



OPEN Prevalence and lifestyle determinants of depressive symptoms among Chinese children and adolescents

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Based on Chinese Students' Fitness Health Examination, this study sought to investigate the relationships between depressive symptoms and family environment, physical activity, dietary habits, sleep and sedentary behavior among children and adolescents. A cross-sectional study was carried out to estimate the prevalence of depressive symptoms in 32,389 participants (grades 4–12) using the CES-D. Logistic regression was used to evaluate the relationships between lifestyle determinants and depressive symptoms, and a random forest model was used to rank the importance of those determinants. The overall prevalence of depressive symptoms was 39.93%. Students with depressive symptoms had higher grades, lower parental educational levels and unhealthy lifestyles ($P < 0.05$). The top ten most important determinants of depressive symptoms were grade, egg intake, milk/soy product intake, frequency of muscle strength training, screen time, sleep duration, parental educational level, sugar beverage intake and total physical activity. Socioeconomic status, physical activity, sleep and screen time, and diet habits are determinants of depressive symptoms, and surveillance of lifestyles may be an effective way to detect students with depressive symptoms early.

Keywords Depressive symptom, Lifestyles, Children and adolescents, Random forest model

Depression is a common mental disorder that is characterized by persistent sadness and a lack of interest or pleasure in previously rewarding or enjoyable activities^{1,2}. Globally, depression is the number one cause of illness and disability for children and adolescents aged 10–18 years³. According to the latest estimates from the WHO, approximately 280 million people in the world have depression, and 14% of 10–19-year-olds experience mental health conditions, yet these remain largely unrecognized⁴. A survey in India reveals that nearly half of the adolescents are afflicted with depression, 5% of whom suffer from severe depression, 6% of whom experience moderate depression, and 34% of whom experience mild depression⁵.

According to the DSM-5, depression is characterized by five or more symptoms that persist for at least two weeks, such as feelings of worthlessness, decreased interest in activities, changes in appetite or weight, insomnia, restlessness, and thoughts of suicide or death². However, owing to the social stigma associated with mental disorders, many students are hesitant to access mental health services, limiting the ability of psychiatrists to diagnose depression⁶. Therefore, the use of a screening instrument can assist in boosting the rate of mental health assessments among students, thus aiding in the identification and diagnosis of depression before any psychiatric consultation⁷.

The causes of depression include complex interactions between social, psychological and biological factors. Lifestyle factors, together with socioeconomic factors, have a large impact on mental disorders in children and adolescents^{8–10}. However, most studies on depression and lifestyle involve only a few lifestyle factors, and comprehensive analyses of the determinants of depression among children and adolescents are scarce. Therefore, this study randomly selected 32,389 primary and middle school students (from the fourth grade of elementary school to the third grade of high school) who participated in the Students' Fitness Health Examination (SFHE) in 2019–2020 to explore the associations of socioeconomic status, physical exercise, diet habits, sleep and screen time with the prevalence of depressive symptoms and to determine the importance of those variables by adopting a random forest model.

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Method

Study design and population

By adopting a cross-sectional study design, this study was conducted from 2019 to 2020 in China. A total of 32,389 participants (grades 4–12) were randomly recruited from three provinces (Shandong, Chongqing, Guangdong) to complete an online questionnaire under the guidance of regional administrators, physical education teachers and graduate students. Two primary schools, two junior high schools and two senior high schools were randomly chosen from city and rural areas, respectively, in each city, with approximately 120 students (3–4 classes) recruited from each school in each grade. Parents and students provided written consent prior to enrollment in this survey. This study was approved by the Ethics Committee of Shandong Sport University (2022018), and all methods were performed in accordance with the Declaration of Helsinki.

Measurements

Data regarding participants' depressive symptoms, lifestyles, and family demographics were collected using three questionnaires that were developed collaboratively by a multidisciplinary team of researchers.

Depressive symptoms were measured using the Center for Epidemiological Studies Depression Scale (CES-D), a self-reported, generic measure of depression validated for children and adolescents. The reliability and validity of the Chinese version have been validated and reported previously¹¹. The CES-D questionnaire included 20 items, and each item used a four-point Likert-type scale (ranging from 0 to 3); thus, the total CES-D score ranged from 0 to 60 points, with higher scores indicating a greater probability of depression. CES-D scores greater than or equal to 16 were considered to indicate suspected depression^{12–14}, thus individuals with CES-D scores greater than or equal to 16 were considered as the depression group in this study.

The participants' lifestyles included physical activity and exercise, diet, sleep and screen time. The physical activity level (PA) of the participants was assessed using the International Physical Activity Questionnaire (IPAQ). This questionnaire is a self-reported measure of physical activity and has been used widely in a variety of research studies. The IPAQ was used to calculate the overall physical activity level (MET-min/wk) by using the following equation: 8.0 METs × total duration of vigorous activity + 4.0 METs × total duration of moderate activity + 3.3 METs × total duration of walking¹⁵. Exercise included exercise frequency, exercise time, feeling in exercise, days of physical education classes, and muscle strength training frequency. Data on dietary habits, including the frequency of consuming breakfast, milk/soy products, eggs and sugar beverages, were collected. Sleep duration was calculated by asking about the time of getting sleep and getting up in the past month, and time spent napping was obtained via a direct questionnaire. The screen time survey collected the average time spent using electronic devices (watching TV, playing games with mobile phones, tablets, video games, computers, etc., watching videos or e-books, etc.) every weekday and weekend in the past week.

