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Physical education exercise improves physical fitness and working memory function: a randomized controlled trial study of Uyghur adolescents in Xinjiang, China

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Abstract

Background Physical education exercise has a positive effect on adolescents' physical fitness and working memory function, but it has not been found in studies on Uyghur adolescents, an ethnic minority in western China. To this end, this study conducted a randomized controlled trial of physical education exercise for 12 weeks in Uyghur adolescents from Xinjiang, China. The effects of physical education exercise on physical fitness and working memory function of Uyghur adolescents were analyzed.

Methods Randomly selected 222 Chinese Xinjiang Uyghur secondary school students were randomly divided into a control group and an exercise intervention group. The physical education exercise was conducted for 12 weeks for the intervention group, and no intervention was conducted for the control group. The subjects were tested on physical fitness items (height, weight, waist circumference, 1000 m/800 m running) and working memory function before and after the intervention. Pre- and post-intervention test results were analyzed using paired-sample t-tests (within-group comparisons). Post-intervention comparisons between intervention and control groups were analyzed using analysis of covariance (between-group comparisons).

Results The differences between the pre-intervention and post-intervention physical fitness indicators of Chinese Uyghur adolescents in the intervention group were statistically significant (all P values < 0.01). The height and $VO_{2\ max}$ of boys increased by 0.41 cm and 4.08 mL/kg. min, and weight, BMI, and waist circumference decreased by 0.4 kg, 0.26 kg/m^2, and 0.4 cm, respectively; the girls' height and $VO_{2\ max}$ increased by 0.40 cm and 2.87 mL/kg. min, weight, BMI, and waist circumference decreased by 0.40 kg, 0.26 kg/m^2, and 2.02 cm, respectively. The differences between the pre-intervention and post-intervention 1-back reaction time and 2-back reaction time of the adolescents in the intervention group were statistically significant (all P values < 0.05). The 1-back reaction time and 2-back reaction time were reduced by 150.53 ms and 180.00 ms for boys and 204.84 ms and 228.53 ms for girls, respectively. There was no significant difference between the pre-intervention and post-intervention physical fitness indicators, 1-back reaction time, and 2-back reaction time in the control group (all P values > 0.05).

Conclusion The study confirmed that physical education exercise may be one of the effective means to improve the physical fitness and working memory function of Chinese Xinjiang adolescents. However, whether the same intervention effect exists in other groups should be further studied and analyzed. Our study provides reference and help

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for the government and education department to develop future educational policies to enhance physical education exercise in schools.

Trial registration This study adheres to CONSORT guidelines. This study was conducted retrospectively trial registration: ChiCTR2400088822; China Clinical Trial Registration; August 27, 2024.

Keywords Physical fitness, Working memory function, Randomized controlled trial, Adolescents, Uyghurs

Introduction

Physical fitness is of great importance for the development of the physical and mental health of adolescents. Improving physical fitness through physical exercise is recognized as the most cost-effective and efficient way to improve physical health, and related studies have been increasing in recent years both at home and abroad. Studies have found that regular participation in physical exercise can improve mental health, such as lowering self-esteem, anxiety, and depression levels in exercisers, which has the effect of improving and promoting mental health [1]. Studies have also shown that scientific physical exercise can effectively promote the overall health of the subjects, especially in the regulation of blood pressure, insulin resistance, and blood lipids [2], and can also enhance the cognitive function of the brain [3].

It is of interest to note that the benefits associated with physical exercise are largely influenced by how the intervention is performed, and the effects of the intervention vary considerably depending on the manner or intensity of the intervention. Studies have shown that after an acute intervention of a single session of physical exercise (5—60 min), subjects experienced a sharp increase in endorphins, cerebral blood flow, and a temporary improvement [4]. Conversely, after a chronic physical exercise intervention of 2 physical exercises per week for a total of 10 weeks, subjects experienced physiological adaptations and changes in brain structure and function, which had a positive effect on the development of cognitive function [5]. A recent meta-analysis confirmed that physical exercise intervention improved cognitive function in subjects (Hedges' $g=0.31$), as evidenced by improvements in reaction speed ($g=0.39$), attention ($g=0.34$), and inhibition ($g=0.32$), thus promoting enhanced executive function [6]. It has also been confirmed that 8 weeks of aerobic exercise has a significant effect on memory in obese women, and this strategy can be used to improve memory in obese women [7]. Another survey of 600 adolescents showed a strong correlation between physical activity, breakfast frequency, etc., and cognitive performance [8].

In recent years, a growing number of studies have also investigated the improvement of physical fitness through physical exercise through direct or indirect psychological, physiological, and learning approaches, leading to improved cognitive and academic performance [9, 10]. Studies have confirmed that higher levels of physical fitness can be effective in improving participants' brain attention, concentration, thinking skills, and thus academic performance, a concept that has generated a high level of interest among educators and physical educators [11]. However, despite the widespread benefits of physical activity, 80% of adolescents worldwide still do not achieve the 60 min of moderate to vigorous physical activity per day recommended by international physical activity guidelines [12]. It has also been shown that there is a sharp decline in physical activity observed during adolescence, with a 7% annual reduction in physical activity levels in the 12 to 19 age group [13, 14]. As societal concerns about adolescent health continue to grow, recent data suggest that only 44.6% of adolescents in England are achieving the recommended amount of physical activity [15], while only 10.4% of adolescents in China engage in at least 60 min of moderate to vigorous physical activity per day [16]. These salient issues suggest the need to effectively address the lack of physical exercise among adolescents and thus promote healthy physical and mental development. For school youth, school physical education classroom instruction is the best way to engage in physical activity and deserves attention and focus.

