetrical loading score			1.100 (1.018–1.188)	0.015		
Excessive flexibility and large-amplitude movements score			1.128 (1.043–1.220)	0.003		
Insufficient core strength and trunk stability score			1.086 (1.005–1.173)	0.037		
Inadequate movement technique and motor control score			0.941 (0.872–1.016)	0.122		
Low back discomfort related to sports behavior score			1.023 (0.947–1.104)	0.568		
Insufficient training protection score			0.937 (0.868–1.011)	0.093		
MVPA, per 10 min/week increase					0.987 (0.975–0.999)	0.04
Weekday sedentary time, per 10 min/day increase					1.021 (1.002–1.041)	0.029

Note: Cobb angle ≥ 10° was coded as 1 and Cobb angle < 10° as 0. Binary logistic regression results are presented as adjusted odds ratios (aORs) and 95% confidence intervals (CIs). Model 1 included region, sex, grade, and BMI; Model 2 additionally included eight sports behavior dimension scores; and Model 3 additionally included IPAQ14 MVPA time and IPAQ7 weekday sedentary time. Shanghai and male sex were reference categories. Grade and BMI were treated as continuous variables. ORs for IPAQ14 and IPAQ7 were calculated per 10-min/week and 10-min/day increase, respectively.

Table 4
Model Fit Indices

Model	Sample size included	AIC	BIC	McFadden R^2
Model 1: Basic model	9464	2002.223	2045.154	0.064
Model 2: Sports behavior dimension model	9464	1988.543	2088.716	0.078
Model 3: IPAQ model	9464	1995.283	2052.525	0.07

Comparison of Accelerometer-Derived Physical Activity Indicators

A total of 321 students from Shanghai were included in the valid accelerometer sample. Compared with the non-radiographically confirmed group, the Cobb angle ≥ 10° group had significantly higher wear time, wear proportion, total valid wear days, and valid wear days on both weekdays and weekends (all $P < 0.001$). This group also showed higher sedentary behavior time, light-intensity physical activity time (both $P < 0.001$), and vigorous-intensity physical activity time ($P = 0.004$), while no significant differences were observed in moderate-intensity physical activity time, total MVPA time, or average daily MVPA time.

For standardized or relative indicators, the Cobb angle ≥ 10° group had a lower MVPA proportion (3.47 ± 1.15% vs. 3.93 ± 1.61%, $P = 0.026$), as well as lower Vector Magnitude CPM and Axis 1 CPM ($P = 0.041$ and $P = 0.016$, respectively). The proportion of students meeting the 60-min/day MVPA recommendation was also lower in this group ($P = 0.011$). Although total step count was higher ($P < 0.001$), average step count did not differ significantly ($P = 0.588$), and cadence showed only a non-significant trend ($P = 0.056$).

Overall, despite longer wear time and higher total-volume activity indicators, students with Cobb angle ≥ 10° showed lower MVPA proportion and CPM-based standardized activity intensity, suggesting lower relative activity intensity. Detailed univariable accelerometer results are presented in Table 5.

Table 5
Univariable Analysis of Accelerometer-Derived Indicators in the Valid Sample

Factor	Option	N	Non-radiographically confirmed group	Cobb angle ≥ 10° group	Statistic	P value
Wear time (h)	Mean ± SD	321	103.78 ± 19.35	123.47 ± 12.13	U = 4829.50	< 0.001
Wear proportion (%)	Mean ± SD	321	61.78 ± 11.52	73.49 ± 7.22	U = 4832.50	< 0.001
Number of days with wear records	Mean ± SD	321	6.30 ± 0.95	7.00 ± 0.00	U = 7020.00	< 0.001
Number of weekdays with wear records	Mean ± SD	321	4.64 ± 0.58	5.00 ± 0.00	U = 8580.00	< 0.001
Number of weekend days with wear records	Mean ± SD	321	1.68 ± 0.64	2.00 ± 0.00	U = 9620.00	< 0.001
Sedentary behavior time (min)	Mean ± SD	321	4579.69 ± 938.35	5592.13 ± 742.51	U = 5011.50	< 0.001
Light-intensity physical activity time (min)	Mean ± SD	321	1404.47 ± 345.53	1559.84 ± 366.99	U = 9547.50	< 0.001
Moderate-intensity physical activity time (min)	Mean ± SD	321	196.19 ± 78.20	202.47 ± 67.05	U = 11681.00	0.369
Vigorous-intensity physical activity time (min)	Mean ± SD	321	45.71 ± 38.90	53.67 ± 33.55	U = 10076.00	0.004
Total MVPA time (min)	Mean ± SD	321	241.90 ± 104.46	256.14 ± 85.79	U = 10935.50	0.07
Average daily MVPA time (min/d)	Mean ± SD	321	38.40 ± 15.51	36.59 ± 12.26	U = 12998.00	0.475
MVPA proportion (%)	Mean ± SD	321	3.93 ± 1.61	3.47 ± 1.15	U = 14238.50	0.026
Achievement of 60 min/d recommendation	No	300	173(57.67)	127(42.33)	Fisher	0.011
	Yes	21	18(85.71)	3(14.29)		
Total step count	Mean ± SD	321	43798.17 ± 13131.22	49625.21 ± 12831.64	U = 9039.50	< 0.001
Average step count (steps/d)	Mean ± SD	321	6989.29 ± 1894.51	7089.32 ± 1833.09	U = 11972.50	0.588
Cadence (steps/min)	Mean ± SD	321	7.05 ± 1.65	6.69 ± 1.54	U = 13975.50	0.056
Vector Magnitude CPM	Mean ± SD	321	655.52 ± 182.09	615.82 ± 170.95	U = 14082.50	0.041
Axis 1 CPM	Mean ± SD	321	332.88 ± 105.41	305.46 ± 92.69	U = 14376.50	0.016
Number of epochs	Mean ± SD	321	24908.40 ± 4643.60	31615.51 ± 6918.61	U = 4632.50	< 0.001