The participants' socioeconomic factors included residential location (urban or rural), parents' educational level, and whether the participant was the only child of the family.

Statistical analysis

Descriptive analysis was used to describe participants' demographic characteristics and prevalence of depressive symptoms. The standardized prevalence of depressive symptoms in students with different lifestyles was adjusted for grade, sex, and urban/rural area. Logistic regression was used to explore the associations between individual lifestyles and depressive symptom after adjusting for grade, sex, and urban/rural area, and the effect sizes (odds ratio (OR)) and 95% confidence intervals (95% CIs) were calculated. *P* values < 0.05 were considered to indicate statistical significance.

Furthermore, machine learning was used to rank variable importance^{16,17}. For comparing model performance, we adopted random forest, artificial neural network, decision tree algorithm, and logistic regression algorithms to develop models in the training set (2/3 participants), and assessed model performance in the validation set (1/3 participants), by using area under the ROC curve (AUC), classification accuracy (ACC), balanced error rate (BER), false positive rate (FPR), positive predictive value (PPV) and negative predictive value (NPV) as the evaluation¹⁸. The random forest model performed best (see supplementary Fig. 1 and supplementary Table 2) thus we adopted random forest model to rank variable importance. Imputation method had been extensively applied to account for missing data, by adopting "missForest" package¹⁹, and further sensitive analysis were conducted by adjusting for different sets of possible confounders.

SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC) and R 4.2.0 were used in this study.

Results

Among the 32 389 participants, 12 932 (39.93%) had a CES-D score ≥ 16. The prevalence of depressive symptoms was 39.9% (6461/12301) in males and 40.0% (6471/16189) in females, with no significant difference between the sexes (*P* = 0.870). The prevalence of depressive symptoms increased significantly with increasing grade (*P* < 0.001), and the prevalence of depressive symptoms was 42.5% (7007/16498) in urban students and 37.3% (5925/15892) in rural students (*P* < 0.001). The grade-, sex-, rural/urban-specific prevalence of depressive symptoms is shown in Fig. 1, and the baseline characteristics of the study population are shown in Table 1. Students with depressive symptoms had higher grades, lived in the city, had lower parental educational levels, and had unhealthy lifestyles. They performed less exercise and muscle strength training, participated in fewer physical education classes, and had lower metabolic equivalents of physical activity. Students who were depressed tended to skip breakfast, consume fewer eggs and milk/soy products, and consume more sugary drinks. They slept less, took shorter naps, and spent more time watching television (*p* < 0.05).

The crude prevalence and grade-, sex-, rural/urban-adjusted prevalence of depressive symptoms, as well as the logistic regression model, are shown in Table 2. Only children had a lower prevalence of depressive

