A comparison of the effects of two protocols of concurrent resistance and aerobic training on physical fitness in middle school students

Zhen Li [Equal first author, 1] , **Teng Ding** [Equal first author, 2] , **Yanan Gao** [1] , **Xiaowei Han** [3] , **Yang Liu** [4] , **Zhixiong Zhou** [Corresp. 5]

[1] School of Physical Education and Sport Science, Fujian Normal University, Fuzhou, Fujian, China

[2] School of Physical Education, Ningxia University, yinchuan, Ningxia, China

[3] Faculty of Education, Beijing Normal University, Beijing, Beijing, China

[4] Hebei institute of international business and economics, Qinhuangdao, Hebei, China

[5] Institute of Artificial Intelligence in Sports, Capital University of Physical Education and Sports, Beijing, China

Corresponding Author: Zhixiong Zhou
Email address: zhouzhixiong@cupes.edu.cn

Objective: This study aimed to compare the effects of two concurrent training (CT) protocols on the physical fitness of middle school students. Method: A 12-week quasi-experimental pre-test/post-test study was conducted with 157 middle school students (age=12.48±0.34, n=90 females) divided into three groups: CT group A (CT-0h) received combined resistance training (RT) and aerobic training (AT) in each physical education session, CT group B (CT-48h) received RT and AT across two separate physical education classes 48 hours apart, and a control group (Con) received no training. Training occurred twice a week. Test indicators included cardiorespiratory fitness (CRF) measured by estimated VO_2max and 20 m shuttle run (laps), as well as muscle strength assessed through long jump, vertical jump, and handgrip strength. Results: The intervention groups exhibited significant increases in estimated VO_2max and muscle strength compared to their baseline values (p<0.05). Both CT-0h and CT-48h groups demonstrated significant improvements in 20 m shuttle run (laps) (mean difference: 8.88 laps, p<0.01; mean difference: 4.81 laps, p<0.01, respectively), standing long jump (mean difference: 6.20 cm, p<0.01; mean difference: 3.68 cm, p<0.01, respectively), vertical jump (mean difference: 4.95 cm, p<0.01; mean difference: 4.04 cm, p<0.01, respectively), and handgrip strength (mean difference: 11.17 kg, p<0.01; mean difference: 6.99 kg, p<0.01, respectively). CT-0h group exhibited significantly increased estimated VO_2max (mean difference: 1.47 ml/kg/min, p<0.01) compared to the CT-48h group. Conclusion: Both CT programs effectively improved adolescents' physical fitness indicators. However, the program that integrated RT and AT within the same physical education class demonstrated superior enhancement in adolescents' CRF.

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3 Zhen Li, [1†]Teng Ding, [2†] Yanan Gao,[1] Xiaowei Han,[3] Yang Liu,[4] and Zhixiong Zhou [5]

4 [1]School of Physical Education and Sport Science, Fujian Normal University, Fuzhou, P.R. China

5 [2]School of Physical Education, Ningxia University, Yinchuan, P. R. China

6 [3]Faculty of Education, Beijing Normal University, Beijing, P. R. China

7 [4]Hebei Institute of International Business and Economics, Qinhuangdao, P. R. China

8 [5]Institute of Artificial Intelligence in Sports, Capital University of Physical Education and
9 Sports, Beijing, P. R. China

10 †Equal contributors

11 Corresponding Author:

12 Zhixiong Zhou[5]

13 Haidian District, Beijing, P. R. China

14 Email address: zhouzhixiong@cupes.edu.cn

16 Abstract

17 Objective: This study aimed to compare the effects of two concurrent training (CT) protocols on
18 the physical fitness of middle school students.

19 Method: A 12-week quasi-experimental pre-test/post-test study was conducted with 157 middle
20 school students (age=12.48±0.34, n=90 females) divided into three groups: CT group A (CT-0h)
21 received combined resistance training (RT) and aerobic training (AT) in each physical education
22 session, CT group B (CT-48h) received RT and AT across two separate physical education
23 classes 48 hours apart, and a control group (Con) received no training. Training occurred twice a
24 week. Test indicators included cardiorespiratory fitness (CRF) measured by estimated VO_2max
25 and 20 m shuttle run (laps), as well as muscle strength assessed through long jump, vertical
26 jump, and handgrip strength.

27 Results: The intervention groups exhibited significant increases in estimated VO_2max and
28 muscle strength compared to their baseline values ($p<0.05$). Both CT-0h and CT-48h groups

29 demonstrated significant improvements in 20 m shuttle run (laps) (mean difference: 8.88 laps,
30 p<0.01; mean difference: 4.81 laps, p<0.01, respectively), standing long jump (mean difference:
31 6.20 cm, p<0.01; mean difference: 3.68 cm, p<0.01, respectively), vertical jump (mean
32 difference: 4.95 cm, p<0.01; mean difference: 4.04 cm, p<0.01, respectively), and handgrip
33 strength (mean difference: 11.17 kg, p<0.01; mean difference: 6.99 kg, p<0.01, respectively).
34 CT-0h group exhibited significantly increased estimated VO$_2$max (mean difference: 1.47
35 ml/kg/min, p<0.01) compared to the CT-48h group.

36 Conclusion: Both CT programs effectively improved adolescents' physical fitness indicators.
37 However, the program that integrated RT and AT within the same physical education class
38 demonstrated superior enhancement in adolescents' CRF.

