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# Physical activity and social anxiety symptoms among Chinese college students: a serial mediation model of psychological resilience and sleep problems

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## Abstract

**Background** Social anxiety symptoms are common and harmful psychological illness in college students. Although some studies have illustrated that physical activity could reduce social anxiety symptoms, the specific mechanism is still unclear. Based on theoretical studies on resilience and sleep, this study constructed a serial mediation model to explore whether they mediate between physical activity and social anxiety symptoms among college students.

**Methods** This study surveyed 9,530 college students from three colleges in China to explore the mediating effect of physical activity and sleep problems between physical activity and social anxiety symptoms. Participants were investigated with the International Physical Activity Questionnaire, Connor-Davidson Resilience Scale, Sleep-related problems, and the Social Interaction Anxiety Scale and the Social Phobia Scale. Correlations between variables were analysed using Pearson correlation analysis and mediation analyses were performed using SPSS PROCESS macro 3.3 software.

**Result** The study found that physical activity was negatively associated with social anxiety symptoms and sleep problems, but positively with psychological resilience. After controlling for sociodemographic variables, physical activity can not only indirectly alleviate social anxiety symptoms through the separate mediation of psychological resilience and sleep problems, but also through the serial mediation of psychological resilience and sleep problems.

**Conclusion** These results suggest that improving physical activity levels could reduce social anxiety scores by increasing psychological resilience and sleep quality. This is of great reference significance for the prevention and intervention of college students' mental health.

**Keywords** Physical activity, Psychological resilience, Sleep problem, Social anxiety

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## Introduction

Social anxiety disorder, or social phobia, characterized by exhibiting intense fear, anxiety, and avoidance social interaction and situations what an individual feels they can be critically examined by others, such as talking with unfamiliar people, eating and drinking in public, performing in front of other people and so on [1]. An individual diagnosed with social anxiety disorder fears that their words or actions may lead to a negative evaluation from someone else and being humiliated or disgraced [2]. What's more, social anxiety disorder is a common and disabling psychiatric disorder with a worldwide prevalence of 5~10% and a lifetime prevalence rate ranging from 8.4~15.0% [3]. College is an important stage of psychological development in life. According to the Erikson's theory of personality development [4], if college students in early adulthood cannot share and communicate their emotions with others, they will feel lonely and prone to symptoms of social anxiety. Data from a nationally representative sample of the United States shows that the prevalence of social anxiety disorders among US college students was 3.4% [5]. A study of incoming Chinese university students found that 23.7% had social anxiety symptoms [6]. Furthermore, numerous studies have demonstrated that social anxiety can harm normal interpersonal communications and academic performance, reduce quality of life, and increase the risk of suicide [7–9]. Consequently, there is a need to identify social anxiety symptoms as early as possible, identify protective factors, and explore early interventions.

### Physical activity and social anxiety

Cognitive-behavioral therapy combined with pharmacotherapy is often used as the most classic treatment for social anxiety disorders, but a recent meta-analysis found that the recovery rate from social anxiety disorder was lower than the other primary anxiety disorders after young people received cognitive-behavioral therapy [10]. Therefore, we need to find other effective alternatives or treatments for social anxiety. The available evidence strongly suggested that physical activity has a significant reductive effect on anxiety symptoms [11]. A study from 17,550 adolescents found that sports participation predicted lower social anxiety symptoms [12]. Moreover, some researchers confirmed that physical activity can treat clinical social anxiety disorder and reduce social anxiety symptoms in non-clinical samples through systematic review and meta-analyse [13]. PA may act to alleviate social anxiety through a range of different physiological and psychological mechanisms. For example, PA may modulate the stress response through the hypothalamic-pituitary-adrenal (HPA) axis or the glucocorticoid cycle [14]. PA may also reduce anxiety by promoting or mediating the functioning of certain brain regions

[15]. Another possibility is that PA affects the inflammatory system associated with the etiology of anxiety and symptom severity [16]. In addition, individuals may prevent the development of social anxiety by expanding the student's social circle while participating in physical activity [17], which favours the generation of good peer relationships and thus influences core self-evaluations [18]. Physical activity has also been found to indirectly alleviate social anxiety in college students by increasing social support and psychological capital [19]. Overall, physical activity may have an impactful effect on social anxiety through a variety of direct and indirect pathways, and examining the mechanisms between physical activity and social anxiety could better provide insights into preventing and addressing this disorder and warrants further exploration.