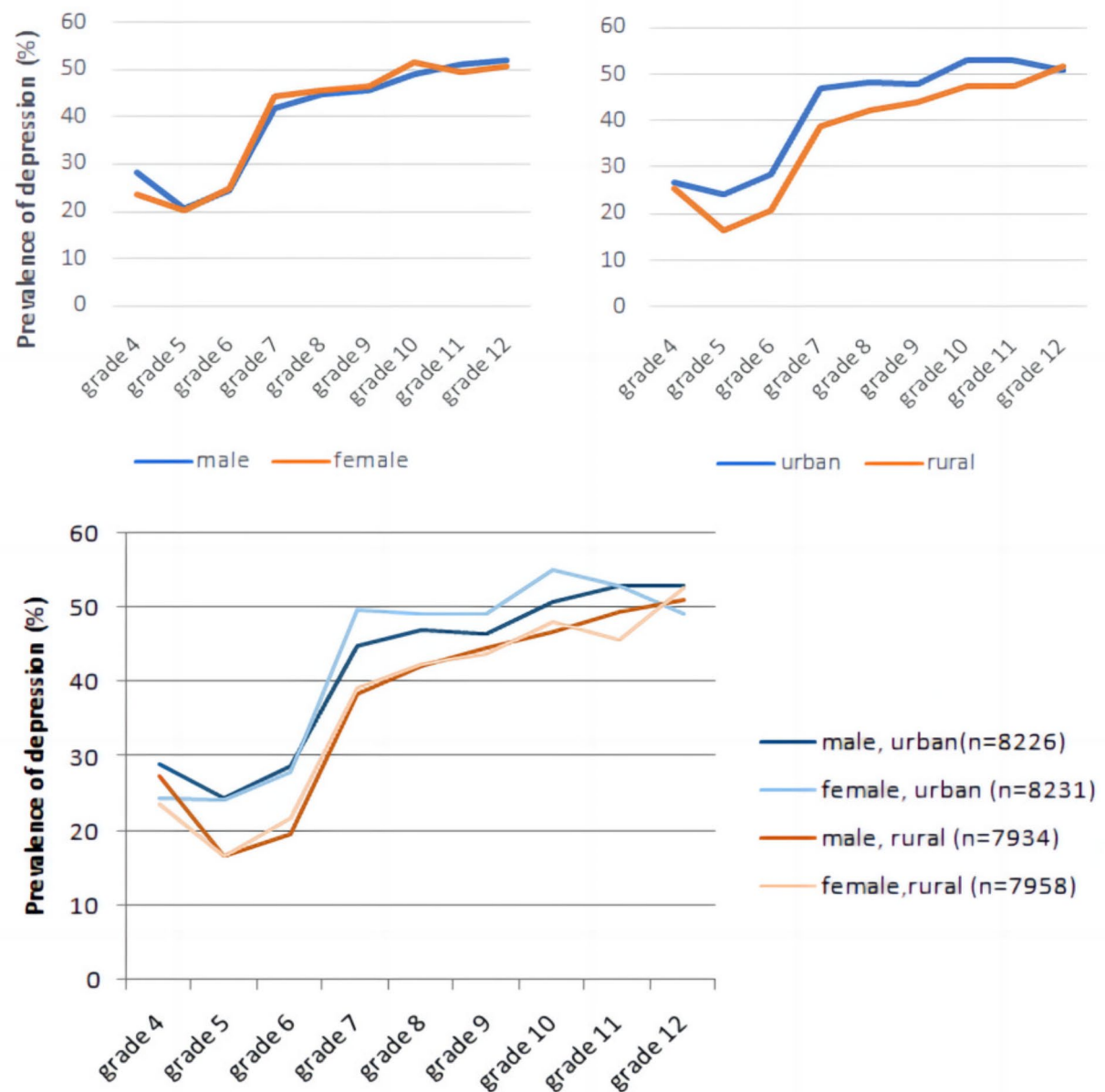


Fig. 1. Grade-, gender-, rural/urban-specific prevalence of depressive symptoms.

symptoms than non-only children (OR (95%CI) = 0.85 (0.80–0.90), $P < 0.001$), and a higher parental educational level was a protective factor against depressive symptoms ($P < 0.05$). An increased number of days participating in exercise, increased duration of exercise per day, increased number of physical education classes per week, and increased total physical activity per day were protective factors against depressive symptoms ($P < 0.05$). Specifically, children taking muscle strength 5+ times per week had 74% lower risk of depressive symptoms than children do not taking muscle strength (OR (95%CI) = 0.26(0.23–0.29), $P < 0.001$), indicating the importance of muscle strength in the prevention of mental disorders. A healthy diet and adequate sleep were protective factors against depressive symptoms in students, e.g, children having 10+ hours of sleep had 77% lower risk of depressive symptoms than children having less than 8 h of sleep (OR (95%CI) = 0.23(0.20–0.26), $P < 0.001$). While the risk of depressive symptoms for children having sugary drinks more than 5 times/week was 2.07 (95%CI = 1.68–2.54, $P < 0.001$) times than those do not have sugary drinks, and screen time was also a risk factor for depressive symptoms (OR (95%CI) of 60+ minutes vs. <10 min per day = 2.07(1.91–2.25), $P < 0.001$). The results were almost the same in imputed dataset (results not shown), and robust after adjusting for different confounding variables (see supplementary Table 3).

Additionally, random forest models were applied to rank the importance of all the variables, and the ten most important factors for depressive symptoms were grade, egg intake, milk/soy product intake, number of muscle

Characteristic, <i>n</i> (%)	Depressive Symptom			
	Total (<i>N</i> = 32,389)	Yes (<i>N</i> = 12,932)	No (<i>N</i> = 19,457)	<i>P</i> value
Sex				0.870
Male	16,200(50.0)	6,461(50.0)	9,739(50.1)	.
Female	16,189(50.0)	6,471(50.0)	9,718(49.9)	.
School Level				<0.001
Primary school	10,592(32.7)	2,509(19.4)	8,083(41.5)	.
Junior High school	10,869(33.6)	4,876(37.7)	5,993(30.8)	.
Senior High school	10,928(33.7)	5,547(42.9)	5,381(27.7)	.
Rural				<0.001
Urban	16,497(50.9)	7,007(54.2)	9,490(48.8)	.
Rural	15,892(49.1)	5,925(45.8)	9,967(51.2)	.
Only child in family				0.140
No	20,200(63.5)	8,078(64.0)	12,122(63.2)	.
Yes	11,594(36.5)	4,539(36.0)	7,055(36.8)	.
Father's educational level				<0.001
Primary school and Below	1,709(5.5)	814(6.6)	895(4.8)	.
Junior High school	10,647(34.5)	4,648(37.9)	5,999(32.3)	.
Senior High school	9,800(31.8)	3,735(30.4)	6,065(32.7)	.
College	7,424(24.1)	2,653(21.6)	4,771(25.7)	.
Master and Above	1,249(4.1)	417(3.4)	832(4.5)	.
Mother's educational level				<0.001
Primary school and Below	3,337(10.8)	1,590(13.0)	1,747(9.4)	.
Junior High school	10,843(35.2)	4,590(37.6)	6,253(33.6)	.
Senior High school	9,062(29.4)	3,516(28.8)	5,546(29.8)	.
College	6,494(21.1)	2,169(17.8)	4,325(23.2)	.
Master and Above	1,078(3.5)	346(2.8)	732(3.9)	.
Frequency of PE class (class/week)				<0.001
1	1,647(5.1)	1,072(8.3)	575(3.0)	.
2	11,943(36.9)	5,888(45.5)	6,055(31.1)	.
3	14,902(46.0)	4,856(37.6)	10,046(51.6)	.
4	1,506(4.6)	459(3.5)	1,047(5.4)	.
≥ 5	2,391(7.4)	657(5.1)	1,734(8.9)	.
"Skipping" PE class				<0.001
Always exist	1,057(3.3)	686(5.3)	371(1.9)	.
Occasionally exist	6,218(19.2)	3,816(29.5)	2,402(12.3)	.
Nonexistence	25,114(77.5)	8,430(65.2)	16,684(85.7)	.
Feeling in PE class				<0.001
No sweat, very relaxed	3,905(12.1)	1,201(9.3)	2,704(13.9)	.
Sweaty, a little tired	20,583(63.5)	8,167(63.2)	12,416(63.8)	.
Sweaty, tired	6,851(21.2)	3,065(23.7)	3,786(19.5)	.
Very sweaty and very tired	1,050(3.2)	499(3.9)	551(2.8)	.
Exercises between classes (times/day)				<0.001
0	497(1.5)	292(2.3)	205(1.1)	.
1	10,943(33.8)	4,800(37.1)	6,143(31.6)	.
2	17,916(55.3)	6,367(49.2)	11,549(59.4)	.
3	844(2.6)	444(3.4)	400(2.1)	.
≥ 4	2,189(6.8)	1,029(8.0)	1,160(6.0)	.
School Sports Meeting (times/year)				<0.001
0	1,546(4.8)	906(7.0)	640(3.3)	.
1	12,541(38.7)	6,206(48.0)	6,335(32.6)	.
2	15,113(46.7)	4,809(37.2)	10,304(53.0)	.
≥ 3	3,189(9.8)	1,011(7.8)	2,178(11.2)	.
Exercise time in school (hours/day)				<0.001
<0.5 h	1,619(5.0)	1,106(8.6)	513(2.6)	.
0.5–1 h	12,831(39.6)	6,128(47.4)	6,703(34.5)	.
Continued				