39 1. Introduction

40 Declining levels of physical activity and increased sedentary behaviors have become widespread
41 problems among adolescents worldwide (Loo et al. 2022; Valanju et al. 2022). As a direct result,
42 problems such as being overweight, having reduced cardiorespiratory endurance, and
43 cardiometabolic dysfunction are beginning to appear in the adolescent population. Without
44 timely intervention, these problems significantly increase the risk of cardiovascular disease, type
45 II diabetes, and cardiovascular disease in adulthood. Therefore, innovative solutions are urgently
46 needed to address this public health challenge (Duft et al. 2020).
47   Evidence suggests that school-based interventions are effective at improving young people's
48 physical health. For instance, increasing high-intensity physical activity is effective at improving
49 child and adolescent cardiorespiratory endurance (Cao et al. 2022; Hartwig et al. 2021). School
50 physical education classes offer opportunities for young people to engage in physical activity and
51 health promotion (Hartwig et al. 2021). However, it has also been suggested that school physical
52 education classes are ineffective at improving adolescent fitness, possibly because most school-
53 based intervention strategies focus on enhancing adolescents' cardiorespiratory fitness (CRF)
54 through aerobic training (AT) while neglecting muscular strength (Alves et al. 2018). There is
55 considerable evidence that levels of muscle health in adolescence are highly correlated with
56 future health, and there is an international consensus that musculoskeletal health assessments
57 should be included in adolescent health assessments (Janz et al. 2021; Moeskops et al. 2022;
58 Stricker et al. 2020). Additionally, research has shown that maintaining a high level of physical
59 fitness throughout adolescence might predict daily living activities in adulthood and even in old
60 age, as well as lower the risk of cognitive decline (Liu et al. 2021).
61   Given the significance of physical fitness for adolescent health, international organizations
62 like the World Health Organization (WHO) and the American College of Sports and Medicine
63 (ACSM) have recommended AT and resistance training (RT) as part of physical activity
64 guidelines for adolescents to support the development of their physical fitness (De la Corte-
65 Rodriguez et al. 2021; King et al. 2019). Considering that most adolescents only engage in
66 relevant physical activity in physical education classes, embedding AT and RT into the school
67 environment and implementing safety training programs for adolescents to enhance and promote
68 physical activity seems to be an effective approach (Beets et al. 2016).
69   The combination of AT and RT is generally defined as concurrent training (CT) (Wilson et
70 al. 2012). CT builds strength and increases aerobic capacity, saves time and lessens training
71 monotony, and has drawn a lot of interest from researchers in recent years (Jha et al. 2018; Sousa

72   et al. 2019). However, researchers are currently primarily focused on the "interference effect" of
73   the training schedule of CT on strength development in adults or athletes. For example, Sousa et
74   al. (2019) concluded that the intensity schedule of CT should be arranged in such a way that
75   higher RT loads are combined with lower AT intensities in order to increase strength gains and
76   reduce post-training losses. It has also been suggested that the interval between AT and RT is a
77   major factor in the "interference effect"; i.e., performing CT during the same training session
78   (with no interval) or less than 6 hours apart in a single day reduces muscle strength improvement
79   and results in an interference effect, but alternating days (>24 hours) between AT and RT does
80   not (Robineau et al. 2016; Schumann et al. 2022; Vechin et al. 2021). Given the anthropometric,
81   physiological, and biomechanical variations between adolescents and adults, it is crucial to stress
82   that this theory is based on adult data, and it has remained unclear whether it can be applied to
83   the adolescent population (Jansson et al. 2022).
84   Prior research has posited that the interference effect may be age-related. For instance,
85   Bluett et al. (2015) discovered that, in comparison to isolated AT, CT led to a decline in the 3 km
86   running performance of adolescents aged 10 to 13. However, Spurrs et al. (2003) arrived at a
87   contrary conclusion based on adult data. Through a meta-analysis, Gäbler et al. (2018) found that
88   CT was more effective than single-mode AT or RT at enhancing the physical fitness and exercise
89   performance of adolescents. Specifically, CT demonstrated improvements in exercise
90   performance, particularly in children and adolescents, when compared to AT. Furthermore, CT
91   was found to be more effective than RT at enhancing muscular strength in adolescents. Thus, it is
92   evident that applying adult data to children and adolescents, in light of the physiological
93   processes associated with growth and maturation, lacks validity.
94   Considering the diversity of CT programs and the minimal hormonal impact of exercise
95   training, as well as children and adolescents' faster recovery, reduced fatigue, lower muscular
96   strength and intensity, and greater adaptability to aerobic activities, designing an efficient CT
97   training program to enhance the physical fitness of this demographic has become a pressing issue
98   (Jansson et al. 2022; Mang et al. 2022). However, the current body of research has primarily
99   indicated that CT is linked to a reduction in several cardiovascular disease risk factors in obese
100 children and adolescents (Duft et al. 2020; Fanelli et al. 2022; Kelley et al. 2022). Additionally,
101 CT offers superior benefits in terms of fat loss, body mass reduction, and cardiopulmonary
102 function compared to isolated AT or RT (Bouamra et al. 2022). Nonetheless, research on the
103 impact of CT on the physical fitness of adolescents remains limited. Only one recent study found
104 that combining CT training with varying-intensity AT (high-intensity interval training [HIIT] vs.
105 moderate-intensity continuous training [MICT]) had a similar effect on health-related physical
106 components in adolescents (Mendonca et al. 2022), although the influence of intervals between
107 AT and RT training on the development of adolescent physical fitness was not explored.
108   The objectives of this study were to investigate the feasibility and effectiveness of CT
109 delivery in physical education classes at improving adolescent fitness and to compare the
110 effectiveness of CT with different intervals of AT and RT for improving student fitness. This
111 will provide new approaches to the design of physical education policies and programs and
112 improving student fitness. Based on previous research (Robineau et al. 2016), this study
113 hypothesized that CT delivered in a physical education class can improve students' physical
114 fitness (muscular strength and cardiorespiratory endurance) and that CT programs that separate
115 AT and RT may be more effective.