Note: Only valid accelerometer samples from Shanghai were included, defined as ≥ 4 wear days and total wear time ≥ 2400 min. Cobb angle ≥ 10° indicated radiographically confirmed scoliosis. Categorical variables are shown as n (%) and compared using Fisher's exact test; continuous variables are shown as mean ± SD and compared using the Mann–Whitney U test. P < 0.05 was considered significant. Total-volume indicators were interpreted alongside standardized indicators such as average daily MVPA, MVPA proportion, cadence/frequency, and CPM.

Multivariable Logistic Regression Analysis of Accelerometer-Derived Indicators and Cobb Angle ≥ 10°

In the valid accelerometer sample from Shanghai, multivariable logistic regression was used to examine associations between accelerometer-derived indicators and Cobb angle ≥ 10°, adjusting for sex, age, BMI, and wear time. Longer sedentary behavior time was associated with a higher likelihood of Cobb angle ≥ 10°; each 100-min increase corresponded to an adjusted OR of 1.136 (95% CI: 1.016–1.270, P = 0.025). In contrast, meeting the recommendation of 60 minutes of MVPA per day was associated with a lower likelihood of Cobb angle ≥ 10° (adjusted OR = 0.035, 95% CI: 0.004–0.287, P = 0.002).

Higher activity indicators were generally associated with lower likelihood of Cobb angle ≥ 10°. Each 1000-step increase in total step count (adjusted OR = 0.952, P = 0.006), each 1000-step/day increase in average daily step count (adjusted OR = 0.684, P = 0.002), each 1 step/min increase in cadence/frequency (adjusted OR = 0.718, P = 0.011), and each 100-unit increase in Axis 1 CPM (adjusted OR = 0.659, P = 0.039) were all associated with lower likelihood of Cobb angle ≥ 10°. Average daily MVPA, MVPA proportion, and Vector Magnitude CPM showed negative but non-significant trends.

No significant associations were observed for light-, moderate-, vigorous-intensity activity time, or total MVPA time. Overall, after adjustment, longer sedentary time was associated with higher likelihood of Cobb angle ≥ 10°, whereas meeting MVPA recommendations, greater step counts, higher cadence, and higher Axis 1 CPM were associated with lower likelihood. The complete adjusted results are presented in Table 6.

Table 6
Multivariable Logistic Regression Analysis of Accelerometer-Derived Indicators Associated with Cobb Angle ≥ 10°

Indicator	N	Adjusted OR (95% CI)	P value
Sedentary behavior time (min), per 100-min increase	321	1.136 (1.016–1.270)	0.025
Light-intensity physical activity time (min), per 100-min increase	321	0.892 (0.794–1.001)	0.052
Moderate-intensity physical activity time (min), per 100-min increase	321	0.686 (0.403–1.170)	0.167
Vigorous-intensity physical activity time (min), per 10-min increase	321	0.955 (0.873–1.045)	0.316
Total MVPA time (min), per 100-min increase	321	0.745 (0.501–1.106)	0.144
Average daily MVPA time (min/d), per 10-min/d increase	321	0.790 (0.601–1.037)	0.09
MVPA proportion (%), per 1% increase	321	0.799 (0.597–1.070)	0.132
Achievement of 60 min/d recommendation, yes vs. no	321	0.035 (0.004–0.287)	0.002
Total step count, per 1000-step increase	321	0.952 (0.920–0.986)	0.006
Average step count, per 1000-step/d increase	321	0.684 (0.536–0.874)	0.002
Cadence (steps/min), per 1-step/min increase	321	0.718 (0.556–0.927)	0.011
Vector Magnitude CPM, per 100-unit increase	321	0.812 (0.653–1.009)	0.06
Axis 1 CPM, per 100-unit increase	321	0.659 (0.444–0.979)	0.039
Number of epochs, per 1000-epoch increase	321	Not interpreted due to high correlation with wear time	

Note: Only valid accelerometer wear samples from Shanghai were included. Cobb angle ≥ 10° was the dependent variable. Binary logistic regression was performed, with each accelerometer-derived indicator entered separately and adjusted for sex, age, BMI, and wear time. Results are presented as adjusted odds ratios (aORs) and 95% confidence intervals (CIs). Indicators were scaled per 100 min, 10 min, 10 min/day, 1%, 1000 steps, 1 step/min, 1000 steps/day, or 100 CPM, as appropriate. Epoch number was not interpreted because of its high correlation with wear time. $P < 0.05$ was cons idered statistically significant.