Characteristic, <i>n</i> (%)	Depressive Symptom			
	Total (<i>N</i> = 32,389)	Yes (<i>N</i> = 12,932)	No (<i>N</i> = 19,457)	<i>P</i> value
1–2 h	14,076(43.5)	4,568(35.3)	9,508(48.9)	.
>2 h	3,863(11.9)	1,130(8.7)	2,733(14.0)	.
Muscle strength Training (day/week)				<0.001
0	3,035(9.4)	1,855(14.3)	1,180(6.1)	.
1	4,197(13.0)	2,360(18.2)	1,837(9.4)	.
2	7,231(22.3)	3,363(26.0)	3,868(19.9)	.
3	6,546(20.2)	2,332(18.0)	4,214(21.7)	.
4	2,520(7.8)	783(6.1)	1,737(8.9)	.
≥ 5	8,860(27.4)	2,239(17.3)	6,621(34.0)	.
Physical activity, METs/day				<0.001
<2	9,521(30.0)	4,574(36.3)	4,947(25.8)	.
2–	9,483(29.9)	3,875(30.8)	5,608(29.3)	.
4–	5,825(18.3)	1,934(15.4)	3,891(20.3)	.
6–	6,925(21.8)	2,202(17.5)	4,723(24.6)	.
Afternoon nap time				<0.001
≤ 10 min	3,714(11.7)	1,885(14.9)	1,829(9.6)	.
≤ 30 min	12,428(39.1)	4,973(39.4)	7,455(39.0)	.
≤ 60 min	12,882(40.6)	4,901(38.8)	7,981(41.7)	.
> 60 min	2,732(8.6)	868(6.9)	1,864(9.7)	.
Sleeping time, hour/day				<0.001
< 8	10,456(33.3)	5,804(46.8)	4,652(24.5)	.
8–	7,956(25.3)	3,219(25.9)	4,737(24.9)	.
9–	7,875(25.1)	2,264(18.2)	5,611(29.5)	.
10–	5,122(16.3)	1,127(9.1)	3,995(21.0)	.
Screen time, min/day				<0.001
< 10	8,770(33.0)	2,452(25.5)	6,318(37.3)	.
10–	7,135(26.9)	2,499(26.0)	4,636(27.4)	.
30–	5,171(19.5)	2,104(21.9)	3,067(18.1)	.
60–	5,470(20.6)	2,560(26.6)	2,910(17.2)	.
Having breakfast (day/week)				<0.001
0	368(1.1)	240(1.9)	128(0.7)	.
1	288(0.9)	233(1.8)	55(0.3)	.
2	353(1.1)	258(2.0)	95(0.5)	.
3	424(1.3)	306(2.4)	118(0.6)	.
4	334(1.0)	233(1.8)	101(0.5)	.
5	1,122(3.5)	747(5.8)	375(1.9)	.
6	1,472(4.5)	953(7.4)	519(2.7)	.
7	28,028(86.5)	9,962(77.0)	18,066(92.9)	.
Having eggs (days/weeks)				<0.001
0	2,570(7.9)	1,535(11.9)	1,035(5.3)	.
1	2,155(6.7)	1,209(9.3)	946(4.9)	.
2	2,777(8.6)	1,521(11.8)	1,256(6.5)	.
3	3,135(9.7)	1,573(12.2)	1,562(8.0)	.
4	1,734(5.4)	792(6.1)	942(4.8)	.
5	3,279(10.1)	1,386(10.7)	1,893(9.7)	.
6	2,148(6.6)	851(6.6)	1,297(6.7)	.
7	14,591(45.0)	4,065(31.4)	10,526(54.1)	.
Drinking milk/yogurt/soy milk (days/weeks)				<0.001
0	1,799(5.6)	1,095(8.5)	704(3.6)	.
1	1,574(4.9)	876(6.8)	698(3.6)	.
2	2,419(7.5)	1,355(10.5)	1,064(5.5)	.
3	2,767(8.5)	1,455(11.3)	1,312(6.7)	.
4	1,722(5.3)	791(6.1)	931(4.8)	.
5	3,051(9.4)	1,322(10.2)	1,729(8.9)	.
Continued				