Executive Function (EF), understood as the brain's "air traffic control system," is a set of cognitive skills that facilitate planning behavior, problem-solving, and purposeful activity and affect lifelong development [17]. Recent studies have also found that high levels of physical exercise are positively associated with the development of executive functioning in adolescents [18]. An increasing number of studies have focused on intervention studies of executive function, providing important theoretical and applied value for executive function development. Studies have shown that adolescence is a period of rapid executive function development during the human lifespan and is critical for future adult achievement and development [19]. In addition, the executive function in adolescence has a large plasticity, and the development of the executive function in adolescence is influenced by a combination of factors, such as educational environment, dietary behavior, environmental exposure, physical activity, and exercise habits [20]. Among them, physical exercise is considered to be the most important influential factor in promoting executive function in adolescents and is also the factor that is easier to change [18]. With the continuous research on adolescent executive function, studies on improving executive function using physical exercise interventions have gradually increased, and their studies have focused on physical exercise [21], cardiorespiratory endurance [22], and muscular strength [23], while fewer studies have been conducted using classroom exercise interventions.

The working memory function is a system that temporarily stores and processes information in a limited capacity during the execution of a cognitive task by an individual. Working memory, transformational flexibility, and inhibitory control are considered to be three relatively independent central executive functions. Compared to transformational flexibility and inhibitory control, the working memory function is most closely associated with higher cognitive functions. It has been found that working memory function can be improved by later training, and its improvement can be further transferred to cognitive functions such as brain intelligence and emotion regulation.

Foreign research on physical exercise to improve physical fitness and working memory function is increasing. In terms of acute physical activity interventions, a meta-analysis pooling the effects of physical exercise on working memory function in children (6 ~ 12 years), adolescents (13 ~ 17 years), and young adults (18 ~ 35 years) showed a moderately strong positive association between acute physical exercise and working memory function relationship and a significant effect on the overall level of executive function (d = 0.52, 95% *CI* 0.29 ~ 0.76, $p < 0.001$) [24]. In terms of chronic aerobic exercise, a maximal oxygen uptake intervention in adolescents aged 16 to 19 years showed a significant association between maximal oxygen uptake and working memory function, and an increase in cardiorespiratory endurance had a positive effect on the level of working memory function. This suggests that there is an association between physical exercise cognitive changes and brain function [25]. There are relatively few studies on improving working memory function through physical exercise in China, and the only studies so far have focused on the economically developed eastern regions of China, while there are fewer intervention studies for adolescents in the western regions of China, where economic development is relatively backward.

Xinjiang is located in western China and is a multi-ethnic region, mainly dominated by Uyghurs. Uyghurs have a higher rate of obesity due to the large differences between Uyghurs and Han Chinese in terms of culture, living habits, and religious beliefs. This is coupled with some differences in the recognition of physical exercise, which may cause differences in executive function. In addition, the economic level of this region is relatively backward, and the level of physical fitness and working memory function of adolescents is relatively low. Previous studies have demonstrated the effectiveness of improving adolescents' physical fitness and working memory function using physical exercise, but no similar studies have been conducted among Uyghur adolescents in Xinjiang, China. Therefore, we aimed to understand the effects of classroom physical exercise on physical fitness and working memory function among Uyghur adolescents in Xinjiang, China, through a randomized controlled experimental study in Xinjiang, China, to provide reference and help the government or education department in this region to develop public health and school policies. The hypothesis of this study was that physical exercise would improve physical fitness and working memory function among Uyghur adolescents in Xinjiang, China.

Materials and methods

Participant

Our study was conducted in a middle school in Urumqi, Xinjiang, China. A randomized controlled experimental design method was used in this study. Applying the paired t-test in GPower 3.1 software to estimate the required sample size, the software outputs a minimum sample size of 182 cases, and considering a 20% sample size loss, the minimum sample size for inclusion in this study is 219 cases. The selection of participants for this study was based on a randomized whole-cluster sampling of classes, with five instructional classes randomly selected out of the eight instructional classes in the school, and the students in the classes who met the inclusion criteria served as participants in this study. Written informed consent was obtained from the students themselves before the survey. After excluding adolescents with physical disabilities, intellectual disabilities, and severe physical or psychological disorders, a total of 222 Chinese Uyghur secondary school students were studied in this study, which satisfied the experimental requirements. The selected 222 Uyghur secondary school students were randomly divided into a control group of 108 (57 males and 51 females) and an exercise intervention group of 114 (59 males and 55 females). For grouping, 1 and 2 random numbers were used to divide into control and intervention groups. Eventually, all 222 secondary school students completed the whole experiment and all of their data were considered valid. The specific sampling procedure is shown in Fig. 1.

Before and after the experiment, 222 Uyghur secondary school students participated in tests of height,