Discussion

Based on school-based screening data from Shanghai, Xinjiang, and Fujian, this study combined radiographic confirmation using the Cobb angle, a sports behavior questionnaire, the IPAQ physical activity survey, and accelerometer data from Shanghai to examine the associations of scoliosis in children and adolescents with sports behavior and physical activity levels. Among 9,464 students, 225 were radiographically confirmed as having scoliosis with a Cobb angle ≥ 10°, yielding an overall detection proportion of 2.38%. The detection proportions in Shanghai, Xinjiang, and Fujian were 2.59%, 2.33%, and 1.96%, respectively, with no significant regional difference. Most confirmed students had mild scoliosis, and Lenke type 1 was the most common classification. Multivariable analysis showed that female sex, higher grade level, lower BMI, higher sports behavior risk, lower MVPA level, and longer sedentary time were associated with the detection of Cobb angle ≥ 10°.

The radiographically confirmed detection proportion in this study is generally consistent with previous school-based screening and epidemiological studies. Li et al. [49] reported that the prevalence of scoliosis among children and adolescents varies across regions and study designs, while studies by Adobor et al. [50] and Zheng et al. [51] showed findings similar to ours. Because this study did not perform universal radiographic examination for all students, but conducted imaging assessment based on positive screening results and referral criteria, the findings should be interpreted as the radiographically confirmed detection proportion under a school-based screening and referral pathway, rather than the overall population prevalence. The predominance of mild scoliosis suggests that school-based screening may facilitate early detection, follow-up, and management [52–54].

Regarding demographic and body morphology factors, girls, students in higher grades, and students with lower BMI had a higher likelihood of Cobb angle ≥ 10°. Previous studies have also reported that adolescent idiopathic scoliosis is more common during adolescence and occurs more frequently in girls [55]. Lower BMI has been observed in patients with AIS [56], and may be causally associated with AIS risk [57]. Ramírez et al. [58] further suggested that girls with AIS may differ in body composition, including BMI, fat mass, and fat-free mass. Therefore, the association between low BMI and scoliosis detection should not be simply interpreted as low body weight causing scoliosis; lean mass, bone mass, muscle strength, and nutritional status should also be considered. In addition, postural habits, learning environments, and lifestyle factors may contribute to scoliosis risk in adolescents [22, 59, 60]. The present study adds evidence from the perspective of sports behavior, suggesting that school-based spinal health promotion should integrate posture management, desk and chair adaptation, recess activity, and sports behavior guidance.

In terms of sports behavior, unilateral sports and asymmetrical loading, excessive flexibility and large-amplitude movements, and insufficient core strength and trunk stability were associated with a higher likelihood of Cobb angle ≥ 10°. Longworth et al. [24] found that adolescent ballet dancers had a higher proportion of positive scoliosis screening results than non-dancers, while Guan et al. [61] suggested that different types of physical activity may have different associations with AIS. In contrast, Negrini et al. [1] reported that sports participation among adolescents with mild idiopathic scoliosis may be associated with a lower risk of progression and reduced need for bracing. These findings indicate that exercise itself should not be simply regarded as a risk factor; rather, the type of exercise, loading pattern, and quality of movement control are more important. School-based physical education should therefore

focus not only on increasing exercise volume, but also on improving exercise quality, including movement symmetry, core stability, appropriate loading, and motor control [62].

The physical activity survey showed that students with Cobb angle ≥ 10° had lower MVPA time and longer weekday sedentary time. Previous findings on this issue are not entirely consistent. Diarbakerli et al. [63] found similar self-reported physical activity levels between adolescents with and without AIS, whereas Zhu et al. [64] reported that insufficient MVPA and excessive screen time were associated with AIS. Chu et al. [65] also found that longer sedentary time may be associated with a higher likelihood of positive scoliosis screening. The WHO guidelines recommend that children and adolescents engage in an average of at least 60 minutes of MVPA per day and reduce sedentary behavior [41]. In this study, meeting the daily 60-min MVPA recommendation was associated with a lower proportion of Cobb angle ≥ 10°, whereas achieving ≥ 600 MET-min/week was not significantly associated with scoliosis detection. This suggests that the daily MVPA recommendation may be more suitable for identifying spinal health risk among adolescents. However, the cross-sectional design prevents causal inference.