2. Materials and Methods

2.1 Study design

This study employed a quasi-experimental approach with a pre-and post-test design using a control group. To ensure comparability among intervention centers, we selected three coeducational middle schools in Beijing, China, considering factors such as teacher-student ratios, teacher qualifications, experience levels, consistent educational curriculum, similar household incomes, and parental education levels. Adequate indoor and outdoor space for physical activities was also a criterion for selection.

Randomization was conducted at the class level within each intervention center. Using SPSS software, random numbers were generated, and one existing class of seventh graders was chosen at random at each center. These classes were then further randomized into three groups: CT-0h (combined AT and RT in the same class), CT-48h (AT and RT in separate sessions), and the control group (Con). Individual-level randomization within schools was avoided to prevent potential confounding effects (Weston et al. 2021).

The study involved a team of assistants responsible for data collection, sports coaches who conducted training sessions, and researchers who oversaw the training and performed statistical analyses. Data collection occurred at two time points (baseline: October 2018, outcome: January 2019), with post-intervention assessments carried out 72 hours after the conclusion of the training period. Ethical approval was obtained from the Capital Institute of Sports Ethics Committee (code: 201712001, approval date: 2017/12/26), and the study was registered in the Chinese Clinical Trial Registry (ChiCTR-OOC-17014153).

2.2 Participants

Before the study commenced, all subjects received information about the training program's risks and requirements, and informed consent was obtained from both the subjects and their guardians. A total of 163 adolescents were recruited, and the inclusion criteria for the subjects were as follows: (1) adolescents (12-13 years old), including both males and females, without any contraindications for exercise; (2) individuals who had not engaged in in-school or out-of-school sports training within the preceding 3 months; and (3) those who were not affected by any psychological disorders, such as anxiety or depression. The exclusion criteria consisted of: (1) prior participation in in-school or out-of-school sports training and (2) the presence of physical or psychological disorders.

A total of 157 individuals underwent baseline assessment (mean age: 12.48 ± 0.34 years) (Table 1). No injuries were reported during the 12-week intervention period, but seven individuals dropped out for personal reasons (two in the CT-0h group, three in the CT-48h group, and two in the control group), and their data were therefore excluded from all analyses (Figure 1).

2.2 Description of intervention

The intervention was applied at both the group and individual levels. Specifically, we conducted interventions for a group at a standardized time, with adjustments made to the load at the individual level based on each person's circumstances within the group. RT sessions took place in the school's designated gym facility, while AT sessions were conducted at the school's

157   track and field area. The research used a supervised exercise program that combined RT and AT
158   in accordance with the WHO recommendations (De la Corte-Rodriguez et al. 2021). For 12
159   weeks, the intervention groups participated in twice-weekly physical education training sessions.
160   A rest time of 48 hours followed each training session. Each session included pre-intervention
161   warm-up (3 minutes), intervention (35 minutes), and post-intervention stretching and relaxation
162   (2 minutes) for a total of 40 minutes overall. All training sessions were held at the same time of
163   day to eliminate differences due to circadian rhythms. A certified physical education teacher,
164   along with two assistants, oversaw and led the training sessions.

165   2.2.1 Combined training protocol

166   The RT intervention was meticulously crafted to align with the developmental
167   characteristics of adolescent growth and muscle strength (Moeskops et al. 2022; Myers et al.
168   2017). It was specifically designed to incorporate exercises that targeted the upper and lower
169   limbs, as well as lumbar and abdominal movements. These exercises collectively addressed key
170   muscle groups, including the pectoral muscles, latissimus dorsi, biceps, triceps, and quadriceps.
171   Before the intervention, participants' one-repetition maximum (1RM) was assessed.
172   Subsequently, the number of repetitions for each exercise was dynamically adjusted as the
173   subject's strength progressed: 15 to 20 reps of 1RM during weeks 1 to 4, followed by 10 to 12
174   reps of 1RM during weeks 5 to 8, and finally, eight to 10 reps of 1RM during weeks 9 to 12
175   (Stricker et al. 2020). Comprehensive details of the RT protocol are available in the attached
176   supplementary materials.

177   The AT intervention was meticulously crafted, drew on insights from a previous systematic
178   review, and employed a HIIT approach (Costigan et al. 2015). This method involved running
179   intervals of 1 minute at 75%-85% of HRmax, followed by 1-minute intervals of rest at 50% of
180   HRmax, with each set lasting 10 minutes. The participants' maximum aerobic running speed
181   (MAS) was measured in the 4th and 8th weeks, and the running speed was adjusted based on
182   MAS changes to maintain the AT training load at the designated heart rate. For a comprehensive
183   understanding of the MAS testing method, please consult previous research studies (Cao et al.
184   2022). During the exercise sessions, participants' heart rates were meticulously monitored using
185   the Mio ALPHR heart rate monitor (Petaluma, CA, United States). This device recorded heart
186   rate changes per second during wear, ensuring that participants adhered to the prescribed
187   exercise intensity throughout the intervention. Comprehensive details of the AT protocol are
188   available in the attached supplementary materials.

189   2.2.2 Exercise session

190   **CT-0h group:** This group performed the exercise programs described in the RT and AT
191   protocols in the same session, with one set of RT followed by one set of AT. The training was
192   performed twice a week for 35 to 40 min each session.

193   **CT-48h group:** This group performed the exercise programs described in the RT and AT
194   protocols in two physical education classes per week, respectively. Two sets of RT were
195   performed on Mondays and two sets of AT were performed on Wednesdays, with 35-40 min of
196   training each time.

197 **Con group:** This group maintained their normal daily activities without intervention (Figure 2).

198 2.3 Study measurements

199 2.3.1 Procedure

200 We measured the height and weight of each student before and after the intervention using a
201 body composition analyzer (InBody J20, BIOSPACE, Seoul, Korea), known for its strong
202 validity in Asian children and utilization in large-scale intervention trials with children (Kriemler
203 et al. 2010). Additionally, we calculated the body mass index (BMI) as weight in kilograms
204 divided by the square of the height in meters.