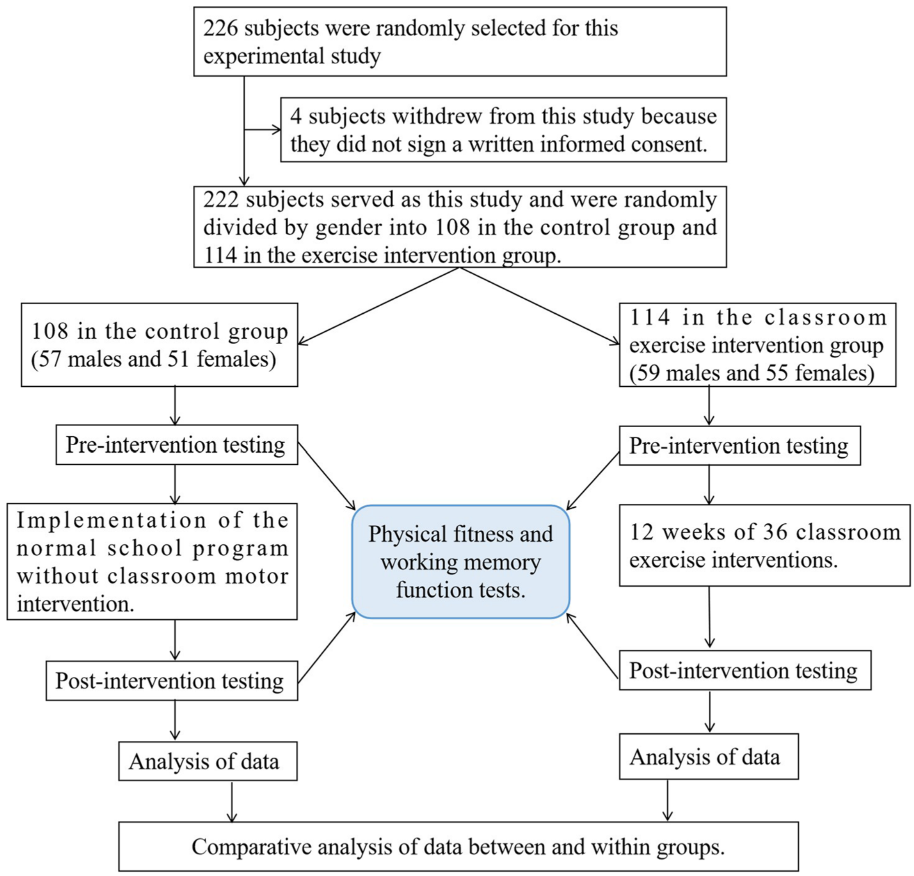

Fig. 1 Sampling process of an experimental study of Uyghur adolescents in Xinjiang, China

weight, waist circumference, 1000 m running (boys), 800 m running (girls), and working memory function. The investigation of this study was approved by the Human Ethics Committee of Xinjiang Normal University (202102215). The experimental procedures and processes were by ethical requirements and were strictly reviewed. Written informed consent was obtained from the students themselves and their guardians before the experiments. This study adheres to CONSORT guidelines.This study was conducted retrospectively trial registration: ChiCTR2400088822; China Clinical Trial Registration; August 27, 2024.

Physical fitness tests

The tests of physical fitness items include height, weight, waist circumference, 1000 m run (male), and 800 m run (female). Body mass index (BMI) was calculated from the results of height and weight tests, BMI = weight (kg)/height (m)^2. The physical fitness items were tested according to the testing methods and instruments required by the China Student Physical Fitness Research [26], as follows.

(1) *Height* The subject stood barefoot on the height measuring instrument, requiring the heel and head to be close to the column, and the tester slid the scale plate down to the top of the subject's head and read the test number with a flat view, with the result accurate to 0.1 cm. the result was recorded on the test record paper after the test.
(2) *Weight* requires the subject to stand on the weight meter barefoot and wearing light clothing, and read the data after the number has stabilized, and the test data is accurate to 0.1 kg.
(3) *Waist circumference* Requires the subject to stand in front of the testing staff, leaving out the abdomen, and the staff uses a nylon ruler at 1 cm above the navel to circle the abdomen horizontally and read the data, the test value is accurate to 0.1 cm.
(4) *1000 m run (boys), 800 m run (girls) test* The staff used a stopwatch for timing, and the subjects tried their best to run 1000 m or 800 m in the shortest time, and finally recorded the finished run in seconds. The 1000/800 m running projection equation formulated by Liu Haiyun for Chinese adolescents

was used for the projection of VO_{2max}, and the specific equation was as follows

$$VO_{2max}\ (\mathrm{mL/kg.\,min}) = 1.640 - 0.004 \times \mathrm{gender}\ (\mathrm{boys} = 1,\ \mathrm{girls} = 2) \times \mathrm{time}\ (\mathrm{s}) + 0.037 \times \mathrm{weight}\ (\mathrm{kg})$$

This equation is widely used in Chinese adolescents and has good reliability ($R^2 = 0.703$) [27].

Working memory (WM) function

The testing of the working memory function was performed using the internationally accepted N-back paradigm. The 1-back and 2-back paradigms were performed concerning the back paradigm of Smith [28]. The working memory function was tested on a computer based on E-prime 1.0 software. The units were calculated using milliseconds. A shorter time indicates a higher level of working memory function of the subject.

Each letter was displayed individually in the center of the computer screen. In the task test, subjects were asked to memorize carefully and accurately the letters that appeared and to quickly press the "F" key on the keyboard if the capital letter appeared to be the same as the previous letter. If a capital letter appears that is different from the previous letter, the "J" key on the keyboard is pressed rapidly. The test was divided into 2 phases, each of which was tested 25 times, with 5 letters appearing at random. Each capital letter appeared in the center of the computer screen at 3-s stimulus intervals, and the letter was displayed on the screen for 2000 ms. The faster the response and the shorter the time taken, the better the participant's working memory function.

For the 2-back, a capital letter appearing in the center of the screen with the same letter as the previous interval, the "F" key on the keyboard was pressed rapidly. The "J" key on the keyboard was pressed rapidly if a capital letter appeared in the center of the screen that was not the same as the letter that appeared one letter before. Other test requirements and methods are the same as for the 1-back.

The test of working memory function in this study was conducted in a bright, spacious, and quiet computer room. The subjects were not allowed to drink excitatory beverages the day before the test, and they were required to maintain a normal sleep schedule. Subjects were asked to concentrate on the test to ensure the quality of the test results.

Physical education exercise interventions

The classroom physical exercise intervention program in our study was developed based on reference to the Chinese Physical Education and Health Curriculum Standards and the actual situation in the Xinjiang region of China. In the schools where the intervention was conducted, the intervention program was designed under the guidance and assistance of a full-time physical education teacher. The classroom physical exercise intervention content was focused on improving students' physical fitness.