Characteristic, <i>n</i> (%)	Total (<i>N</i> = 32,389)	Depressive Symptom		
		Yes (<i>N</i> = 12,932)	No (<i>N</i> = 19,457)	<i>P</i> value
6	2,030(6.3)	864(6.7)	1,166(6.0)	.
7	17,027(52.6)	5,174(40.0)	11,853(60.9)	.
Sugary Drinks (times/day)				<0.001
no	11,172(34.5)	3,216(24.9)	7,956(40.9)	.
< 1 time/day	16,750(51.7)	7,264(56.2)	9,486(48.8)	.
1 time/day	2,482(7.7)	1,313(10.2)	1,169(6.0)	.
2 time/day	678(2.1)	399(3.1)	279(1.4)	.
3 time/day	228(0.7)	127(1.0)	101(0.5)	.
4 time/day	139(0.4)	89(0.7)	50(0.3)	.
5 time/day	940(2.9)	524(4.1)	416(2.1)	.

Table 1. General characteristics of the participants. Note: Missing numbers are as follows: only child, 595; father’s education, 1560; mother’s education, 1575; sleep time, 980; napping time: 633; physical activity, 635; screen time, 5843.

strength training sessions, screen time, sleep duration, parents’ educational level, sugar beverage intake and total physical activity (see Fig. 2).

Discussion

Our analysis revealed that the overall prevalence of depressive symptoms was 39.93% in Chinese primary and middle school students, which was greater than we expected. The questionnaire we used to measure depressive symptoms was CES-D questionnaire, which was a questionnaire used world-wide and had been used successfully across wide age ranges²⁰. The CES-D also provides cutoff scores (e.g., 16 or greater) that aid in identifying individuals at risk for clinical depression, with good sensitivity and specificity and high internal consistency¹⁴. One meta-analysis showed that the prevalence of depressive symptoms generally increased over time, and the prevalence estimate was 26.3% (95% CI, 21.9–30.8%) in China among children and adolescents; the prevalence widely varied across studies, ranging from 4.41–55.7%^{21,22}. As depression has been a major public health problem for children and adolescents, more efforts should be made to prevent depression and other mental health issues²³. A significant association between lifestyle factors and depressive symptoms was observed in our data, and the ten most important factors for depressive symptoms were grade, egg intake, milk/soy product intake, number of muscle strength training sessions, screen time, sleep duration, parents’ educational level, sugar beverage intake and total physical activity, which indicated that lifestyle factors, including getting adequate sleep, eating a healthy diet, and staying physically active and away from screens, could be potential determinants of depression in children and adolescents².

Physical activity and exercise have long been considered helpful in promoting mental health^{24,25}. Recent researches have suggested that physical activity may be even more effective in preventing depression in children and adolescents than in adults^{26,27}. In China, the importance of physical activity for mental health has been increasingly recognized, and there is growing evidence that it could have a positive impact on depression in children and adolescents^{28,29}. The mechanism might be that exercise improves mood by enhancing the utilization of neurotransmitters such as 5-HT, dopamine, and norepinephrine³⁰. The results of this study suggested that attention should be given to students who perform infrequent exercise, and it is recommended that schools create a good exercise atmosphere to improve physical health of students for the prevention of depression.

Our analysis revealed that dietary habits play an important role in influencing the prevalence of depressive symptoms. Researches have demonstrated that a healthy diet could help to reduce the risk of depression and anxiety, as well as improve overall mood and cognitive function^{31,32}. Meat, eggs, milk and beans are high-quality proteins that contain relatively high amounts of tryptophan, with 200–455 mg per 100 g³³. Moreover, studies have suggested that those who consumed a greater proportion of processed food, such as packaged snacks, fast food, and sweetened drinks, were more likely to be depressed than those who consumed more fresh fruits and vegetables^{34,35}. Animal experiments also showed that large amounts of added sugar could increase anxiety and depressive behaviors as well as cortisol levels, which affected the maturation of the hypothalamic-pituitary-adrenal axis, causing disruptions in the stress regulation system and thus increasing the risk of depression³⁵.

Screen time has been linked to a variety of mental health issues, including depression, in children and adolescents³⁶. Studies have shown that the more time children and adolescents spend on screens, the more likely they are to experience depressive symptoms^{37,38}. In China, screen time based behavior is significantly associated with depression risk and the effects vary in different populations³⁷. Furthermore, more screen time might lead to reduced physical activity, social isolation, and sleep deprivation, all of which could increase the risk of depression³⁹.