205 We executed the measurement of pertinent parameters during two distinct time frames: 1 week
206 preceding the intervention and the initial week following the intervention. Our deliberate choice
207 to distribute these evaluations across multiple days aimed to alleviate the potential influence of
208 participant fatigue and maintain the precision of measurements. The procedural chronology for
209 these assessments was delineated as follows:

210 **Body composition analysis:** This assessment was administered on the inaugural day, prior to the
211 commencement of any physical activities.

212 **Primary outcome assessments:** These included evaluations of CRF through the estimated
213 VO_2max test and assessments of muscle strength, including the standing long jump, vertical
214 jump, and handgrip strength test (Cadenas-Sanchez et al. 2016; Janz et al. 2021). We
215 meticulously ensured that each of these assessments was conducted on distinct days in order to
216 uphold the accuracy of results while minimizing the risk of participant fatigue.

217 **Secondary outcome evaluations:** These included the 30-second sit-up test, 50 m sprint, and
218 aerobic capacity index, with distances of 1,000 m for boys and 800 m for girls. In consonance
219 with the primary outcome tests, these assessments were conducted on separate days, serving to
220 comprehensively characterize the participants' physical fitness profiles.

221 2.3.2 Primary outcome

222 In this study, we considered CRF and muscle strength as the primary outcome indicators, as they
223 are direct indicators of health in adolescents (Loo et al. 2022).

224 **Estimated VO_2max:**

225 We used the multistage 20 m shuttle run test, which is used to estimate VO_2max (Leger et al.,
226 1988). This test involved running back and forth on a 20 m track with an audio signal until
227 exhaustion. VO_2max was estimated using a specific formula suitable for adolescents aged 10–16
228 years (Cadenas-Sanchez et al. 2016; Lang 2018).

229 **Muscle strength tests:**

230 Standing long jump: Participants performed three jumps, and the best jump length (measured in
231 centimeters) was recorded.

232 Handgrip strength: The data collection process was carried out according to the methodology
233 described in Li et al. (Li et al. 2023). The handgrip strength of the subjects was measured using a
234 pneumatic squeeze bulb dynamometer (Baseline, White Plains, NY, USA) while seated and with
235 their elbows resting on a table. Two unilateral grip strength measurements were taken
236 consecutively, with the first measurement being taken on the dominant hand. A 30-second rest
237 period was introduced between each measurement to prevent fatigue. From the two trials, the
238 best value for each hand was selected.

239 2.3.3 Secondary outcomes

240 We assessed various secondary outcomes to gain a comprehensive understanding of the students'
241 physical fitness.

242 Muscular endurance (30-second sit-up test): For the 30-second sit-up test, participants were
243 instructed to lie on their backs with their knees bent and feet flat on the ground. Their hands were
244 placed behind their heads with fingers interlocked to support the neck. Participants then
245 performed sit-ups by raising their upper bodies until their elbows touched their knees and then
246 returned to the starting position. The number of correctly completed sit-ups within the 30-second
247 time frame was recorded. (Janz et al. 2021).

248 Speed and anaerobic capacity (50 m sprint): Participants sprinted as quickly as possible along a
249 50 m track, and the running time in seconds was recorded. The experimenter timed the tests with
250 a stopwatch used in track races (Casio, Tokyo, Japan), which was accurate to 0.01 s (Fjortoft et
251 al. 2011).

252 Aerobic capacity index: For boys and girls, we measured the aerobic capacity index using a
253 1,000 m and 800 m run, respectively, following the Chinese National Students' Physical Fitness
254 and Health Standard.

255 Each test was carefully selected based on its relevance and validity in assessing specific aspects
256 of the students' physical fitness.

257 2.3 Statistical analysis

258 We estimated the sample size using G*Power 3.1. Based on a previous study (Alves et al.
259 2016b), we set the test efficacy (1-β) to 0.80, incidence of type I error α to 0.05, correlation
260 between pre-and post-intervention to 0.80, and effect size to 2.68. The sample size required for
261 each group was calculated to be 38. To account for a potential drop-out rate of 20%, we have
262 determined that each group should consist of at least 48 subjects, so the total number of subjects
263 should not be less than 144, and 157 subjects were recruited.
264 The collected data were analyzed using IBM SPSS Statistics 26 software. Descriptive statistics,
265 including the mean ± SD, were used to summarize the data. The normal distribution of variables
266 was assessed using the Shapiro-Wilk test, while the homogeneity of variances was examined

267 using the Levene test. To evaluate the differences associated with demographic variables (such
268 as age, height, weight, and BMI), a one-way analysis of variance was conducted. The chi-square
269 test was employed to assess gender differences.

270 For the experimental groups, a 3 (group: CT-0h, CT-48h, and control) × 2 (time: pre- and post-
271 test) repeated measures analysis of variance was utilized to examine the effect of the intervention
272 before and after implementation. Confounding variables (baseline, sex, BMI, and age) were
273 controlled for by analysis of covariance, and outcome indicators were compared across groups
274 (Bonferroni). In addition, the effect size with statistical significance was calculated, which was
275 expressed as η_p^2 and Cohen's d, in which a small effect was 0.01/0.20, a medium effect was
276 0.06/0.50, and a large effect was 0.14/0.80 (Batista et al. 2013; Richardson 2011). The
277 significance level was set to $p < 0.05$.