Specific exercise intervention programs are listed below:

(1) The exercise programs: Included programs in basketball, soccer, ethnic fitness exercises, and sports games. Ethnic fitness exercises is an exercise program combining Uyghur ethnic dance and aerobics, which is loved by Uyghur youth and has a high motivation to exercise. The exercise interventions of the different programs were conducted under the guidance and leadership of professional physical education instructors. The different exercise programs were alternated to guarantee the motivation of the participants.
(2) Frequency of exercise interventions: Using students' physical education class time, the intervention was conducted 3 times a week with physical education classes on alternate days for 12 weeks, for a total of 36 sessions. Exercise interventions were carried out in strict accordance with the pre-established intervention program.
(3) Timing of exercise interventions: Each session was 40 min, with about 20 min of skill practice and 10 min of physical exercise, ensuring 30 min of exercise time and the remaining 10 min for preparation activities, finishing activities, and teacher explanation during the sessions. Skill practice includes dribbling, shooting, three-player games, and group play in basketball. The soccer program includes kicking the ball with the inside of the back of the foot, passing the ball, shooting and other skill practice. The exercise program includes movement learning, movement reinforcement exercises, and group exercises.
(4) Exercise intervention intensity: An exercise intensity of 140 ~ 160 beats per minute should be ensured. A Polar meter was used to monitor the participants' heart rate during exercise in real time. Exercise interventions were primarily based on a high-intensity interval exercise regimen, combining aerobic and anaerobic exercise.

All intervention sessions were conducted by a full-time physical education teacher with an assistant teacher to monitor intensity and assist in teaching. Interventions were conducted in the school athletic field and, in special weather, in the gymnasium.

The control group did not undergo any additional exercise interventions and carried out the school's daily teaching schedule and work and rest time normally. This included daily physical education classes (mean heart rate between 90 and 130 beats/min) and extracurricular activities. The pre-test and post-test of the intervention were performed simultaneously with the intervention group before and after the intervention, with the same test items.

Quality control

In terms of physical fitness testing: on the one hand, each item test is required to be conducted by a fixed staff member, and the testing instruments are checked and calibrated every day to ensure the accuracy of the test results. On the other hand, the test results were required to be recorded on the test paper after the test, and students were strictly prohibited from altering them by themselves.

In terms of classroom exercise interventions: on the one hand, our study experimental subjects were all Uyghur secondary school students who were in boarding school, and their life, study, work and rest, diet, and extracurricular activity time were all conducted according to the school's prescribed time. On the other hand, the monitoring of intensity during our study intervention used the Polar Gofit Team Heart Rate Monitoring System for real-time monitoring of exercise heart rate. Students were asked to wear it on their wrist or arm and their heart rate was presented on a tablet during the exercise. The heart rate was required to be controlled between 140 ~ and 160 beats/min, and students who were below or above the heart rate range were given alerts to ensure the effectiveness of the exercise intervention. Third, during the intervention period, students in the control and intervention groups were asked to live and study according to the school's work schedule, and their eating behavior was performed in the cafeteria, while all subjects were asked to perform the school's uniform extracurricular and cultural activities, etc., to try to exclude the interference of additional factors during the intervention period. Physical exercise fitness and working memory function were tested using the same method on the day before and the day after the exercise intervention, respectively.

Statistical analysis

All data in this study were expressed using Mean ± SD. Given the large differences in physical fitness between genders, comparisons of intervention outcomes were stratified by gender and then compared separately. Comparisons of physical fitness items and working memory function were divided into two parts. First, within-group comparisons between the intervention and control groups were performed using paired-sample t-tests. Two, post-intervention intergroup comparisons between the intervention and control groups were analyzed using analysis of covariance (ANCOVA), where pre-intervention scores were analyzed as a covariate to obtain an *F*-value. Pre-testing was conducted prior to the intervention in this study to ensure the effectiveness and feasibility of the intervention approach. A two-sided test level of $\alpha = 0.05$ was used. Data were analyzed statistically using SPSS25.0 software (IBM Corp., Armonk, NY, United States), and images were created using Graph Pad Prism8 software (Graph Pad Software, Inc., CA).

Results

Our study is a 12-week intervention study of physical education exercise in 222 Uyghur adolescents in Xinjiang, China. The study was a randomized controlled trial design designed to analyze the effects on physical fitness and working memory function. The mean age of the subjects in this study was (14.03 ± 0.17) years. Among them, 116 (52.25%) were male.

The results in Table 1 show that there were no statistically significant differences in the results of each index of physical fitness, height, weight, BMI, waist circumference, and $VO_{2\ max}$ before and after intervention in the control group compared to those after intervention (all P values > 0.05). The differences between the pre-intervention and post-intervention indices of physical fitness of adolescents in the intervention group were statistically significant (P-values < 0.01). The height and $VO_{2\ max}$ of male students increased by 0.41 cm and 4.08 mL/kg. min, and the weight, BMI, and waist circumference decreased by 0.4 kg, 0.26 kg/m^2, and 0.4 cm, respectively. Height and VO_{2max} increased by 0.40 cm and 2.87 mL/kg. min, and weight, BMI, and waist circumference decreased by 0.40 kg, 0.26 kg/m^2, and 2.02 cm, respectively, in female students.