Additionally, less sleep time could be a risk factor for depression in children and adolescents. Studies have shown that inadequate sleep could lead to an increased risk of depression in both children and adolescents, while an increased duration of sleep has been associated with a decrease in depressive symptoms^{40–42}. Thus, it is important for parents and healthcare providers to be aware of the potential effects of inadequate sleep on mental

	Population	Depression	Crude rate (95% CI)	Adjusted rate (95% CI) [#]	Adjusted OR [*] (95%CI)	P value
Only child in family						
No	20,200	8078	40.0(39.3-40.7)	40.9(40.2-41.6)	ref	ref
Yes	11,594	4539	39.2(38.3-40.0)	37.3(36.4-38.2)	0.85(0.80-0.90)	<0.001
Father's education level						
Primary school and Below	1709	814	47.6(45.3-50.0)	48.8(46.4-51.2)	ref	ref
Junior High school	10,647	4648	43.7(42.7-44.6)	43.0(42.1-44.0)	0.88(0.77-1.00)	0.057
Senior High school	9800	3735	38.1(37.2-39.1)	38.1(37.1-39.0)	0.72(0.63-0.82)	<0.001
College	7424	2653	35.7(34.6-36.8)	35.8(34.7-36.9)	0.64(0.56-0.73)	<0.001
Master and Above	1249	417	33.4(30.8-36.0)	36.1(33.5-38.8)	0.61(0.50-0.74)	<0.001
Mother's education level						
Primary school and Below	3337	1590	47.6(46.0-49.3)	46.7(45.0-48.4)	ref	ref
Junior High school	10,843	4590	42.3(41.4-43.3)	42.0(41.1-43.0)	0.88(0.80-0.97)	0.011
Senior High school	9062	3516	38.8(37.8-39.8)	38.6(37.6-39.6)	0.77(0.69-0.85)	<0.001
College	6494	2169	33.4(32.3-34.5)	34.2(33.1-35.4)	0.63(0.57-0.70)	<0.001
Master and Above	1078	346	32.1(29.3-34.9)	36.4(33.5-39.3)	0.66(0.55-0.80)	<0.001
PE classes per week						
0-1	1647	1072	65.1(62.8-67.4)	63.5(61.1-65.8)	ref	ref
2	11,943	5888	49.3(48.4-50.2)	47.2(46.3-48.1)	0.52(0.45-0.59)	<0.001
3	14,902	4856	32.6(31.8-33.3)	37.2(36.5-38.0)	0.39(0.34-0.45)	<0.001
4	1506	459	30.5(28.2-32.8)	31.3(29.0-33.7)	0.40(0.33-0.49)	<0.001
≥5	2391	657	27.5(25.7-29.3)	33.2(31.3-35.1)	0.29(0.24-0.35)	<0.001
Exercise time (hours/day)						
<0.5	1619	1106	68.3(66.0-70.6)	64.5(62.1-66.8)	ref	ref
0.5-1	12,831	6128	47.8(46.9-48.6)	47.2(46.3-48.1)	0.43(0.37-0.49)	<0.001
1-2	14,076	4568	32.5(31.7-33.2)	33.3(32.5-34.1)	0.24(0.21-0.28)	<0.001
≥2	3863	1130	29.3(27.8-30.7)	30.6(29.1-32.0)	0.19(0.16-0.23)	<0.001
Muscle strength Training (day/week)						
0	3035	1855	61.1(59.4-62.9)	56.4(54.6-58.2)	ref	ref
1	4197	2360	56.2(54.7-57.7)	54.5(53.0-56.1)	0.86(0.76-0.98)	0.021
2	7231	3363	46.5(45.4-47.7)	45.4(44.2-46.5)	0.57(0.51-0.64)	<0.001
3	6546	2332	35.6(34.5-36.8)	36.4(35.2-37.6)	0.42(0.37-0.47)	<0.001
4	2520	783	31.1(29.3-32.9)	31.6(29.8-33.4)	0.33(0.29-0.39)	<0.001
≥5	8860	2239	25.3(24.4-26.2)	27.6(26.6-28.5)	0.26(0.23-0.29)	<0.001
METs/day						
<2	9521	4574	48.0(47.0-49.0)	48.3(47.3-49.3)	ref	ref
2-	9483	3875	40.9(39.9-41.9)	39.7(38.7-40.7)	0.68(0.63-0.73)	<0.001
4-	5825	1934	33.2(32.0-34.4)	33.7(32.5-34.9)	0.52(0.48-0.57)	<0.001
6-	6925	2202	31.8(30.7-32.9)	33.6(32.5-34.7)	0.49(0.45-0.53)	<0.001
Afternoon nap time						
≤10	3714	1885	50.8(49.1-52.4)	53.9(52.3-55.6)	ref	ref
10-30	12,428	4973	40.0(39.2-40.9)	42.0(41.2-42.9)	0.56(0.50-0.62)	<0.001
30-60	12,882	4901	38.0(37.2-38.9)	36.3(35.5-37.2)	0.43(0.38-0.47)	<0.001
>60	2732	868	31.8(30.0-33.5)	34.2(32.5-36.0)	0.30(0.26-0.34)	<0.001
Sleeping time, hour/day						
<8	10,456	5804	55.5(54.6-56.5)	53.4(52.4-54.3)	ref	ref
8-	7956	3219	40.5(39.4-41.5)	38.9(37.8-39.9)	0.56(0.52-0.60)	<0.001
9-	7875	2264	28.7(27.8-29.7)	30.9(29.9-31.9)	0.34(0.30-0.37)	<0.001
10-	5122	1127	22.0(20.9-23.1)	33.7(32.4-35.0)	0.23(0.20-0.26)	<0.001
Screen time, min/day						
<10	8770	2452	28.0(27.0-28.9)	30.2(29.2-31.1)	ref	ref
10-	7135	2499	35.0(33.9-36.1)	35.1(34.0-36.2)	1.27(1.18-1.38)	<0.001
30-	5171	2104	40.7(39.3-42.0)	38.9(37.5-40.2)	1.56(1.44-1.69)	<0.001
60-	5470	2560	46.8(45.5-48.1)	45.4(44.1-46.7)	2.07(1.91-2.25)	<0.001
Having breakfast (day/week)						
0	368	240	65.2(60.4-70.1)	61.4(56.5-66.4)	ref	ref
Continued						