The accelerometer subsample from Shanghai further showed that the Cobb angle ≥ 10° group had lower intensity-related indicators, including MVPA proportion, Vector Magnitude CPM, and Axis 1 CPM. After adjustment for sex, age, BMI, and wear time, longer sedentary behavior time was associated with a higher likelihood of Cobb angle ≥ 10°, whereas meeting the daily 60-min MVPA recommendation, higher step count, higher cadence, and higher Axis 1 CPM were associated with a lower likelihood. These findings suggest that, when interpreting the relationship between physical activity and scoliosis, total step count and total activity time should be considered together with intensity-related indicators such as MVPA proportion, CPM, and cadence.

From the perspective of school-based health promotion, scoliosis prevention and control in children and adolescents should not be limited to posture screening and radiographic referral, but should also include sports behavior assessment, physical activity promotion, and sedentary behavior intervention. Girls, students in higher grades, and students with low BMI may be priority groups for attention. School physical education should emphasize movement symmetry, trunk control, core stability, and appropriate loading, while reducing prolonged unilateral force production, excessive flexibility training, and unreasonable large-amplitude movements. Previous evidence suggests that core stabilization training may improve AIS-related indicators [66], and SOSORT guidelines emphasize individualized, regular, and professionally supervised scoliosis-specific exercises [1]. For students with postural abnormalities or mild scoliosis, exercise should not be simply restricted; instead, individualized exercise guidance, regular reassessment, and dynamic management should be implemented [67].

The strengths of this study include its relatively large school-based sample from three regions and the use of on-site screening combined with radiographic confirmation based on the Cobb angle. In addition, sports behavior, IPAQ-derived indicators, and accelerometer-derived indicators were included, allowing scoliosis-related factors to be analyzed from both subjective and objective perspectives. This study also focused not only on the quantity of physical activity but also on the quality of exercise, providing more specific evidence for school-based physical education interventions.

This study has several limitations. First, its cross-sectional design does not allow causal relationships to be determined. Lower physical activity levels may contribute to scoliosis risk, but may also result from spinal discomfort, postural abnormalities, or parental restrictions on exercise. Second, radiographic examination was not performed for all students, and radiographic confirmation was based on the school-based screening and referral pathway; therefore, detection results may have been influenced by the screening process and referral criteria. Third, IPAQ-based physical activity data were self-reported and may be affected by recall and social desirability biases. Fourth, the accelerometer subsample was limited to Shanghai, and the valid sample size was relatively small, so generalization should be made with caution. Finally, although the sports behavior questionnaire showed good internal consistency, its predictive validity and sensitivity to intervention require further validation. Future longitudinal studies are needed to clarify the temporal relationships among sports behavior, MVPA, sedentary time, and the onset and progression of scoliosis.

Conclusions

Based on school-based screening data from 9,464 students in grades 4–12 from Shanghai, Xinjiang, and Fujian, the detection proportion of scoliosis with Cobb angle ≥ 10° was 2.38%, with most confirmed cases being mild and Lenke type 1 being the most common. Girls, higher-grade students, and those with lower BMI had a higher likelihood of scoliosis detection. Unilateral sports and asymmetrical loading, excessive flexibility and large-amplitude movements, insufficient core strength and trunk stability, lower MVPA levels, and longer sedentary time were associated with scoliosis detection. School-based spinal health promotion should focus on high-risk students and strengthen sedentary behavior intervention, core stability training, and symmetrical movement guidance.

Abbreviations

AIS
adolescent idiopathic scoliosis
aOR
adjusted odds ratio
ATR
angle of trunk rotation
BMI
body mass index
CI
confidence interval

CPM
counts per minute
IPAQ-SF
International Physical Activity Questionnaire-Short Form
MET
metabolic equivalent
MVPA
moderate-to-vigorous physical activity
OR
odds ratio
SD
standard deviation
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology.

Declarations

Ethics approval and consent to participate

Human Ethics and Consent to Participate declarations: This study was approved by the Ethics Review Committee of Shanghai University of Sport (approval no. 102772024RT110). Written informed consent to participate was obtained from all participating students and their parents or legal guardians before enrollment.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was funded by the Key Research Project of the Ministry of Science and Technology of China, titled “Research on Intelligent Analysis of Teenagers' Sports Learning and Intelligent Recommendation of Personalized Prescriptions”(No. 2023YFC3305804); supported by the Research and Innovation Grant for Graduate Students from Shanghai University of Sport (Project No. YJSCX-2024-038); and funded by the 2025 Shanghai Education Research Project: “Innovative and Empirical Research on Precise Services for School Physical Education after Class Driven by Sports Literacy and Enabled by Digital Intelligence” (C2025076).