When comparing the control group with the intervention group, there was no statistically significant difference in the physical fitness indexes before the intervention (P-value > 0.05). Post-intervention comparisons between groups were analyzed by analysis of covariance. After the intervention, VO_{2max} increased by 3.35 mL/kg. min in the control group compared with the physical fitness indexes in the intervention group, and the difference was statistically significant ($P < 0.001$). In female students, weight, BMI, and waist circumference decreased by 2.05 kg, 1.94 kg/m2, and 3.40 cm, respectively, after the

Table 1 Comparison of intervention results of 12-week physical education exercise on physical fitness of Uyghur adolescents in Xinjiang, China

Group	Projects	Pre-intervention		Post-intervention		*T-value*	*P-value*
		N	M ± SD	N	M ± SD		
Control group							
Boys	height (cm)	57	155.37 ± 7.59	57	155.52 ± 7.27	−0.442	0.66
	weight (kg)	57	45.89 ± 10.37	57	45.06 ± 8.46	0.952	0.345
	BMI (kg/m²)	57	18.83 ± 2.94	57	18.49 ± 2.33	1.338	0.186
	waist circumference (cm)	57	72.12 ± 8.61	57	72.08 ± 7.88	0.144	0.886
	VO_{2max} (mL/kg. min)	57	43.59 ± 3.29	57	44.10 ± 3.52	−0.854	0.397
Girls	height (cm)	51	155.04 ± 5.15	51	155.53 ± 5.13	−1.856	0.069
	weight (kg)	51	44.45 ± 6.45	51	44.55 ± 6.00	−0.644	0.523
	BMI (kg/m²)	51	18.44 ± 2.15	51	19.37 ± 2.15	0.687	0.495
	waist circumference (cm)	51	66.90 ± 5.50	51	66.27 ± 5.03	1.759	0.085
	VO_{2max} (mL/kg. min)	51	40.64 ± 1.70	51	40.75 ± 1.87	−0.342	0.734
Intervention group							
Boys	height (cm)	59	155.35 ± 8.03	59	155.76 ± 8.02	−11.257	< 0.001
	weight (kg)	59	44.95 ± 10.36	59	44.55 ± 10.36	11.276	< 0.001
	BMI (kg/m²)	59	18.48 ± 3.29	59	18.22 ± 3.30	11.898	< 0.001
	waist circumference (cm)	59	69.95 ± 7.69	59	69.55 ± 7.72	11.276	< 0.001
	VO_{2max} (mL/kg. min)	59	43.37 ± 3.40	59	47.45 ± 4.59 [c]	−6.983	< 0.001
Girls	height (cm)	55	154.67 ± 7.05	55	155.07 ± 7.04	−10.730	< 0.001
	weight (kg)	55	42.45 ± 6.84	55	42.05 ± 6.85 [a]	10.730	< 0.001
	BMI (kg/m²)	55	17.69 ± 2.19	55	17.43 ± 2.18 [a]	10.727	< 0.001
	waist circumference (cm)	55	64.89 ± 6.32	55	62.87 ± 5.82 [a]	3.536	0.001
	VO_{2max} (mL/kg. min)	55	40.22 ± 2.83	55	43.09 ± 3.01 [c]	−6.368	< 0.001

Post-intervention comparisons between the intervention and control groups were analyzed by analysis of covariance

M mean, *SD* standard deviation

[a] indicates $P < 0.05$

[b] indicates $P < 0.01$, and

[c] indicates $P < 0.001$

intervention, and the differences were statistically significant (all P values < 0.05); VO_{2max} increased by 2.34 mL/kg. min and the differences were also statistically significant ($P < 0.001$). This indicates that the overall physical fitness of Chinese Xinjiang Uyghur adolescents was improved after the intervention. The trends of the specific pre-intervention and post-intervention outcomes are shown in Fig. 2.

The results in Table 2 show that there was no significant change in the results of the control group before the intervention compared to after the intervention, both at the 1-back response and at the 2-back response, and none of the differences were statistically significant (all P values > 0.05). The differences between the pre-intervention and post-intervention 1-back reaction time and 2-back reaction time of the adolescents in the intervention group were statistically significant (all P values < 0.05). In boys, the 1-back reaction time and 2-back reaction time were reduced by 150.53 ms and 180.00 ms, respectively, and the differences were statistically significant (P values < 0.05). In the female students, the 1-back reaction time and 2-back reaction time were reduced by 204.84 ms and 228.53 ms, respectively, and the differences were statistically significant (all P values < 0.001).

There was no statistically significant difference in 1-back reaction time and 2-back reaction time before the intervention when compared between the control and intervention groups (all P values > 0.05). Post-intervention comparisons between groups were analyzed by analysis of covariance. After the intervention, the 1-back reaction time and 2-back reaction time in the control group were reduced by 115.21 ms and 198.88 ms, respectively, compared with the intervention group, and the differences were statistically significant (P-values < 0.05). In female students, the 1-back reaction time and 2-back reaction time were reduced by 135.05 ms and 192.84 ms, respectively, after the intervention, and the differences were statistically significant (all P values < 0.01). This