3. Results

279 3.1 Effects of Intervention on Primary Fitness Outcomes

280 The outcomes from the intra-group analysis are detailed in Table 2. Utilizing a repeated-
281 measures ANOVA, notable enhancements were observed in key fitness parameters, signifying
282 the intervention's efficacy. These parameters include Estimated VO2max ($F_{(2,150)}$=6.505,
283 p=0.002, η_p^2=0.063), 20 m shuttle run (laps) ($F_{(2,150)}$=20.216, p<0.001, η_p^2=0.216), standing long
284 jump ($F_{(2,150)}$=4.098, p=0.019, η_p^2=0.053), and handgrip strength ($F_{(2,150)}$=8.23, p<0.001,
285 η_p^2=0.042). These results indicate significant main effects of the interaction between group and
286 time. More specifically, subsequent to the intervention, notable improvements were recorded in
287 the 20 m shuttle run (laps), standing long jump, and handgrip strength across both the CT-0h and
288 CT-48h groups (p<0.05). The CT-0h group alone demonstrated significant enhancements in
289 Estimated VO2max (p<0.05).
290 Further analysis, adjusting for baseline variables such as sex, Baseline data, and age through
291 covariance analysis, highlighted significant differences between groups. These findings, depicted
292 in Figure 3, revealed pronounced disparities in Estimated VO2max ($F_{(2,150)}$=38.038, p<0.001,
293 η_p^2=0.569), 20 m shuttle run ($F_{(2,150)}$=124.52, p<0.001, η_p^2=0.812), standing long jump
294 ($F_{(2,150)}$=104.598, p<0.001, η_p^2=0.784), and handgrip strength ($F_{(2,150)}$=74.25, p<0.001,
295 η_p^2=0.721).
296 In particular, the CT-0h group exhibited significantly greater improvements compared to the
297 control (Con) group (p<0.05) in all assessed parameters: Estimated VO2max, 20 m shuttle run
298 (laps), standing long jump, vertical jump, and handgrip strength. The CT-48h group also showed
299 superior enhancements relative to the Con group (p<0.05) in the same parameters, excluding
300 Estimated VO2max. Differences between the CT-0h and CT-48h groups were statistically
301 significant in Estimated VO2max and 20 m shuttle run (laps) (p<0.05).

302 3.2 Intervention Impact on Secondary Fitness Outcomes

303 The analysis of intra-group comparisons, as outlined in Table 2, demonstrates significant
304 improvements in secondary fitness outcomes including sit-ups ($F_{(2,150)}$=12.41, p<0.001,
305 η_p^2=0.141), 50 m sprint ($F_{(2,150)}$=5.35, p=0.006, η_p^2=0.068), 800 m run ($F_{(2,150)}$=16.76, p<0.001,
306 η_p^2=0.278), and 1,000 m run ($F_{(2,150)}$=10.266, p<0.001, η_p^2=0.265). These results suggest

307 significant interaction effects between group and time. Post-intervention, both CT-0h and CT-
308 48h groups displayed significant progress in sit-ups, 50 m sprint, 800 m run, and 1,000 m run
309 (p<0.01), contrasting with the Con group, which showed no significant changes (p>0.05).
310 Covariance analysis, adjusted for confounders, revealed that post-intervention outcomes of both
311 CT-0h and CT-48h groups were significantly superior to those of the Con group (p<0.05). A
312 noteworthy difference was found in the 50 m sprint between the CT-0h and CT-48h groups
313 (mean difference: 0.30 seconds; 95% CI: -0.60, -0.002; p=0.048). No significant differences
314 were observed in other performance indicators (p>0.05).

315 **4. Discussion**

316 Adolescents taking part in physical education classes frequently perform RT and AT
317 concurrently due to various limitations in the school setting (e.g., little practice time or lack of
318 facilities) (Santos et al. 2012). This study compared how two CT protocols affected adolescents'
319 physical fitness, with RT and AT scheduled for either the same session (CT-0h group) or
320 separate sessions (CT-48h group). The study's findings indicated that both CT programs were
321 successful in increasing adolescent fitness, but that the program combining RT and AT in one
322 session appeared to be more effective at improving adolescent speed indices and estimated
323 VO_2max. The hypothesis of this study was rejected.
324   First, the CT-48h group showed no improvement in estimated VO_2max despite an increase
325 in 20 m shuttle run (laps), which earlier research had suggested was moderately correlated with
326 maximal oxygen consumption (VO_2peak) (R^2=0.49) (Lang 2018). This finding may be due to the
327 fact that the CT-48h intervention protocol was less successful at enhancing cardiorespiratory
328 endurance. The between-group comparison concluded that the protocol that included RT and AT
329 in the same session was superior to the protocol presenting the exercises separately at improving
330 estimated VO_2max in adolescents. This is inconsistent with the findings of Robineau et al.
331 (Robineau et al. 2016), who concluded that performing AT and RT in the same training session
332 (no interval) or in one day (interval <6 h) was not ideal for aerobic capacity improvement, but
333 better adaptation changes were observed when training was performed on alternate days
334 (interval>24 h). The reason for the difference may be related to the intensity of AT, which was
335 more intense (120% maximal aerobic velocity) in the HIIT protocol used in the study by
336 Robineau et al. (2016) than in this study. A different study showed that when implementing a CT
337 protocol, selecting a lower AT intensity induced a higher aerobic adaptation capacity (Sousa et
338 al. 2019). In addition, the choice of subjects can also produce differences in study results;
339 Robineau et al.'s (2016) subjects were athletes, while the present study included general
340 adolescents. A meta-analysis showed that CT produces different adaptations in athletes and non-
341 athletes (Petre et al. 2021). The study by Santos et al. (2011; 2012) also found, in a population of
342 children and adolescents, that estimated VO_2max improved only when RT and AT were
343 performed simultaneously within the class. This outcome can be explained by the fact that in
344 some ways, combining AT and RT in one session can enhance angiogenesis and oxidase activity
345 (such as capillary to fiber area and succinate dehydrogenase (SDH) activity) more than strength
346 or endurance training alone (Grgic et al. 2019), and is, therefore, better for CRF. Considering the
347 importance of CRF levels for the present and future health of adolescents, combining RT and AT
348 into the same sessions should be considered in order to optimize the physical education class
349 schedule in schools.