	Population	Depression	Crude rate (95% CI)	Adjusted rate (95% CI) [#]	Adjusted OR [#] (95%CI)	P value
Only child in family						
1	288	233	80.9(76.4-85.4)	81.7(77.3-86.2)	1.69(0.97-2.94)	0.063
2	353	258	73.1(68.5-77.7)	73.6(69.0-78.2)	1.11(0.71-1.74)	0.650
3	424	306	72.2(67.9-76.4)	69.8(65.4-74.1)	1.33(0.87-2.05)	0.192
4	334	233	69.8(64.8-74.7)	66.8(61.8-71.9)	1.14(0.73-1.79)	0.556
5	1122	747	66.6(63.8-69.3)	65.3(62.5-68.1)	0.96(0.67-1.36)	0.805
6	1472	953	64.7(62.3-67.2)	63.3(60.9-65.8)	0.87(0.62-1.22)	0.414
7	28,028	9962	35.5(35.0-36.1)	36.0(35.4-36.6)	0.28(0.20-0.38)	<0.001
Having eggs (days/week)						
0	2570	1535	59.7(57.8-61.6)	56.8(54.9-58.8)	ref	ref
1	2155	1209	56.1(54.0-58.2)	56.9(54.8-59.0)	0.88(0.76-1.03)	0.108
2	2777	1521	54.8(52.9-56.6)	53.4(51.5-55.3)	0.82(0.71-0.94)	0.006
3	3135	1573	50.2(48.4-51.9)	49.2(47.4-50.9)	0.64(0.56-0.74)	<0.001
4	1734	792	45.7(43.3-48.0)	44.6(42.3-47.0)	0.51(0.44-0.60)	<0.001
5	3279	1386	42.3(40.6-44.0)	41.6(39.9-43.3)	0.46(0.40-0.53)	<0.001
6	2148	851	39.6(37.6-41.7)	39.3(37.2-41.4)	0.42(0.36-0.49)	<0.001
7	14,591	4065	27.9(27.1-28.6)	29.2(28.5-30.0)	0.27(0.24-0.30)	<0.001
Drinking milk/yogurt/soy milk (days/weeks)						
0	1799	1095	60.9(58.6-63.1)	59.2(56.9-61.4)	ref	ref
1	1574	876	55.7(53.2-58.1)	56.8(54.3-59.2)	0.70(0.59-0.85)	0.000
2	2419	1355	56.0(54.0-58.0)	55.4(53.4-57.4)	0.79(0.67-0.93)	0.005
3	2767	1455	52.6(50.7-54.4)	51.4(49.5-53.3)	0.65(0.55-0.76)	<0.001
4	1722	791	45.9(43.6-48.3)	44.7(42.4-47.1)	0.50(0.42-0.59)	<0.001
5	3051	1322	43.3(41.6-45.1)	42.2(40.4-43.9)	0.44(0.38-0.52)	<0.001
6	2030	864	42.6(40.4-44.7)	42.3(40.1-44.4)	0.43(0.36-0.51)	<0.001
7	17,027	5174	30.4(29.7-31.1)	31.2(30.5-31.9)	0.27(0.24-0.31)	<0.001
Sugary Drinks (times/week)						
0	11,172	3216	28.8(27.9-29.6)	31.2(30.4-32.1)	ref	ref
<1	16,750	7264	43.4(42.6-44.1)	41.8(41.1-42.5)	1.69(1.58-1.80)	<0.001
1	2482	1313	52.9(50.9-54.9)	53.6(51.6-55.5)	2.76(2.44-3.11)	<0.001
2	678	399	58.9(55.1-62.6)	57.8(54.1-61.5)	3.63(2.88-4.57)	<0.001
3	228	127	55.7(49.3-62.2)	55.1(48.6-61.5)	3.23(2.20-4.75)	<0.001
4	139	89	64.0(56.1-72.0)	59.0(50.8-67.2)	3.53(1.93-6.47)	<0.001
≥5	940	524	55.7(52.6-58.9)	55.0(51.8-58.2)	2.07(1.68-2.54)	<0.001

Table 2. Crude and adjusted prevalence of depressive symptoms for each risk factor and logistic regression results. # adjusted for grade, gender and urban/rural area.

health in children and adolescents and to ensure that they are getting the amount of sleep recommended for their age.