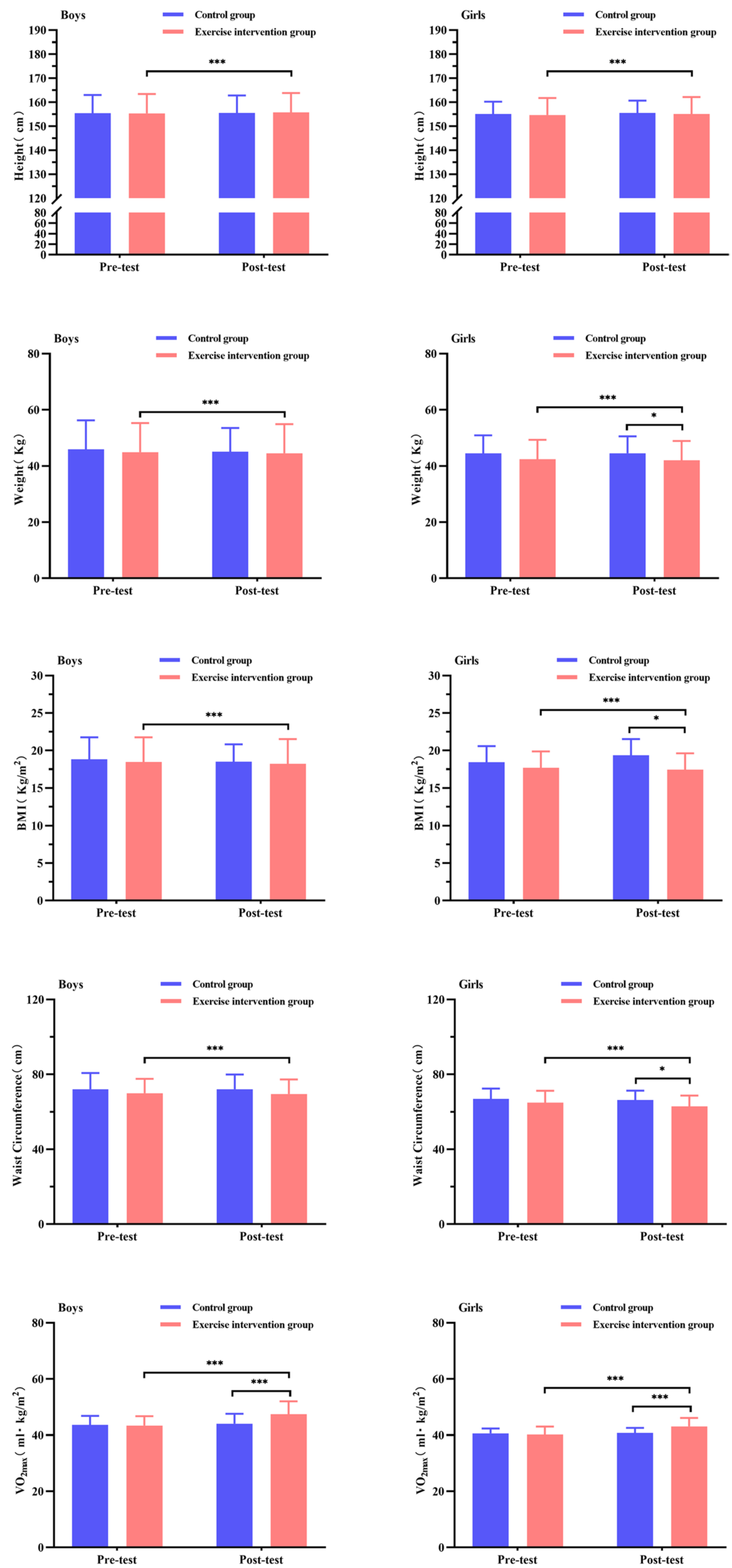

Fig. 2 Trends in intervention outcomes of 12-week physical education exercise on physical fitness of Uyghur adolescents in Xinjiang, China. Note: * denotes $P<0.05$, ** denotes $P<0.01$, *** denotes $P<0.001$

Table 2 Comparison of intervention results of 12-week physical education exercise on working memory function of Uyghur adolescents in Xinjiang, China

Group	Projects	Pre-intervention		Post-intervention		*T-value*	*P-value*
		N	M ± SD	N	M ± SD		
Control group							
Boys	1-back RT	57	1027.34 ± 382.65	57	1025.06 ± 308.59	0.041	0.967
	2-back RT	57	1207.21 ± 386.18	57	1237.02 ± 304.49	−0.467	0.643
Girls	1-back RT	51	1050.30 ± 337.27	51	1030.57 ± 369.23	0.356	0.724
	2-back RT	51	1251.63 ± 336.42	51	1196.25 ± 310.47	0.992	0.326
Intervention group							
Boys	1-back RT	59	1060.38 ± 401.65	59	909.85 ± 198.28 [a]	2.789	0.007
	2-back RT	59	1218.14 ± 354.90	59	1038.14 ± 229.69 [c]	3.665	0.001
Girls	1-back RT	55	1100.36 ± 330.83	55	895.52 ± 219.61 [a]	4.063	< 0.001
	2-back RT	55	1231.94 ± 334.95	55	1003.41 ± 244.82 [b]	4.536	< 0.001

Post-intervention comparisons between the intervention and control groups were analyzed by analysis of covariance

M mean, *SD* standard deviation, *RT* reaction time

[a] indicates $P < 0.05$

[b] indicates $P < 0.01$, and

[c] indicates $P < 0.001$

indicates that the working memory function reaction time of Chinese Uyghur adolescents was shortened after the intervention, i.e., the working memory function was improved. The trends of the specific pre-intervention and post-intervention results are shown in Fig. 3.

Discussion

There is a strong association between physical fitness and executive function. The present study showed that physical exercise increased the level of physical fitness and executive function in adolescents, and this result is consistent with the findings of several studies. For example, one study confirmed that physical exercise improves bone health, mental health, cognition, and academic performance [29]. There is also evidence of a strong link between the integration of physical exercise into school life and improvements in adolescents' attention and classroom task time [30].

Studies have shown that physical fitness, specifically cardiorespiratory fitness (CRF), is associated with many physical, emotional, psychological, and social health benefits in adolescents. The results of the present study are consistent with previous studies in that physical activity improved physical fitness in adolescents, specifically in terms of improved cardiorespiratory fitness. Uyghur adolescents like ethnic dances, and the use of ethnic dances as an intervention in this study increased the motivation of Uyghur adolescents to participate in physical activity, and may be an important reason for the better exercise results in this study. Related studies have shown that a clear benefit of regular physical exercise participation is the enhancement of physical fitness, i.e., improved CRF, and body composition [2]. There is also sufficient evidence that adolescents should participate in high-intensity physical exercise because it provides greater health benefits compared to light and moderate-intensity physical exercise [31, 32]. Improvement or enhancement of cardiorespiratory fitness levels through exercise can be as high as 45 ~ 50% [33]. Similarly, reverse studies have shown that CRF can reflect a person's past and present level of physical fitness, and the higher the CRF the stronger the physical fitness [34].