### The potential mediating role of psychological resilience

Psychological resilience is a widely-used concept, which defined as a multi-system dynamic process of successful adaptation or recovery in the context of risk or threat [20], which is essential for physical and mental health. Resilience can provide individuals with relatively stable individual psychological protection, and individuals with high psychological resilience tend to exhibit higher cognitive flexibility and emotional regulation and are able to cope with negative emotions more positively [21]. Individuals with lower psychological resilience are more sensitive to interpersonal relationships, are susceptible to events such as peer rejection, and are more prone to social avoidance, which can lead to negative emotions such as interpersonal tension and social anxiety [22]. There is evidence that individuals with social anxiety disorder have lower levels of resilience compared to the healthy population [23]. Psychological resilience was also found to be negatively correlated with social anxiety in college students [24]. As we all know, the protective effect of physical activity on psychological resilience has been demonstrated in many studies [25, 26]. Physical activity is conducive to the development of the individual's mental qualities of perseverance, courage and strength, which are closely related to psychological resilience [27]. In addition, many researchers have confirmed that psychological resilience plays a mediating or mediating role between physical activity and mental health, such as depression and psychological distress [28, 29]. Hence, given the important role of physical activity and mental resilience in improving mental health, this study explores whether resilience is another mediator between physical activity and social anxiety symptoms based on the above relationships.

### The potential mediating role of sleep problems

Staying up late has become the norm for Chinese college students, according to the China Sleep Research Report 2023. A nationwide study found that 55.13% of Chinese college students sleep < 7 h, 33.7% fall asleep for more than 30 min, and only 12.36% get a good night's rest [30]. Another survey of 22,624 Chinese college students found that the insomnia rate among college students was 11.6% [31]. A meta-analysis of 76,112 college students showed that sleep disorders were prevalent among Chinese college students [32]. Sleep has been defined as an important factor in mental health in a wide range of studies [33]. A large number of studies have shown demonstrated that sleep disorders such as insomnia, nightmare, sleepwalking, and hypersomnia lead to the onset, recurrence, and maintenance of mental health problems [34, 35]. Moreover, Yuan et al. found that poor sleep quality was significantly associated with the higher odd of social anxiety ( $HR=2.54 [1.99, 3.25]$ ) [36]. Researchers explained that changes in neural network activity (such as hypersensitivity in brain regions that signal social rejection) appear among individuals with insufficient sleep, leading to social withdrawal and avoidance of social interaction [37]. Therefore, improving sleep quality has become an important influencing factor in reducing anxiety symptoms. At the same time, previous studies have shown that physical exercise positively affect the quality of sleep. One study, which involved 12,459 participants 11 to 19 years old, concluded that physical activity was positively correlated with sleep quality in both males and females, and a higher level of activity leads to better sleep quality [38]. One possible explanation was that physical activity changes the secretion of melatonin and affects the quality of sleep [39]. In conclusion, we suggest that sleep problems may play a mediating role between physical activity and social anxiety among college students. It is well known that sleep problems are individually modifiable behaviours. Given the prevalence of sleep problems among Chinese college students, it is important to understand the role of sleep problems in the association of physical activity in and social anxiety, and to raise college students' awareness of the adverse effects of sleep problems in order to prevent and alleviate social anxiety.

### The potential chain mediating role of sleep problems and psychological resilience

According to the above mentioned literature, most of studies were interested in psychological resilience or sleep problems mediated the relationship between physical activity and mental health. At the same time, plenty of studies showed that good psychological resilience is significantly positive correlation with sleep quality [40, 41]. This can be explained by the fact that highly resilient individuals have less rumination at night-time, do not ruminate over all possible stressors they may face, and sleep more intensively, so that they have good sleep quality [42]. Therefore, in addition to the single mediation of psychological resilience and sleep problems, the possible chain mediating role of both of them could not be ignored. This study hypothesizes that psychological resilience and sleep problems can jointly influence social anxiety and have a potential dual mediating role. Meaningfully, identification of modifiable influencing factors may provide a new direction for the early prevention of social anxiety symptoms in college students.