Author Contribution

Yuanyuan Cao and Xiaohan Li contributed equally to this work and share first authorship. YC and XH contributed to the study conception and design, data curation, statistical analysis, interpretation of the results, and drafting of the manuscript. SS and YW contributed to school coordination, participant recruitment, on-site screening, questionnaire administration, and data collection. MF and XuL contributed to physical fitness testing, accelerometer data collection, data cleaning, and quality control. XZ contributed to radiographic assessment, Cobb angle measurement, Lenke classification, and clinical interpretation of scoliosis-related findings. WW and JX contributed to the study conception, methodology, project administration, funding acquisition, supervision, and critical revision of the manuscript. All authors read and approved the final manuscript.

Acknowledgement

The authors would like to thank all participating students and their guardians for their cooperation and support. We are also grateful to the participating schools, teachers, and local education administrators in Shanghai, Xinjiang, and Fujian for their assistance with school-based screening, questionnaire surveys, physical fitness testing, and accelerometer data collection. We sincerely acknowledge the research staff, screening personnel, and radiographic assessment team for their contributions to data collection and quality control.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to privacy and ethical restrictions involving minors but are available from the corresponding author on reasonable request and with approval from the relevant ethics committee.

References

1. NEGRINI S, DONZELLI S, AULISA A G, et al. 2016 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth[J]. Scoliosis Spinal Disord. 2018;13:3.
2. KUZNIA A, HERNANDEZ A. Adolescent Idiopathic Scoliosis: Common Questions and Answers[J]. Am Family Phys. 2020;101:19–23.
3. AUERBACH JD, LONNER B S, CRERAND C E, et al. Body image in patients with adolescent idiopathic scoliosis: validation of the Body Image Disturbance Questionnaire–Scoliosis Version[J]. J Bone Joint Surg Am. 2014;96(8):e61.
4. HUH S, EUN L Y, KIM N K, et al. Cardiopulmonary function and scoliosis severity in idiopathic scoliosis children[J]. Korean J Pediatr. 2015;58(6):218–23.
5. GALLANT J, MORGAN C D, STOKLOSA JB, et al. Psychosocial Difficulties in Adolescent Idiopathic Scoliosis: Body Image, Eating Behaviors, and Mood Disorders[J]. World Neurosurg. 2018;116:421–32.
6. WEINSTEIN S L, DOLAN L A, CHENG JC, et al. Adolescent idiopathic scoliosis[J]. Lancet. 2008;371(9623):1527–37.
7. CHENG JC, CASTELEIN R M, CHU W C, et al. Adolescent idiopathic scoliosis[J]. Nat Reviews Disease Primers. 2015;1(1):15030.
8. WEINSTEIN S L, DOLAN L A, WRIGHT J G, et al. Effects of Bracing in Adolescents with Idiopathic Scoliosis[J]. N Engl J Med. 2013;369(16):1512–21.
9. KONIECZNY M R, SENYURT H. Epidemiology of adolescent idiopathic scoliosis[J]. J Child Orthop. 2013;7(1):3–9.
10. FU X, MENG S, HUANG X, et al. The prevalence of scoliosis among adolescents in China: a systematic review and meta-analysis[J]. J Orthop Surg Res. 2024;19(1):585.
11. LUK K D K, LEE C F, CHEUNG K M C et al. Clinical effectiveness of school screening for adolescent idiopathic scoliosis: a large population-based retrospective cohort study[Z]. 2010: 35, 1607–14.