Long-term physical exercise interventions are bound to have varying degrees of positive effects on physical fitness, such as significant gains in muscle strength, flexibility, and CRF [35]. Considering that adolescents spend a significant amount of time in school during their childhood life, school is an ideal environment for exercise, which in turn improves physical fitness levels [34, 36]. There is evidence that 30% of adolescents in Western Europe get their daily MVPA from physical education classes [37]. And improving the quality of physical education classes improves adolescents' cognitive performance (Hedges' g = 0.38, 95% CI 0.15 ~ 0.60; I2 = 83.70%) and academic achievement, mainly math-related skills are significantly improved (g = 0.15, 95% CI 0.06 ~ 0.24; I2 = 41.75%) [38].

The executive function consists mainly of several cognitive processes that contribute to the organization and control of goal-directed behavior, including inhibition, working memory function, and cognitive flexibility, with working memory function being particularly important

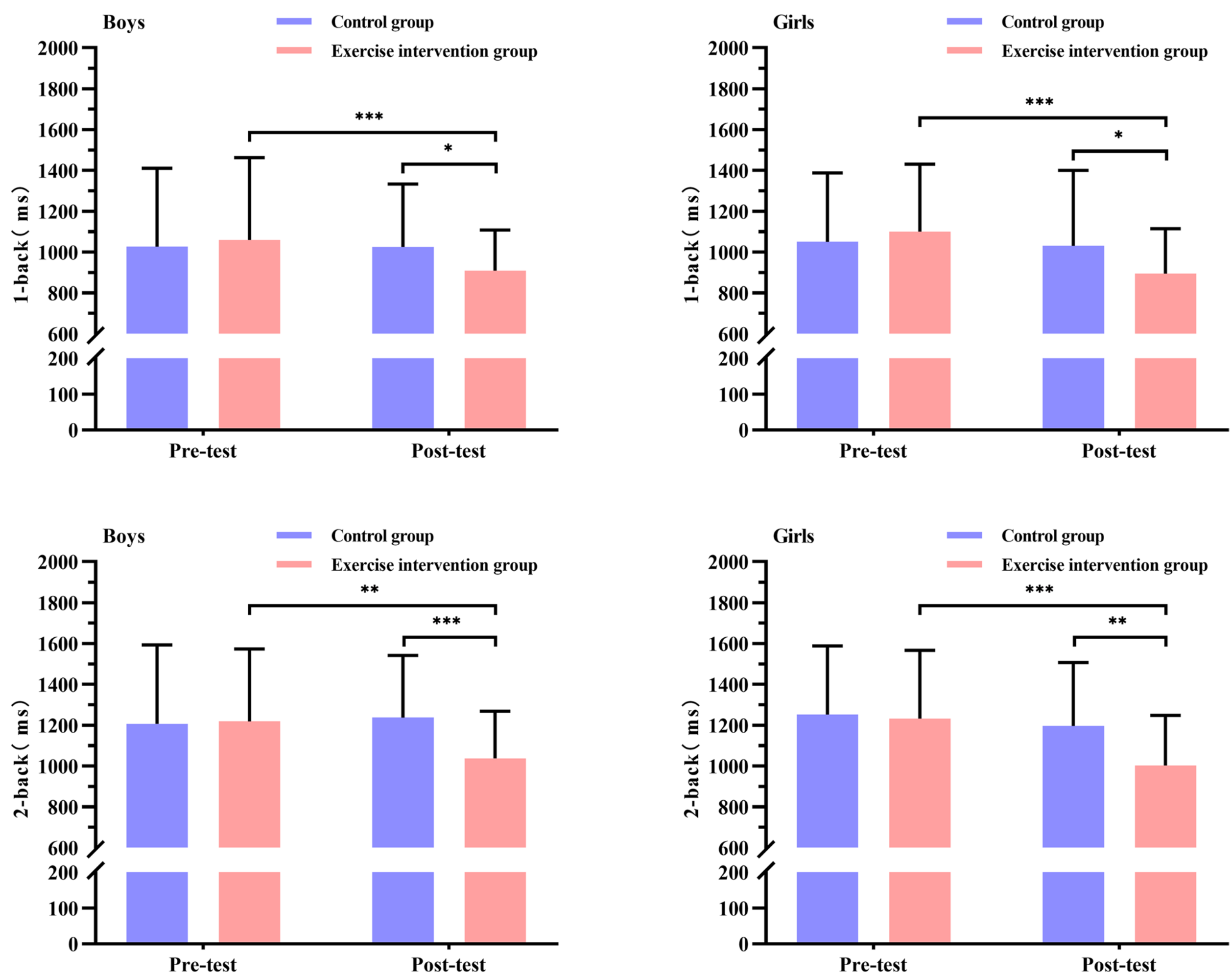

Fig. 3 Trends of intervention results of 12-week physical education exercise on working memory function of Uyghur adolescents in Xinjiang, China. Note: * denotes $P < 0.05$, ** denotes $P < 0.01$, *** denotes $P < 0.001$

[39]. Improvements in executive function are often associated with vigorous physical exercise and improvements in physical fitness as well as academic achievement [3]. The present study showed that 12 weeks of physical education classroom exercise improved executive function in adolescents. Similarly, a 4-month cluster-randomized controlled study of Spanish adolescents ($n = 67$) showed that, overall, there were no significant differences in cognitive performance or academic achievement among students who attended 2 regular-intensity physical education classes per week; however, students randomly assigned to 3 intense physical education workouts per week showed improvements in all cognitive performance variables and academic grade point average, with a particularly working memory function was significantly more effective in providing [40]. Although class attendance in adolescent physical education classes affects adolescents' cognitive and academic performance [41], the effect of intensity does not seem to have been studied more. Results of another 11-week intervention showed that physical exercise improved adolescents' physical fitness, such as improved cardiorespiratory endurance, muscular strength, speed sensitivity, and agility, and significantly improved inhibitory control of executive functions, working memory function, reaction time, and cognitive flexibility ($P < 0.05$) [42].