350   In addition, previous studies have suggested that CT significantly reduces the development
351   of strength and muscle hypertrophy compared to RT alone, which is often referred to as the
352   "interference effect" (Camera 2022; Hickson 1980). Recently, a growing body of evidence has
353   demonstrated that CT does not impair strength development in prepubertal adolescents (Alves et
354   al. 2018; Alves et al. 2016a; Bouamra et al. 2022; Gabler et al. 2018; Jansson et al. 2022),
355   possibly because adolescents have different neuromuscular and endurance characteristics than
356   adults (Marta et al. 2013), such as their lack of muscle hypertrophy in response to RT (Gabler et
357   al. 2018). However, current research is still limited in that it ignores the variable of the training
358   interval between RT and AT. We concluded that the length of the training interval did not have a
359   significant effect on the development of strength in adolescents and that there was no difference
360   between the two CT protocols in improving muscle strength in adolescents. The findings of this
361   study disprove the previous theory that a training interval of less than 6 h between RT and AT
362   affects muscle strength and hypertrophy (Petre et al. 2021; Robineau et al. 2016), at least among
363   teenagers.
364   The AT training method chosen for this study and the training order between AT and RT
365   may be the cause for the training interval between AT and RT not affecting muscle strength in
366   adolescents. It was previously concluded that medium-intensity and long-duration endurance
367   training inhibits the activation of the protein kinase B–mammalian rapamycin pathway and
368   adenosine monophosphate-activated protein kinase (AMPK), which in turn negatively affects the
369   development of muscle strength (Methenitis 2018). While the present study used the HIIT form
370   of AT, previous studies have found that HIIT shares the same metabolic adaptations as RT, such
371   as activating the receptor-γ coactivator (PGC-1a) pathway via the peroxisome proliferator, which
372   contributes to an increase in muscle strength. Recently, it was also shown that HIIT does not
373   have a disruptive effect on muscle strength improvement (Vechin et al. 2021). Therefore, it is
374   reasonable to assume that performing AT in the same session using CT based on HIIT, an AT
375   protocol, will not impair any increase in muscle strength. The "chronic interference hypothesis",
376   another explanation for the "interference effect", which contends that performing aerobic
377   endurance training first in a session can negatively impact the effectiveness of RT and cause
378   excessive fatigue that is harmful to muscle recovery (Lee et al. 2020). The sequencing used in
379   this study, however, put RT before AT, which has been proven to be more favorable for lower
380   body strength adaptation (Murlasits et al. 2018).
381   In addition to muscle strength and explosive power, we observed significant changes in
382   abdominal muscle endurance (sit-ups) in both training groups after 12 weeks of intervention, a
383   positive result that is significant because muscle fitness (strength, explosive power, and
384   endurance) is negatively associated with clustered cardiometabolic risk, obesity (Silva et al.
385   2020), and positively associated with skeletal health and self-esteem (including adolescents'
386   physical self-concept, perceived physical appearance, and perceived athletic ability)(Smith et al.
387   2014). Therefore, actively encouraging adolescents to participate in RT or CT is essential to
388   maintain and/or improve muscle fitness.
389   While sports performance, which is dependent on muscle strength, is as crucial to
390   preserving health as aerobic capacity, many recent studies on physical fitness have concentrated
391   on aerobic capacity (Alves et al. 2016a; Taanila et al. 2011). This study concluded that CT was
392   very effective at improving adolescent sports performance (1,000 m and 800 m run). Previous
393   studies have concluded that CT is more effective than unimodal AT in terms of sports
394   performance. This is due to the fact that RT increases musculotendinous unit stiffness, which
395   leads to an increased ability of the muscle to store elastic energy in tandem and parallel elastic

396   components when doing centrifugal movements. This in turn increases the strength of the muscle
397   when doing centripetal movements, which can improve sports economy (Bazyler et al. 2015;
398   Gabler et al. 2018). The improvement of cardiorespiratory endurance and exercise economy is
399   the basis for improving sports performance and endurance (Gabler et al. 2018). Additionally, this
400   study discovered that CT-0h improved the speed index more effectively than CT-48h. Speed is
401   positively correlated with maximal oxygen uptake and leg strength (Suchomel et al. 2016).
402   Study strengths and limitations
403   The results of this study demonstrate the possibility for integrating CT into school physical
404   education lessons to enhance adolescent health. This study could act as a guide for scheduling
405   CT of strength and aerobic exercise components in physical education classes in schools and
406   offers scientific support for the development of instructional content in middle school physical
407   education programs. To our knowledge, this study is the first to consider how CT training
408   protocols with different training intervals between RT and AT affect physical fitness in
409   adolescents, and the results can be used to enrich and develop theories related to CT training in
410   adolescents. In practice, twice-weekly CT of either protocol has been shown to improve muscle
411   fitness in adolescents; however, the CT-0h program without training intervals appeared to be
412   more effective at improving CRF. This serves as a useful resource for developing exercise plans
413   and establishing objectives for health promotion in the adolescent population.
414   However, there are some limitations to this study. First, due to its implementation in a
415   school physical education class, it was not possible to perform a complete random assignment of
416   each student. However, minor differences in performance abilities between the three groups were
417   considered acceptable, as observed in previous studies conducted in a school setting (Bossmann
418   et al. 2022). Second, this study did not assess the affective (i.e., sensory state) and enjoyment
419   responses of adolescents participating in the two CT protocols. This aspect should be addressed
420   in future studies, as perceived responses are known to correlate with habitual physical activity
421   and exercise adherence throughout an individual's lifespan (Ricci et al. 2020). Additionally, this
422   study overlooked the measurement of participants' "maturation," which may introduce a certain
423   degree of variability. Future research should further investigate the impact of adolescents'
424   "maturation" on the effectiveness of interventions. Finally, it's worth noting that only a running
425   format was employed for AT in this study. Whether other AT protocols (e.g., cycling) have
426   different effects on the outcomes of CT intervention remains unknown and warrants exploration
427   in future research.