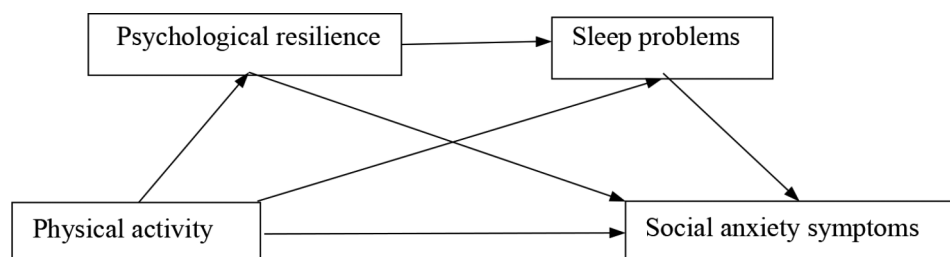
### The current study

To the best of our knowledge, this is the first study to explore the mediating role of both psychological resilience and sleep problems between physical activity and social anxiety among college students. Based on previous empirical research, we established a theoretical hypothesis model presented in Fig. 1, and verify the following hypotheses: (1) physical activity is negatively correlated with social anxiety symptoms among college students; (2) psychological resilience acts as an independent mediator between physical activity and social anxiety; (3) sleep problems acts as an independent mediator between physical activity and social anxiety. (4) physical activity reduce social anxiety symptoms through the serial mediation of psychological resilience and sleep problems.

## Methods

### Participants and procedures

The study was conducted from May to June 2022. Considering that freshmen are in a critical period of transition from adolescence to adulthood, they are more prone



**Fig. 1** Hypothesized conceptual model of the chain mediation/serial mediation

to emotional symptoms such as social anxiety [43]. So, we selected freshman aged 18.91 ( $\pm 0.92$ ) years from three universities in Anhui Province using cluster sampling, but those taking medicines for psychological illness and suffering from serious health problems affecting physical activity were excluded. All participants completed an anonymous electronic questionnaire, responses from participants who failed to adequately describe the variables in the questionnaire or completed the questionnaire repeatedly were excluded from the analysis. The final sample included 9,530 respondents, including 3,947 males (41.4%) and 5,583 females (58.6%). This study was approved by the biomedical ethics committee of Anhui Medical University (20200573), and all respondents provided informed consent before completing the questionnaire.

## Measures

### Demographic factors

Demographic factors included gender (male or female), age, registered residence (rural, towns or county, and urban), only-child status (yes or no), parents' educational level (less than primary school, primary school, junior middle school, senior middle school, college or higher), perceived family economic level (lower, medium, or upper) and number of friends (0, 1~2, 3~5,  $\geq 6$ ).

### Physical activity

The International Physical Activity Questionnaire Short Form (IPAQ-SF) was used to assess the participants' physical activity in the past week [44]. The participants reported the number of days and cumulative duration per day they spent on activities at three intensity levels (walking, moderate, and vigorous). Different metabolic equivalents (MET) correspond to these different physical activity intensities, the METs used in the study for vigorous, moderate, and low intensity activities were 8.0, 4.0, and 3.3, respectively. We presented the level of physical activity using MET-minutes/week (MET level  $\times$  minutes/day  $\times$  days/week) and the total physical activity level using the sum of the three physical activity intensity levels. Cronbach's alpha coefficients for the IPAQ-SF in this study were 0.599, and the Chinese version of the IPAQ-SF has been validated in previous studies [45, 46].

### Psychological resilience

Psychological resilience was assessed using Connor-Davidson Resilience Scale (CD-RISC) [47], which comprises of 25 items. The scale was scored by Likert's 5-point, ranging from 0 (never) to 4 (always). The higher scores indicate greater ability to cope with adversity. The previous study have shown that CD-RISC has good reliability among college students [48]. In this study, the

internal consistency was good, and the Cronbach's coefficients were 0.979.

### Sleep problems

Participants were asked about their experience of sleep problems included insomnia symptoms, nightmare, non-restorative sleep, and daytime fatigue. Insomnia symptoms consists of three items, difficulty initiating sleep, difficulty maintaining sleep, and early awakening and difficulty resuming sleep [49], each item has four answers: 0 event/week,  $\leq 1$  event/week, 1–2 events/week,  $\geq 3$  events/week. Questions for the nightmare, non restorative sleep, and daytime fatigue were "Did you have nightmares over the last month?", "Did you feel refreshed after sleeping over the last month?", and "Did you feel fatigue and easily nod off during the daytime over the last month?"; respectively [50]. The response to each question are "never", "sometimes", "often", and "always". Those who endorsed the frequency of "0 events/week" or "never" were classified as having no sleep problem, otherwise defined as having such sleep problems. Therefore, the range of sleep problems in this study was 0–6, higher scores represent more sleep problems and poorer sleep quality. Cronbach's alpha coefficient for the Sleep Problems Scale was 0.763.