Physical exercise is an important factor in increasing neuroplasticity and induces important structural and functional changes in brain function. These changes include increased cerebral blood flow, increased gray matter volume in the frontal and hippocampal regions, and elevated levels of brain-derived neurotrophic factors, such as increased levels of peripheral BDNF [43]. Further findings also found that high-intensity exercise was an effective way to improve EF, with effects comparable to those observed with moderate-intensity exercise

[44]. A systematic review of school-aged adolescents showed that high-intensity activity improved cognitive performance more than moderate-intensity and light activity [45]. Although the mechanisms of these effects are unclear, it has been shown that, in particular, high concentrations of several neurochemicals induced by high-intensity exercise, namely brain-derived neurotrophic factors and catecholamines, such as dopamine and epinephrine, may improve cognitive performance in the brain [46]. Mechanisms by which executive function benefits from physical exercise may include increased cerebral blood flow and metabolism, enhanced brain networks, and neurotrophic factors to provide functional coupling between and better neurotransmitter regulation [10]. One study also found that long-term physical activity stimulates neovascularization and neurogenesis in brain regions, which ultimately affects cognitive performance [5]. Additional neurological evidence further demonstrates the modulatory role of the left pallidum of the brain in the positive effects of physical exercise on executive functions such as spatial learning and working memory. Due to the relationship between left pallidum activity and cortical and thalamic neuronal networks, it may be associated with improvements in executive function [47]. It was also found that brain areas such as dorsolateral prefrontal cortex (DLPFC) and posterior parietal cortex (PPC) were in a state of activation when subjects performed n-back tasks, and physical exercise was able to further enhance the activation of DLPFC and PPC sites, which may be important for the improvement of working memory function by physical exercise [48]. This shows that exercise not only improves cerebral blood flow, which leads to enhanced oxygen-carrying capacity but also improves muscle strength levels, which has a positive effect on enhancing EF levels. In the intervention program of this study, because the exercise intervention was conducted for Uyghur adolescents, ethnic dances, which are more preferred by Uyghur adolescents, were added to the intervention exercise modality in order to increase the motivation of the exercisers and to improve the effectiveness of the exercise. This result also suggests that future exercise interventions for ethnic minority adolescents should incorporate ethnic dances that are more acceptable to ethnic minority adolescents to increase motivation and intervention effects.

There are certain strengths and limitations of this study. Strengths: First, to our knowledge, this is the first intervention study on physical fitness and working memory function of Chinese Xinjiang adolescents using classroom physical exercise. Second, the study used a randomized controlled experimental design, and its findings were more reliable. However, this study also has some research limitations. First, the intervention study in this study had a limited sample size of only 222 Chinese Uyghur adolescents who participated in the study, and only Uyghur adolescents were studied in the intervention study. Second, the duration of classroom physical exercise intervention in this study was only 12 weeks, which is a relatively short intervention period, and in-depth studies and follow-ups should be conducted to determine how effective the long-term classroom physical exercise intervention is. Finally, the concentration of participants in this study in one school may lead to a Hawthorne effect and is a limitation of this study. In addition, body composition indicators, such as BMI, in this study were mainly expressed by imputation, and there may be a bias between them and the objective measurements; more objective measurements of body composition, such as body composition analyzers, should be used in the future.

Conclusion

The present study is a randomized controlled experimental study to analyze the effects on physical fitness and working memory function of Uyghur adolescents in Xinjiang, China, through 12 weeks of physical education exercise. Our study confirmed that physical education exercise may be one of the effective means to improve the physical fitness and working memory function of Chinese Xinjiang adolescents. However, whether the same intervention effect exists in other groups should be further studied and analyzed. Based on our findings, we suggest that measures should be taken to strengthen physical exercise in schools in the future, such as securing teaching time for physical education classes and securing time for extracurricular activities, to promote the physical fitness and working memory function of Chinese Uyghur adolescents and promote healthy physical and mental development.

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Author's contributions

Conceptualization, Xiaodi Cai, Yuefeng Liu; Data curation, Yanhong Li; Formal analysis, Xiaodi Cai; Funding acquisition, Xiaodi Cai, Zhiqiang Chen; Investigation, Xiaodi Cai; Methodology, Xiaodi Cai; Project administration, Zhiqiang Chen; Resources, Zhiqiang Chen; Software, Yanhong Li; Supervision, Yanhong Li, Zhiqiang Chen; Validation, Zhiqiang Chen; Visualization, Zhiqiang Chen; Writing—original draft, Xiaodi Cai, Yuefeng Liu; Writing—review and editing, Xiaodi Cai, Yuefeng Liu. All authors have read and agreed to the published version of the manuscript.

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Data availability

To protect the children's privacy, the questionnaire data will not be disclosed to the public. Upon request, please contact Yuefeng Liu, the corresponding author of this article, and email: yuefengliu621@126.com.

Declarations

Ethics approval and consent to participate

The study was by the requirement of the World Medical Association Declaration of Helsinki along with present statements. Written informed consent was obtained from the students themselves and their guardians before the experiments. The investigation of this study was approved by the Human Ethics Committee of Xinjiang Normal University (202102215).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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