Random forest models were used to rank variable importance in this study as it perform best, after comparing it with other machine learning methods. Because strong correlations between variables existed in this study, random forest model as a machine learning method was adopted as it could handle nonlinear and coassociation problems⁴³. The results of the random forest model showed that the most important determinants for depressive symptoms were grade, diet, exercise, sleep and screen time, which supported the early detection and prevention of depression through behavioral lifestyle surveillance. Therefore, ensuring a balanced lifestyle, healthy eating, enough sleep, time away from screens, and time for physical activity could help reduce the risk of developing depression.

In summary, this research investigated the associations of socioeconomic status, physical activity, sleep and screen time, and diet with depression in children and adolescents by utilizing a large-scale field survey and revealed that surveillance of lifestyles could help early-detection of students with depressive symptom. The limitations of this study included the lack of confidence in defining depression by self-reported scales as well as the lack of causal-effect relationships by adopting a cross-sectional study design. Further research should be conducted through longitudinal studies to gain more insight into the causal effects of lifestyles on the prevention of depression.

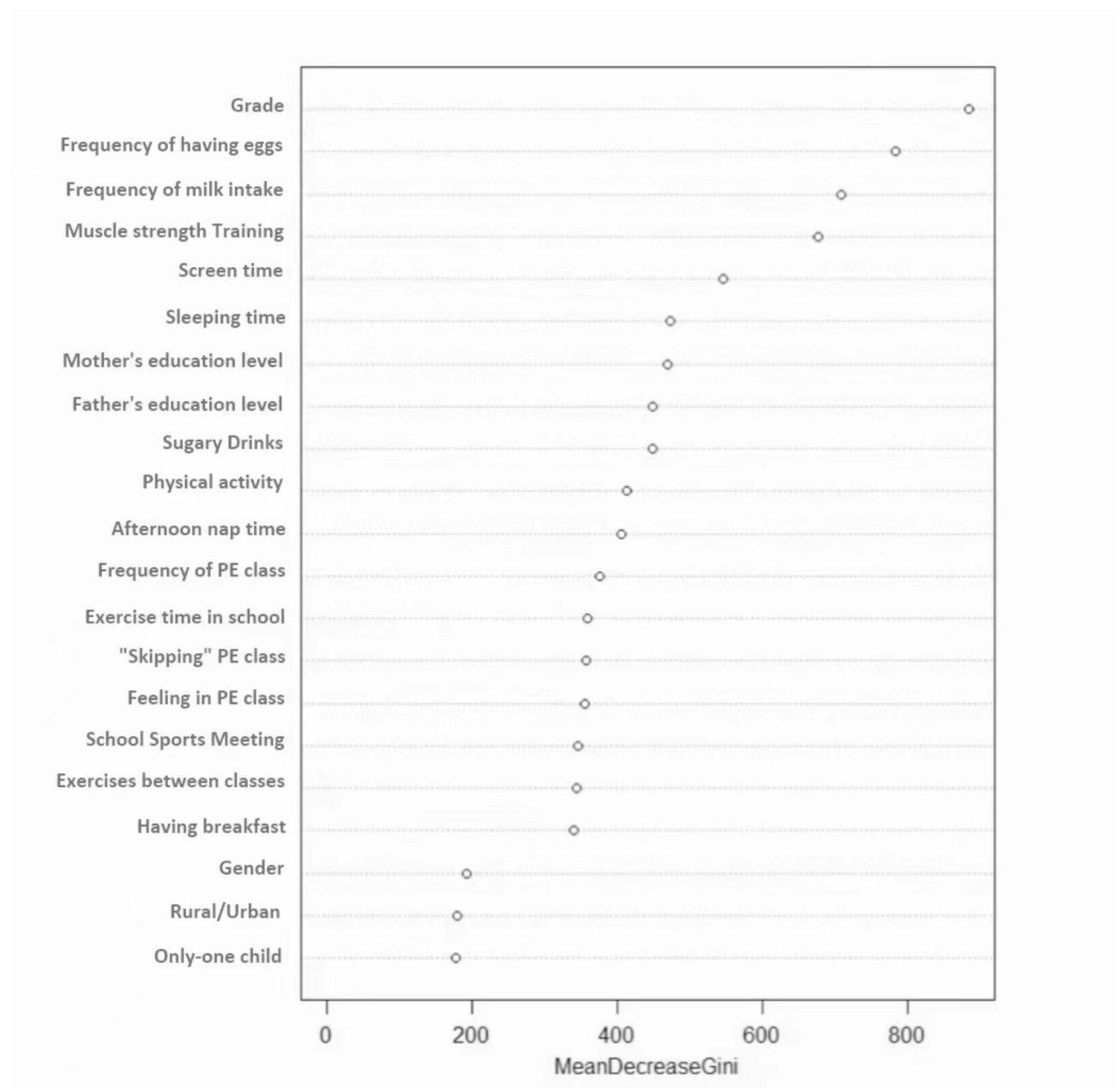


Fig. 2. Importance ranking of risk factors for depressive symptoms in children and adolescents.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Study concept and design: L. Ding, E. Li. Analysis and interpretation of data: L. Ding, Z. Wu, Q. Wu. Drafting of the manuscript: L. Ding, R. Wei. Critical revision of the manuscript for important intellectual content: All au-

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Declarations

Competing interests

The authors declare no competing interests.

Ethics statement

This study was approved by the Ethics Committee of Shandong Sport University (2022018) and informed consent was obtained from all participants. All methods were performed in accordance with Declaration of Helsinki.

Additional information

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