12. DUNN J, HENRIKSON N B, MORRISON C C, et al. Screening for Adolescent Idiopathic Scoliosis: Evidence Report and Systematic Review for the US Preventive Services Task Force[J]. JAMA. 2018;319(2):173–87.
13. WANG S, LI M, REN J, et al. Global prevalence and associated risk factors of scoliosis in children and adolescents: a systematic review and meta-analysis[J]. BMC Public Health. 2025;25(1):3640.
14. KIM S, UHM J, CHAE D, et al. Low Body Mass Index for Early Screening of Adolescent Idiopathic Scoliosis: A Comparison Based on Standardized Body Mass Index Classifications[J]. Asian Nurs Res. 2020;14(1):24–9.
15. DOU Q, ZHU Z. Academic-related factors and daily lifestyle habits associated with adolescent idiopathic scoliosis: a case-control study[J]. Environ Health Prev Med. 2023;28:23.
16. YANG J, HUANG S, CHENG M, et al. Postural habits and lifestyle factors associated with adolescent idiopathic scoliosis (AIS) in China: results from a big case–control study[J]. J Orthop Surg Res. 2022;17(1):472.
17. CHEN H, WU L, ZHANG Y, et al. Correlation between abnormal posture, screen time, physical activity, and suspected scoliosis: a cross-sectional study[J]. J Orthop Surg Res. 2025;20(1):372.
18. QI X, PENG C, FU P, et al. Correlation between physical activity and adolescent idiopathic scoliosis: a systematic review[J]. BMC Musculoskelet Disord. 2023;24(1):978.
19. NEWMAN M, HANNINK E, BARKER KL. Associations Between Physical Activity and Adolescent Idiopathic Scoliosis: A Systematic Review and Meta-analysis[J]. Arch Phys Med Rehabil. 2023;104(8):1314–30.
20. TOBIAS JH, FAIRBANK J, HARDING I, et al. Association between physical activity and scoliosis: a prospective cohort study[J]. Int J Epidemiol. 2019;48(4):1152–60.
21. CHOPRA S, LARSON A, KAUFMAN K et al. Accelerometer based assessment of daily physical activity and sedentary time in adolescents with idiopathic scoliosis[J]. PLoS ONE, 2020,15.
22. de ASSIS S J C, SANCHIS G J B G, et al. Influence of physical activity and postural habits in schoolchildren with scoliosis[J]. Arch Public Health. 2021;79(1):63.
23. WATANABE K, MICHIKAWA T, YONEZAWA I, et al. Physical Activities and Lifestyle Factors Related to Adolescent Idiopathic Scoliosis[J]. J Bone Joint Surg Am. 2017;99(4):284–94.
24. LONGWORTH B, FARY R. Prevalence and predictors of adolescent idiopathic scoliosis in adolescent ballet dancers[J]. Arch Phys Med Rehabil. 2014;95(9):1725–30.
25. TANCHEV P I, DZHEROV A D, PARUSHEV A D, et al. Scoliosis in rhythmic gymnasts[J]. Spine (Phila Pa 1976). 2000;25(11):1367–72.
26. MOUSAVI L, SEIDI F, MINOONEJAD H, et al. Prevalence of idiopathic scoliosis in athletes: a systematic review and meta-analysis[J]. BMJ Open Sport Exerc Med. 2022;8(3):e1312.
27. DUFVENBERG M, ADEYEMI F, RAJENDRAN I, et al. Does postural stability differ between adolescents with idiopathic scoliosis and typically developed? A systematic literature review and meta-analysis[J]. Scoliosis Spinal Disord. 2018;13:19.
28. KOCAMAN H, BEK N, KAYA MH, et al. The effectiveness of two different exercise approaches in adolescent idiopathic scoliosis: A single-blind, randomized-controlled trial[J]. PLoS ONE. 2021;16(4):e249492.
29. BULL F C, AL-ANSARI S S BIDDLES, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour[J]. Br J Sports Med. 2020;54(24):1451–62.
30. CRAIG CL, MARSHALL A L, SJÖSTRÖM M, et al. International physical activity questionnaire: 12-country reliability and validity[J]. Med Sci Sports Exerc. 2003;35(8):1381–95.