428   5. Conclusion

429   This study confirmed that both studied CT programs delivered in school physical education
430   classes were effective at improving physical fitness indicators in adolescents. A program that
431   schedules RT and AT in the same class, with RT followed by aerobic endurance training, may
432   result in greater gains in CRF. Future studies could expand the study size and consider
433   psychological factors and variables such as type, intensity, and duration of AT training, as well
434   as control for habitual behaviors related to physical activity and food consumption during the
435   intervention.
436

437 **Data Availability**

438 The following information was supplied regarding data availability:

439 **Conflicts of Interest**

440 The authors declare no conflict of interest.

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444 **Authors' contributions**

445 Z.Z, Z.L, D.T., and, X.H. conceived and designed this research. T.D. conducted the experiments
446 and collected the data. Z.L. and X.H. analyzed the data. Z.L., D.T., X.H., Y.G., and Z.Z. drafted
447 the manuscript. All authors read and approved the final version of the manuscript.
448

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624 Legends:

625 Table 1. Baseline demographic characteristics of participants (n = 157)

626

627 Table 2. Intra-group comparison of the effects of 12 weeks of training on participants' physical fitness (mean ± sd.)

628

629 Figure 1. Flowchart of the participant selection process

630

631 Figure 2. Schematic diagram of the two concurrent training interventions.

632

633 Figure 3. Inter-group comparison of the effects of 12 weeks of training on participants' physical fitness (mean ± sd.).

634   * indicates p<0.05; ** indicates p<0.001.

635

Baseline demographic characteristics of participants (n = 150)

1   Table 1: Baseline demographic characteristics of participants (n = 150).

Indicators	All (n = 150)	CT-0h (n = 50)	CT-48h (n = 50)	Con (n = 50)
Age (years)	12.5±0.3	12.6±0.3	12.5±0.4	12.4±0.3
Sex (male/female)	67/90	22/30	23/30	22/30
Height (cm)	159.4±7.2	158.6±7.8	160.3±6.6	159.1±7.0
Weight (kg)	53.5±13.0	52.3±14.3	55.8±11.7	52.3±12.8
BMI (kg/m^2)	20.9±4.1	20.6±4.5	21.7±3.9	20.5±4.0

Table 2: Intra-group comparison of the effects of 12 weeks of training on participants' physical fitness (mean ± sd.)

1   Table 2: Intra-group comparison of the effects of 12 weeks of training on participants' physical fitness   (mean ±

2   sd.).

Variables	Group	Pre	Post	Change (95%Cl)	p-value	Cohen's d
Estimated VO2max (mL/kg/min)	CT-0h	37.5±4.8	39.3±4.9	1.8(1.0,2.6)	<0.001	0.4
	CT-48h	36.7±3.4	37.3±3.6	0.6(-0.3,1.4)	0.195	—
	Con	37.5±4.2	37.5±3.4	-0.05(-0.9,0.8)	0.898	—
20-m shuttle run (laps)	CT-0h	33.5±16.9	45.3±18.3	11.7(9.8,13.8)	<0.001	0.7
	CT-48h	30.0±13.0	37.7±14.0	7.8(5.8,9.8)	<0.001	0.6
	Con	32.1±14.9	34.7±13.0	2.6(-0.6,4.7)	0.105	—
Standing long jump (cm)	CT-0h	165.6±20.2	172.5±20.7	6.9(4.1,9.7)	<0.001	0.3
	CT-48h	159.1±20.7	165.4±21.4	6.2(0.4,12.1)	<0.001	0.3
	Con	157.6±17.6	159.2±18.7	1.7(-1.2,4.5)	0.247	—
Handgrip strength (kg)	CT-0h	23.2±5.4	33.9±6.7	10.7(9.3,12.1)	<0.001	1.75
	CT-48h	23.3±4.5	31.8±6.8	8.5(6.8,10.1)	<0.001	1.12
	Con	21.7±4.7	21.6±4.2	-0.1(-1.5,1.3)	0.175	—
Sit-ups (reps)	CT-0h	37.7±9.7	45.0±8.3	7.3(5.6,9.0)	<0.001	0.81
	CT-48h	37.2±8.0	42.1±7.5	4.88(3.2,6.6)	<0.001	0.63
	Con	36.7±8.2	38.0±7.7	1.4(-0.3,3.0)	0.111	—
50-meter sprint (s)	CT-0h	9.2±0.6	8.9±0.7	-0.3(-0.5, -0.2)	<0.001	-0.52
	CT-48h	9.6±0.8	9.3±1.0	-0.1(-2.0, -0.1)	0.792	—
	Con	9.3±1.0	9.3±1.3	0.1(-0.1,0.2)	0.509	—
800 m (s)	CT-0h	263.3±35.2	225.9±21.2	-37.4(-46.9, -27.8)	<0.001	-1.29
	CT-48h	281.4±43.0	244.1±24.9	-37.3(-46.8, -27.8)	<0.001	-1.06
	Con	266.2±33.5	262.7±37.3	-3.4(-12.9,6.1)	0.475	—
1000 m (s)	CT-0h	326.1±60.8	292.9±45.9	-33.3(-46.3, -20.2)	<0.001	-0.62
	CT-48h	322.7±49.3	297.0±39.6	-25.7(-38.7, -12.6)	<0.001	-0.57
	Con	336.2±52.1	342.4±44.1	6.2(-6.9,19.3)	0.347	0.13

4   Note: CT-0h refers to the combination of resistance training (RT) and aerobic training (AT) in

5   the same physical education (PE) session, and CT-48h refers to RT and AT separated between

6   two PE sessions (48 h interval).