### Social anxiety symptoms

Our study used the short forms of the Social Interaction Anxiety Scale (SIAS-6) and the Social Phobia Scale (SPS-6) to evaluate social anxiety and social phobia, respectively [51]. The SIAS-6 and SPS-6 are commonly used together when evaluating social anxiety symptoms. Both measures have 6-item scales, and each item is scored on a scale from 0 ("Not at all characteristic of me") to 4 ("Extremely characteristic of me"), with total scores ranging from 0 to 24 for each scale. The scores were then used to create two dichotomous variables. Individuals with scores  $\geq 12$  on the SIAS-6 were defined as having social anxiety, and those with scores  $\geq 9$  on the SPS-6 were defined as having social phobia. The SIAS-6 and SPS-6 have good reliability and validity and are widely used for Chinese college students [52]. The Cronbach's alpha coefficient for the SIAS-6 and the SPS-6 in this study were 0.926 and 0.949, respectively.

### Statistical analysis

The data collected were analyzed using the SPSS 23.0 software package. First, we described continuous variables with the mean and standard deviation ( $M \pm SD$ ) and qualitative variables with frequencies. Categorical and continuous variables were analysed using independent samples t-tests and chi-square tests, respectively, to compare the between-group differences. Second, We used the Kolmogorov-Smirnov test to check whether the

variables obeyed a normal distribution. We used Spearman correlation analysis to examine the associations between physical activity, psychological resilience, sleep problems, and social anxiety symptoms. Third, After we standardised the variables of interest, the mediation analysis of relevant variables was performed with the bootstrap method of the SPSS PROCESS macro 3.3 software [53]. We chose model 6 to run the serial mediation analysis, physical activity as independent variable (X), psychological resilience (M<sub>1</sub>) and sleep problems (M<sub>2</sub>) as intermediary variables, social anxiety symptoms as dependent variables (Y), and demographic factors such as age and registered residence as covariates. The bias-corrected bootstrap method was used to test the indirect effect. If the 95% confidence interval (CI) did not include 0, it meant that the mediation effect was significant [54].

## Results

### Descriptive statistics

The study participants were 9,530 college students: Among all participants, 820 (8.6%) students experienced social anxiety and 1,377 (14.4%) students had social phobia. Table 1 provides the characteristics of social anxiety symptoms in different sociodemographic variables. Compared with females, the proportion of males is much higher in social anxiety (10.5% vs. 7.3%,  $P < 0.001$ ). College students whose fathers have higher educational level, mothers have lower educational level, and have fewer friends are more likely to experience symptoms of social anxiety (all  $P$  values  $< 0.001$ ). The presence or absence of social anxiety and social phobia were not statistically significant across age, place of residence, and only child ( $P > 0.05$ ).

**Table 1** The characteristics of social anxiety symptoms in different sociodemographic variables among participants

Variables	Total	Social anxiety		P-value	Social phobia		P-value
		No	Yes		No	Yes	
<b>Age</b>	9530	18.9(0.9)	18.9(0.9)	0.312	18.9(0.9)	18.9(0.9)	0.075
<b>Gender</b>				< 0.001			0.269
Male	3947	3533(89.5)	414(10.5)		3358(85.1)	589(14.9)	
Female	5583	5177(92.7)	406(7.3)		4795(85.9)	788(14.1)	
<b>Registered residence</b>				0.643			0.188
Rural	6631	6072(91.6)	559(8.4)		5689(85.9)	933(14.1)	
Towns or County	1505	1368(90.9)	137(9.1)		1283(85.2)	222(14.8)	
Urban	1394	1270(91.1)	124(8.9)		1172(84.1)	222(15.9)	
<b>Only child</b>				0.373			0.157
Yes	1591	1445(90.8)	146(9.2)		1343(84.4)	248(15.6)	
No	7939	7265(91.5)	674(8.5)		6810(85.8)	1129(14.2)	
<b>Father's educational level</b>				< 0.001			< 0.001
Less than primary school	1069	972(90.9)	97(9.1)		926(86.6)	143(13.4)	
Primary school	2014	1871(92.9)	143(7.1)		1740(86.4)	274(13.6)	
Junior middle school	4126	3788(91.8)	338(8.2)		3565(86.4)	561(13.6)	
Senior middle school	1504	1368(91.0)	136(9.0)		1267(84.2)	237(15.8)	
College or higher	817	711(87.0)	106(13.0)		655(80.2)	162(19.8)	
<b>Mother's educational level</b>				< 0.001			< 0.001
Less than primary school	2189	1929(88.1)	260(11.9)		1812(82.8)	377(17.2)	
Primary school	2519	2299(91.3)	220(8.7)		2142(85.0)	377(15.0)	
Junior middle school	3300	3064(92.8)	236(7.2)		2869(86.9)	431(13.1)	
Senior middle school	1083	1000(92.3)	83(7.7)		934(86.2)	149(13.8)	
College or higher	439	418(95.2)	21(4.8)		396(90.2)	43(9.8)	
<b>Perceived family economic</b>				< 0.001			< 0.001
Lower	3425	3049(89.0)	376(11.0)		2861(83.5)	564(16.5)	
Medium	5783	5356(92.6)	427(7.4)		5026(86.9)	757(13.1)	
Upper	322	305(94.7)	17(5.3)		266(82.6)	56(17.4)	
<b>Number of friends</b>				< 0.001			< 0.001
0	307	263(85.7)	44(14.3)		239(77.9)	68(22.1)	
1–2	3631	3270(90.1)	361(9.9)		3047(83.9)	584(16.1)	
3–5	3979	3686(92.6)	293(7.4)		3476(87.4)	503(12.6)	
≥ 6	1613	1491(92.4)	122(7.6)		1391(86.2)	222(13.8)	