31. HAGSTRÖMER M, BERGMAN P, De BOURDEAUDHUIJI, et al. Concurrent validity of a modified version of the International Physical Activity Questionnaire (IPAQ-A) in European adolescents: The HELENA Study[J]. Int J Obes (Lond). 2008;32(Suppl 5):S42–8.
32. LEE PH, MACFARLANE D J, LAM T H, et al. Validity of the International Physical Activity Questionnaire Short Form (IPAQ-SF): a systematic review[J]. Int J Behav Nutr Phys Act. 2011;8:115.
33. TROST S G. State of the Art Reviews: Measurement of Physical Activity in Children and Adolescents[J]. Am J Lifestyle Med, 2007,1(4).
34. REILLY J, PENPRAZE V, HISLOP J, et al. Objective Measurement of Physical Activity and Sedentary Behaviour: Review with New Data[J]. Arch Dis Child. 2008;93:614–9.
35. BUNNELL W P. Outcome of spinal screening[J]. Spine. 1993;18:1572–80.
36. FORCE U S P S. Adolescent Idiopathic Scoliosis. Screening[EB/OL]. [2026-05-06]. https://www.uspreventiveservicestaskforce.org/uspstf/recommendation/adolescent-idiopathic-scoliosis-screening
37. HUANG SC. Cut-off point of the Scoliometer in school scoliosis screening[J]. Spine (Phila Pa 1976). 1997;22(17):1985–9.
38. SELLEN D. Physical Status: The Use and Interpretation of Anthropometry. Report of a WHO Expert Committee. WHO Technical Report Series No. 854. Pp. 452. (WHO, Geneva, 1995.) Swiss Fr 71.00.[J]. Journal of Biosocial Science, 1998,30(1): 135–144.
39. LARSEN M N, KRUSTRUP P, ARAÚJO PÓVOAS S, C, et al. Accuracy and reliability of the InBody 270 multi-frequency body composition analyser in 10-12-year-old children[J]. PLoS ONE. 2021;16(3):e247362.
40. SÁNCHEZ-DELGADO G, CADENAS-SANCHEZ C, MORA-GONZALEZ J, et al. Assessment of handgrip strength in preschool children aged 3 to 5 years[J]. Volume 8. Revista Andaluza de Medicina del Deporte; 2015. p. 43.
41. ORGANIZATION W H. WHO guidelines on physical activity and sedentary behaviour[M]. Geneva. 2020: 104.
42. MONFORT PAÑEGO M, MOLINA-GARCÍA J, MIÑANA-SIGNES V et al. Development and psychometric evaluation of a health questionnaire on back care knowledge in daily life physical activities for adolescent students[J]. Eur Spine J, 2016,25.
43. VIJ N, NARON I, TOLSON H et al. Back pain in adolescent athletes: a narrative review[J]. Orthop Rev, 2022,14.
44. SCHIFANO J. How Delphi studies in the health sciences find consensus: a scoping review[J]. Syst Reviews. 2025;14(1):14.
45. TABER K S. The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education[J]. Res Sci Educ. 2018;48(6):1273–96.
46. MIGUELES JH, CADENAS-SANCHEZ C, EKELUND U, et al. Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations[J]. Sports Med. 2017;47(9):1821–45.
47. VANHELST J, VIDAL F. Comparison and validation of accelerometer wear time and non-wear time algorithms for assessing physical activity levels in children and adolescents[J]. BMC Med Res Methodol. 2019;19(1):72.
48. AADLAND E, ANDERSEN L B, ANDERSSEN S A, et al. A comparison of 10 accelerometer non-wear time criteria and logbooks in children[J]. BMC Public Health. 2018;18(1):323.
49. LI M, NIE Q, LIU J et al. Prevalence of scoliosis in children and adolescents: a systematic review and meta-analysis[J]. Front Pead, 2024,Volume 12–2024.
50. ADOBOR RD, RIMESLATTEN S, STEEN H, et al. School screening and point prevalence of adolescent idiopathic scoliosis in 4000 Norwegian children aged 12 years[J]. Scoliosis. 2011;6(1):23.
51. ZHENG Y, DANG Y, WU X et al. Epidemiological study of adolescent idiopathic scoliosis in Eastern China[Z]. 2017: 49, 512–9.
52. LIU L, WANG X. Prevalence of adolescent idiopathic scoliosis in Shijiazhuang, Hebei, China: a cross-sectional study[J]. Eur Spine J. 2024;33(2):673–9.
53. LUK K D K, LEE C F, CHEUNG K M C et al. Clinical Effectiveness of School Screening for Adolescent Idiopathic Scoliosis: A Large Population-Based Retrospective Cohort Study[J]. Spine, 2010,35(17).
54. IRIANTO K, SB D. Prevalence Rate of Adolescent Idiopathic Scoliosis: Results of School-based Screening in Surabaya, Indonesia[J]. Malaysian Orthop J. 2017;11:17–22.
55. SUNG S, CHAE H, LEE HS et al. Incidence and Surgery Rate of Idiopathic Scoliosis: A Nationwide Database Study: International Journal of Environmental Research and Public Health[Z]. 2021: 18, 8152.
56. TARRANT R C, QUEALLY J M, MOORE D P, et al. Prevalence and impact of low body mass index on outcomes in patients with adolescent idiopathic scoliosis: a systematic review[J]. Eur J Clin Nutr. 2018;72(11):1463–84.
57. OTOMO N, KHANSHOUR A M, KOIDO M, et al. Evidence of causality of low body mass index on risk of adolescent idiopathic scoliosis: a Mendelian randomization study[J]. Front Endocrinol (Lausanne). 2023;14:1089414.
58. RAMÍREZ M, MARTÍNEZ-LLORENS J, SANCHEZ JF, et al. Body composition in adolescent idiopathic scoliosis[J]. Eur Spine J. 2013;22(2):324–9.
59. SCATURRO D, COSTANTINO C, TERRANA P, et al. Risk Factors, Lifestyle and Prevention among Adolescents with Idiopathic Juvenile Scoliosis: A Cross Sectional Study in Eleven First-Grade Secondary Schools of Palermo Province, Italy. Int J Environ Res Public Health[Z]. 2021;18:12335.
60. KHADOUR F A, KHADOUR Y A ALBARROUSHD. Association between postural habits and lifestyle factors of adolescent idiopathic scoliosis in Syria[J]. Sci Rep. 2024;14(1):26784.
61. GUAN Y, ZHAO B, FAN Y et al. Protective and risk physical activities for adolescent idiopathic scoliosis: a systematic review identifying one-hour daily activity threshold and Chinese school-based prevention framework[J]. Front Sports Act Living, 2025,Volume 7–2025.
62. WATANABE K, MICHIKAWA T, YONEZAWA I et al. Physical Activities and Lifestyle Factors Related to Adolescent Idiopathic Scoliosis[J]. JBJS, 2017,99(4).