Figure 1

Flowchart of the participant selection process
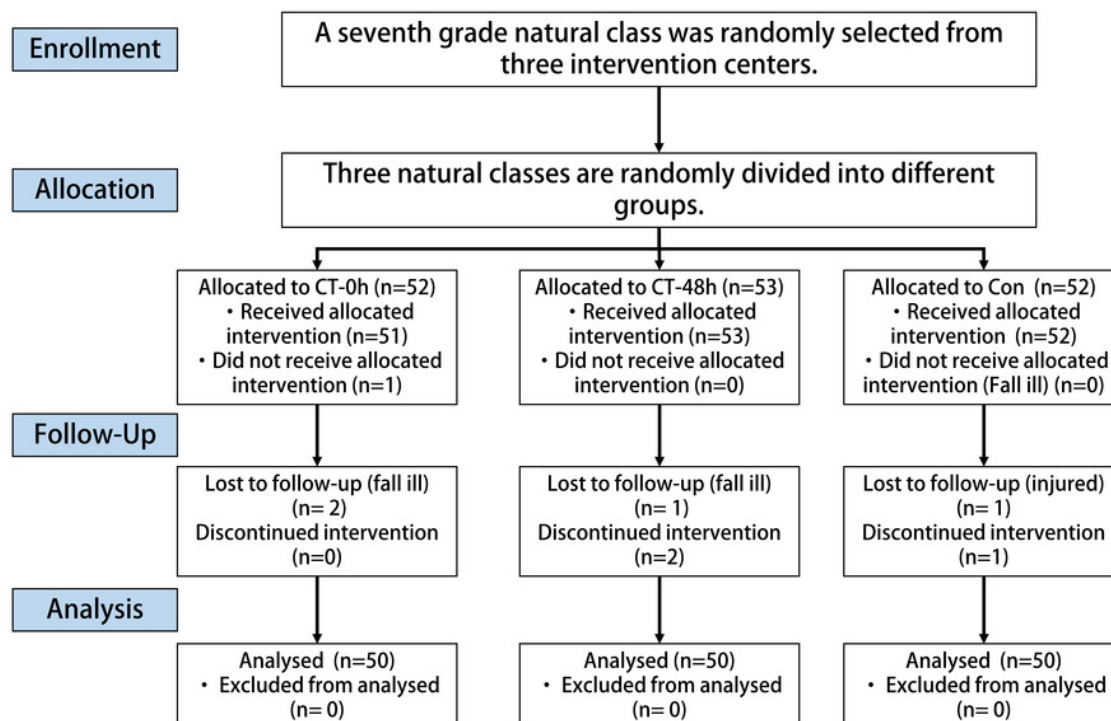
Figure 2

Schematic diagram of the two concurrent training interventions.
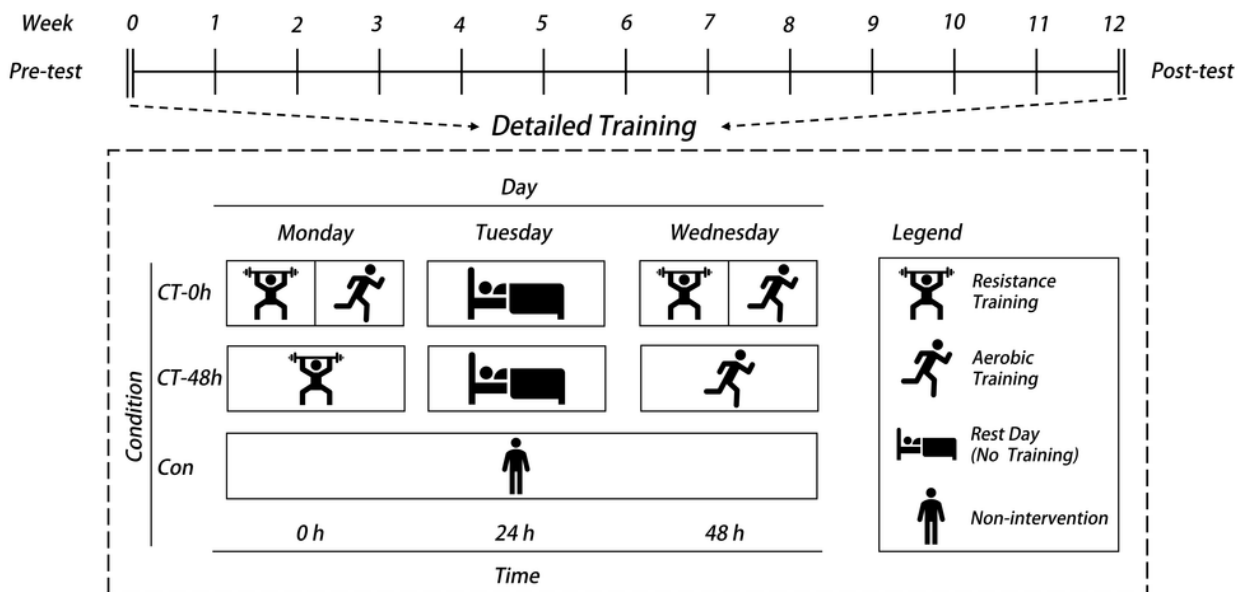
Figure 3

Comparison of the effects of 12 weeks of training on participants' physical fitness (mean ± SD).

All comparisons were adjusted for sex, baseline data, and age of the subjects for each indicator.

##Significant within-group changes, pre- to post-training, p < 0.001 **Significantly different between groups, p < 0.001