**Table 2** Analysis of related variables

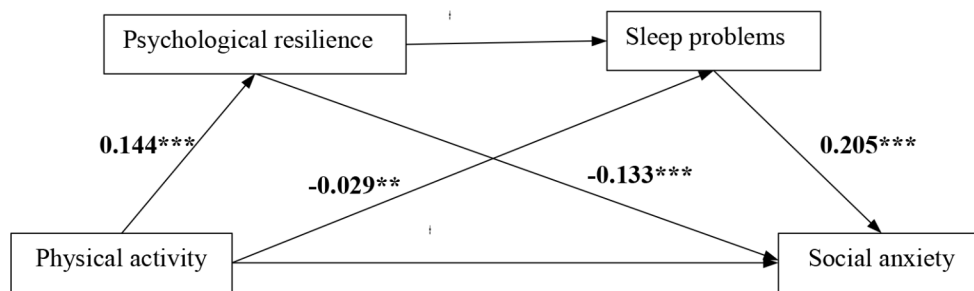
	K	S	M	SD	1	2	3	4	5
1.Physical activity	2.61	8.86	2838.26	3087.26	1.00				
2.Psychological resilience	-0.01	-1.14	53.64	23.71	0.16***	1.00			
3.Sleep problems	-0.15	-0.11	2.99	1.91	-0.05***	-0.10***	1.00		
4.Social anxiety	1.47	2.36	3.81	4.53	-0.08***	-0.18***	0.23***	1.00	
5.Social phobia	1.69	2.92	3.60	4.89	-0.08***	-0.18***	0.23***	0.85***	1.00

\*\*\* $P < 0.001$

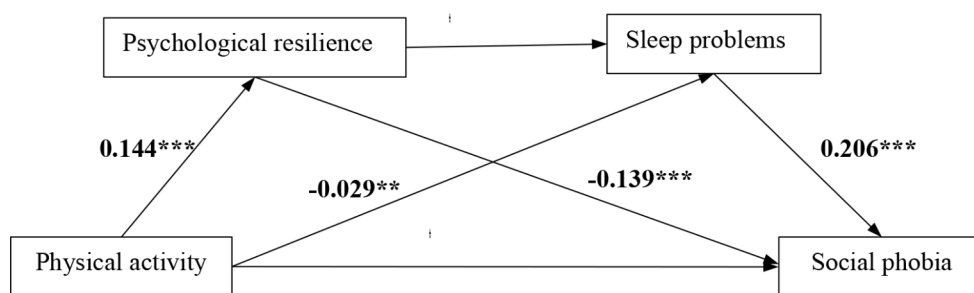
**Table 3** Regression analysis between variables

Outcome variable	Predictor variable	$\beta$	SE	T	CI(95%)		$R^2$	F
					LLCI	ULCI		
Psychological resilience	Physical activity	0.144***	0.010	14.290	0.124	0.163	0.054	68.009
Sleep problems	Physical activity	-0.029**	0.010	-2.818	-0.048	-0.009	0.017	18.675
	Psychological resilience	-0.085***	0.010	-8.137	-0.105	-0.065		
Social anxiety	Physical activity	-0.046***	0.010	-4.646	-0.065	-0.026	0.108	114.895
	Psychological resilience	-0.133***	0.010	-13.361	-0.153	-0.114		
	Sleep problems	0.205***	0.010	21.001	0.186	0.224		
Social phobia	Physical activity	-0.038***	0.010	-3.787	-0.057	-0.018	0.095	99.768
	Psychological resilience	-0.139***	0.010	-13.848	-0.159	-0.120		
	Sleep problems	0.206***	0.010	20.991	0.187	0.226		

\* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$



**Fig. 2** Sequential intermediary model. \* $P < 0.05$ ; \*\* $P < 0.01$



**Fig. 3** Sequential intermediary model. \* $P < 0.05$ ; \*\* $P < 0.01$

**Correlation analysis of the study variables**

Table 2 provides kurtosis (K), skewness(S), mean (M), standard deviation (SD), and correlation of the study variables. Physical activity was negatively related to sleep problems ( $r = -0.05, P < 0.001$ ), social anxiety ( $r = -0.08, P < 0.001$ ), and social phobia ( $r = -0.08, P < 0.001$ ), and positively related to psychological resilience ( $r = 0.16, P < 0.001$ ). Psychological resilience was negatively related to sleep problems ( $r = -0.10, P < 0.001$ ), social anxiety

symptoms (social anxiety:  $r = -0.18, P < 0.001$ ; social phobia:  $r = -0.18, P < 0.001$ ). Furthermore, sleep problems was positively related to social anxiety symptoms (social anxiety:  $r = 0.23, P < 0.001$ ; social phobia:  $r = 0.23, P < 0.001$ ).

**Analysis of intermediation effects**

After adjusted for age, registered residence, only-child status, parents' educational level, perceived family economic level, and number of friends, the results of the

regression analysis were presented in Table 3; Fig. 2, and Fig. 3. Physical activity had a significant negative effect on sleep problems ( $\beta = -0.029$ ,  $P < 0.01$ ), social anxiety symptoms (social anxiety:  $\beta = -0.046$ ,  $P < 0.001$ ; social phobia:  $\beta = -0.038$ ,  $P < 0.001$ ), but positively correlated with psychological resilience ( $\beta = 0.144$ ,  $P < 0.001$ ). Psychological resilience could cause less sleep problems ( $\beta = -0.085$ ,  $P < 0.001$ ), and social anxiety symptoms (social anxiety:  $\beta = -0.133$ ,  $P < 0.001$ ; social phobia:  $\beta = -0.139$ ,  $P < 0.001$ ). Sleep problems has a significant positive predictive effect on social anxiety symptoms (social anxiety:  $\beta = 0.205$ ,  $P < 0.001$ ; social phobia:  $\beta = 0.206$ ,  $P < 0.001$ ).

Table 4 indicated the results of the mediation analysis. The total effect value of physical activity on social anxiety symptoms were  $-0.074$  (social anxiety) and  $-0.067$  (social phobia), the direct effect value of physical activity on social anxiety symptoms were  $-0.046$  (social anxiety) and  $-0.038$  (social phobia), respectively. When psychological resilience was the mediating variable, the indirect

effect were  $-0.019$  (social anxiety) and  $-0.020$  (social phobia), and the effect ratio were 25.68% (social anxiety) and 29.85% (social phobia). When sleep problems was the mediating variable, the indirect effect were all  $-0.006$ , and the effect ratio were 8.11% (social anxiety) and 8.96% (social phobia), respectively. When psychological resilience and sleep problems were used as mediator variables, the indirect effect were  $-0.003$  (social anxiety) and  $-0.003$  (social phobia), and the effect ratio were 4.05% (social anxiety) and 4.48% (social phobia).

## Discussion

In this study, we used the serial mediation model to explain we determined the mediation of sleep problems and psychological resilience between physical activity and social anxiety symptoms among college students. The results of this study suggest that physical activity can not only directly reduce social anxiety symptoms, but also affect social anxiety symptoms through the serial mediation of psychological resilience and sleep problems. The more physical activity, the less it triggered sleep problems, which in turn increased the level of psychological resilience, which decreased the risk of social anxiety and social phobia symptoms. It will provide a new reference for the prevention and intervention of social anxiety symptoms in college students, and will greatly promote the mental health of college students.

### The relationship between physical activity and social anxiety symptoms

The direct association between physical activity and social anxiety symptoms has been proved in this research. Numerous studies have indicated that physical activity and mental health are closely related. A cross-sectional study among Indian college students found that moderate and high levels of physical activity were inversely associated with anxiety and depression [55], while a Chinese study found similar results with inactive college students, who displayed more mental health problems [56]. These findings suggested that adverse mental health problems might be reduced through increasing the level of physical activity. A randomized controlled trial found that the therapeutic effect of high-intensity interval training on social anxiety was twice that of lower intensity training [57]. In addition, some researchers found that people with more physical activity have lower social anxiety symptoms in cross-sectional studies ( $r = -0.12$ ,  $P = 0.003$ ), adults after treatment with physical activity were more effective in reducing social anxiety symptoms than children and adolescents in longitudinal studies ( $d = -0.22$ ,  $P = 0.001$ ) [13]. What's more, there are some hormone secretion and neurobiological mechanisms that could explain the relationship between physical activity and social anxiety symptoms. Researchers believe