63. DIARBAKERLI E, GRAUERS A, MÖLLER H, et al. Adolescents with and without idiopathic scoliosis have similar self-reported level of physical activity: a cross-sectional study[J]. Scoliosis Spinal Disord. 2016;11:17.
64. ZHU L, RU S, WANG W, et al. Associations of physical activity and screen time with adolescent idiopathic scoliosis[J]. Environ Health Prev Med. 2023;28:55.
65. CHU L, YANG D, ZHANG F et al. Association of physical activity and sedentary time with scoliosis screening positive in Chinese primary and secondary school students: a cohort study in Shanghai[J]. Front Public Health, 2025,Volume 13–2025.
66. GÜR G, AYHAN C, YAKUT Y. The effectiveness of core stabilization exercise in adolescent idiopathic scoliosis: A randomized controlled trial[J]. Prosthet Orthot Int. 2017;41(3):303–10.
67. NEGRINI A, DONZELLI S, VANOSSI M et al. Sports participation reduces the progression of idiopathic scoliosis and the need for bracing. An observational study of 511 adolescents with Risser 0–2 maturation stage[J]. Eur J Phys Rehabil Med, 2023,59.

Figures

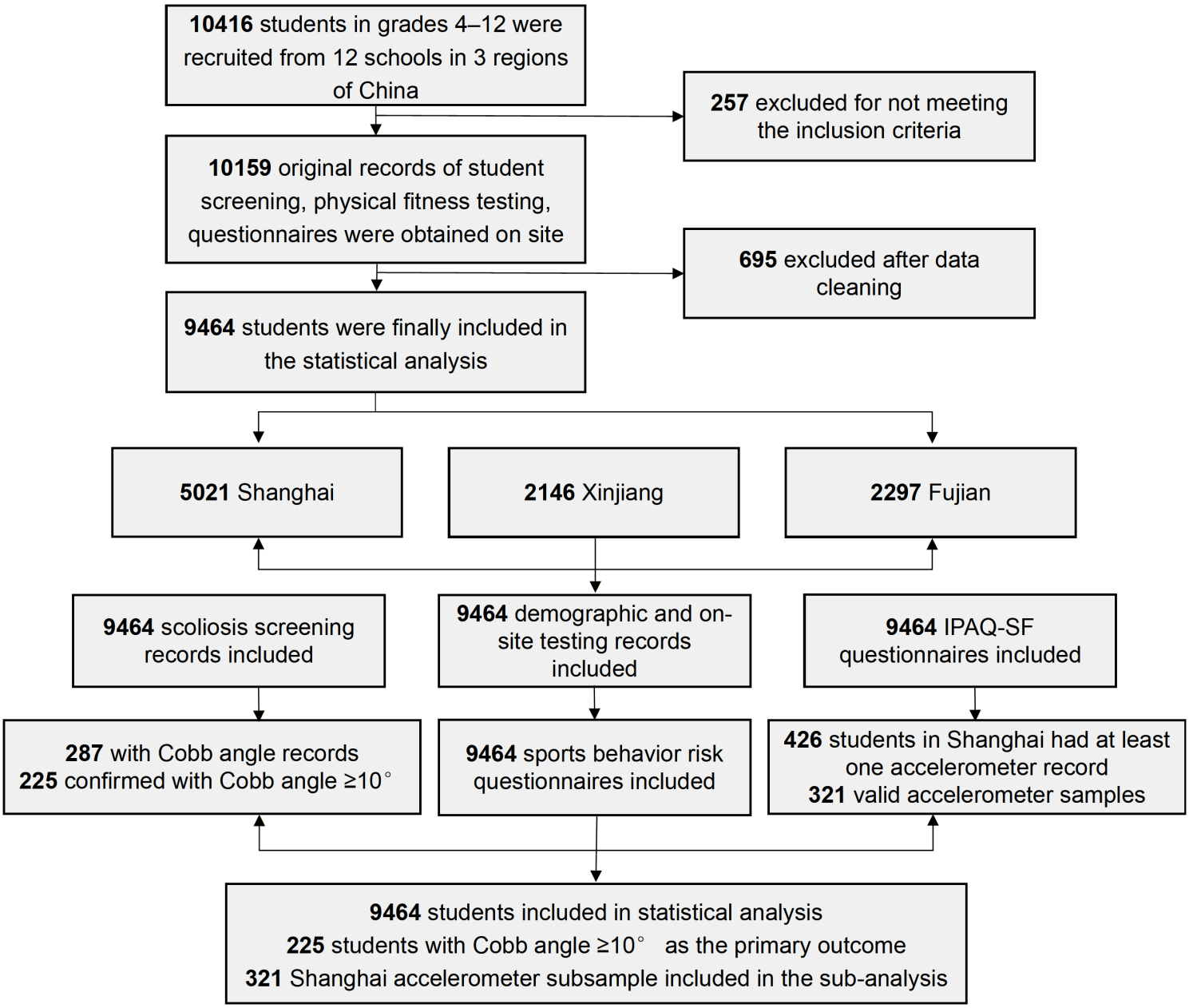


Figure 1

Flowchart of Data Collection