**Table 4** The effect of each path

Effect	Pathways	Estimated	Percentage	CI(95%)	
				LLCI	ULCI
Total effect	Physical activity→Social anxiety	-0.074	100%	-0.093	-0.054
Direct effect	Physical activity→Social anxiety	-0.046	62.16%	-0.065	-0.026
Indirect effect	Physical activity→Psychological resilience→Social anxiety	-0.019	25.68%	-0.024	-0.015
	Physical activity→Sleep problems→Social anxiety	-0.006	8.11%	-0.010	-0.002
	Physical activity→Psychological resilience→Sleep problems→Social anxiety	-0.003	4.05%	-0.003	-0.002
Total effect	Physical activity→Social phobia	-0.067	100%	-0.086	-0.046
Direct effect	Physical activity→Social phobia	-0.038	56.72%	-0.057	-0.018
Indirect effect	Physical activity→Psychological resilience→Social phobia	-0.020	29.85%	-0.025	-0.016
	Physical activity→Sleep problems→Social phobia	-0.006	8.96%	-0.011	-0.001
	Physical activity→Psychological resilience→Sleep problems→Social phobia	-0.003	4.48%	-0.003	-0.002

that the symptoms of social anxiety may be related to the peripheral blood oxytocin, which has the effect of reducing anxiety and can promote individuals to engage in more prosocial behaviors during social interactions, which could improve their social anxiety symptoms [58]. Meanwhile, an animal experiment confirmed that physical activity has a significant positive effect on peripheral blood oxytocin [59]. Another study indicated that physical exercise could alter amygdala reactivity and functional connectivity, which strongly associated with fear and avoidance, and in response to explicit and implicit emotional processing [60, 61]. However, these are only a part of the explanations, and the biological mechanism of physical activity and social anxiety symptoms needs to be further explored by more researchers.

#### **The mediating role of psychological resilience**

In this study, the mediating effect of psychological resilience that when college students perform more physical activity, the higher level of psychological resilience they will have, and this will decrease the occurrence of social anxiety symptoms. The mediation effect of psychological resilience between the physical activity and social anxiety symptoms reached about 30%. This result echoes previous studies, such as psychological resilience and coping styles were observed to play a chain-mediated role in physical activity and negative emotions in Chinese university students [27]. Another study similarly showed an important indirect link between physical activity and reduced negative affect, mediated by psychological resilience [62]. Based on the process-oriented perspective in the resilience theory, resilience is developed by individuals overcoming the adverse effects of exposure to dangerous and traumatic events, which is a result of the interaction between individuals and the environment [63]. Physical activity is often accompanied by challenges, self-improvement and goal attainment. In the course of the exercise, individuals need to socialize by constantly assimilating and adapting to their surroundings, assist them acquire the skills and abilities to better negotiate [64]. Therefore, perform more physical activity may be a booster of psychological resilience. Additionally, people with good psychological resilience have better adaptability and higher emotional regulation skills when faced with some stressful and frightening social situations, and reduce social anxiety symptoms [23, 65]. What's more, a review study revealed the molecular and neurobiological mechanisms involved in the beneficial effect of physical activity on the resilience of the brain to stress, regular physical activity has a positive effect on the central nervous system functions, which is correlated with increased neurogenesis, increased neurotrophic factor expression, modulation of neurotransmission and HPA activity, reduced brain inflammation and oxidative stress, and

improved cognition [66]. In this context, resilient animals do not show social avoidance and depression-or anxiety-like behavior, etc. Instead, they exhibit motor activity like active exploratory behavior [67]. Therefore, this study complements evidence in the area where physical activity alleviates social anxiety symptoms in college students by enhancing psychological resilience.

#### **The mediating role of sleep problems**

In this study, we verified the mediating effect of on physical activity and social anxiety symptoms, and more physical activity, which will reduce sleep problems of college students, and better sleep quality will decrease the symptoms of social anxiety, where sleep problems explains 8.11% and 9.09% of the relationship between physical activity and social anxiety and social phobia, respectively. Similar relationships have also been confirmed in previous studies. Zhang Y et al. found an interactive compensatory mechanism between sleep and physical activity, i.e., moderate and high levels of physical activity helped to reduce mental disorders in college students with poor sleep [68]. In another study of Chinese university students, sleep quality was also observed to mediate the association between physical activity and negative mood, with physical activity influencing students' negative mood through good sleep quality [69]. In other words, sleep quality is an important behavioral mechanism between physical activity and mental illness. Payne's (2004) conceptual model suggests that sleep disorders and mood symptoms may be caused by hormonal imbalances such as cortisol, and that physical activity has been shown to be an effective strategy for reducing cortisol levels [70, 71]. Possible mechanistic explanations for the effect of sleep problems between physical activity and social anxiety symptoms may also be that sleep problems such as sleep deprivation and sleep disorders increase oxidative stress in the prefrontal cortex, hippocampus, and amygdala, which increases negative emotions [72–74]. And regular and acute exercise can alleviate negative moods caused by sleep problems by reducing oxidative stress products and enhancing oxidative enzyme activity [75]. In addition, previous findings suggest that sleep appears to be the health behaviour most associated with mental and emotional health [76, 77], and that greater health gains may be achieved by intervening on proximal factors.

#### **The chain mediating effect of sleep problems and psychological resilience**

Our study discover that psychological resilience and sleep problems play a role of serial mediation in the relation between physical activity and social anxiety symptoms (social anxiety and social phobia) in college students, the effect values of this pathway accounted for



4.05% and 4.55% of the total effect, respectively. In other words, we find that if college students experience more physical activity, they may have a higher level of resilience to life stress and less sleep problems, and this high sleep quality will further decrease the occurrence of social anxiety symptoms, which further explained the mechanism by which physical activity affects social anxiety in college students. Additionally, psychological resilience has a positive impact on the quality of sleep [78]. High resilience means that the activity of the ventromedial prefrontal cortex, which is a pathophysiological consequence of sleep disruption. This may explain that higher resilience scores predict overall better sleep quality and shorter sleep latency [79]. Li et al. indicated that they received material and spiritual support from family, peers and society during the physical activity, which met their growth needs for love and respect, and that prompted them to actively develop good traits, improve psychological resilience and social adaptation, and thus improve the quality of sleep [80]. Previous studies have shown that physical activity has been used as a supplement to cognitive-behavioral therapy to treat social anxiety disorders [13], our findings suggested that some psychological therapies such as improving psychological resilience or decreasing sleep problems could also be used as a supplement or substitute. Generally, the results of this study complement the internal complex pathways of physical activity, psychological resilience, and sleep problems improving college students' social anxiety symptoms, which provides new strategies for developing more targeted psychological interventions to improve the mental health of college students. To the best of our knowledge, physical inactivity among college students is widespread, although some schools give specific credits to students who complete a prescribed running programme (e.g., 'Fun Run'). We believe that the management of university physical education programmes should be strengthened, including the duration and intensity of exercise, in order to increase the physical activity of university students. In addition, there is a need to focus on the development of students' mental resilience and to increase their awareness of health hazards, for example, by providing training or activities that call on students to improve their poor sleep habits.

### Limitations

To the best of our knowledge, this study is the first to examine the association of physical activity, psychological resilience, sleep problems, and social anxiety symptoms college students. One innovative point of this study is that it successfully associates the mechanism between physical activity and both psychological resilience and sleep problems with social anxiety symptoms. Anyway, there are some limitations that must be considered. First,

this study was a cross-sectional study, and reverse causality cannot be excluded. Further cohort studies are needed to validate the results of this paper. Second, all variables were self-reported, as no objectively measured data were available, so recall bias and social desirability bias cannot be avoided. Third, our study included only three colleges in Anhui Province, China, and these results may not be generalizable to other college students either within or outside China. Further studies in more heterogeneous and national populations are needed to confirm our findings.

### Conclusions

In summary, our study verify the following four results: (1) physical activity is negatively correlated with social anxiety symptoms among college students; (2) psychological resilience acts as an independent mediator between physical activity and social anxiety symptoms; (3) sleep problems acts as an independent mediator between physical activity and social anxiety symptoms; (4) physical activity indirectly reduces social anxiety symptoms through the serial mediation of psychological resilience and sleep problems. Our findings fill a gap in the study of potential psychobehavioral mechanisms of physical activity in reducing social anxiety symptoms in college students. Additionally, the finding provides a new perspective on the intervention of social anxiety by developing guidelines for improving physical activity and implementing interventions to promote resilience and sleep quality.

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### Author contributions

Xin Li and Yu liu wrote the main manuscript text and prepared all tables and figures; Fan Rong has completed the data analysis. Lanlan Li, Runyu Wei, Rui Wang, and Shicheng Zhang participated in the survey and completed tasks including on-site investigation, data organization, and data management. Yuhui Wan reviewed the manuscript.

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### Data availability

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

### Declarations

#### Ethical approval

The studies involving human participants were reviewed and approved by the biomedical ethics committee of Anhui Medical University (20200573), and all respondents provided written informed consent before completing the questionnaire.

#### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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