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## Research Article

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# The effects of 9-week triphasic resistance training on the lower limb strength, balance ability and 200-m sprint performance of elite female sprint canoe athletes

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## Abstract

**Background:** This study aimed to investigate the effects of a 9-week triphasic resistance training (TRT) on lower-limb strength, dynamic balance, and sport performance in elite female sprint canoe athletes.

**Methods:** Twenty elite female sprint canoe athletes were randomly assigned to either a TRT group (n = 10) and a traditional strength training (TST) group (n = 10). Both groups completed identical lower-limb resistance training programs three times per week for 9 weeks, with matched training volume, relative intensity, frequency, exercises, and rest intervals. The only difference between groups was the manipulation of movement tempo. The TRT program sequentially emphasized eccentric-, isometric-, and concentric-focused training phases, whereas the TST group performed

conventional resistance training. Lower-limb maximal strength (1RM back squat, 1RM deadlift, and relative peak torque), muscle power (relative average power), explosive strength [50–100 ms Rate of torque development(RTD), Countermovement Jump (CMJ), Squat Jump (SJ), and Eccentric Utilization Ratio(EUR)], dynamic balance (Y-Balance Test), and 200-m sprint performance (200-m sprint time and average boat velocity) were assessed before and after the intervention. Data were analyzed using a two-way mixed ANOVA.

**Results:** No significant between-group differences were observed at baseline ( $P > 0.05$ ). Compared with the TST group, the TRT group demonstrated greater improvements in 1RM back squat, 1RM deadlift, relative peak torque of the hip and knee flexors and extensors, relative average power, RTD50-100 of the hip, knee, and ankle flexors and extensors, CMJ height, and EUR ( $P < 0.05$ ). No significant change was observed in SJ height ( $P > 0.05$ ). Neither group demonstrated significant improvements in dynamic balance, 200-m sprint performance( $P > 0.05$ ).

**Conclusions:** Compared with traditional strength training, a 9-week triphasic resistance training program was more effective in improving lower-limb maximal strength, muscle power, and explosive strength in elite female sprint canoe athletes. However, these physical improvements did not translate into significant improvements in dynamic balance or 200-m sprint performance.

**Keywords:** triphasic training<sup>1</sup> ; lower limb strength<sup>2</sup> ; dynamic balance<sup>3</sup> ; sprint performance<sup>4</sup> ; elite female sprint canoe athletes<sup>5</sup>.

## **Introduction**

Canoe sprint is a high-intensity Olympic sport in which athletes must repeatedly generate large propulsive forces within a short race duration. Consequently, strength and conditioning training has become an important component of preparation for competitive canoe sprint athletes, aiming to develop physical qualities associated with race performance [1]. Traditional resistance training programs primarily emphasize concentric force production to improve maximal strength and power-

45 related abilities [2]. However, resistance training approaches that systematically manipulate  
46 eccentric, isometric, and concentric muscle actions may provide different mechanical stimuli and  
47 contribute to improved strength adaptations [3].

48 TRT involves the manipulation of movement tempo to emphasize eccentric, isometric, and  
49 concentric muscle actions during separate training phases. By exposing athletes to different  
50 contraction-specific demands, this method is intended to improve force production while maintaining  
51 the original movement pattern [4] . In practice, triphasic training can be implemented using simple  
52 tools such as metronomes. Compared with specialized equipment used for isolated eccentric or  
53 concentric training, metronome-based tempo control provides a practical and accessible approach for  
54 regulating contraction velocity [5, 6].

55 In canoe sprint, previous research has predominantly focused on upper-body strength, aerobic  
56 capacity, and anaerobic performance as key determinants of performance [7-10]. However, recent  
57 findings indicate that lower-limb strength and postural stability may also influence force transmission  
58 and performance during paddling [11-13]. Current research on canoe athletes tends to focus on overall  
59 strength assessment, with relatively limited analysis of single-joint strength [13-15]. Therefore, this  
60 study employed Isokinetic dynamometry to evaluate specific muscular information and diagnose  
61 single-joint strength during muscle contraction [16, 17], And further determine the impact of triphasic  
62 training on the strength of each joint in the lower limbs of canoe sprint athletes.

63 Although various resistance training approaches are commonly applied during canoe sprint  
64 preparation, the comparative effects of triphasic resistance training and traditional resistance training  
65 on lower-limb strength, balance ability, and canoe sprint performance in elite athletes have not been  
66 fully established. Therefore, this study aimed to compare the effects of a 9-week triphasic resistance

67 training program and traditional resistance training on lower-limb maximal strength, explosive  
68 strength, dynamic balance, and 200-m sprint performance in elite female canoe sprint athletes.

## 69 **Materials and Methods**

### 70 **Study Design**

71 A 9-week randomized controlled trial was conducted from [Oct 2025] to [Dec 2025] to investigate  
72 the effects of triphasic resistance training on lower-body strength and athletic performance in elite  
73 flatwater canoe athletes. Participants were randomly allocated to either the TRT group or the TST  
74 group using a computer-generated randomization procedure, with an allocation ratio of 1:1. All  
75 participants completed a 2-week familiarization period before the intervention. During this period,  
76 they were introduced to the testing procedures, resistance training exercises, prescribed movement  
77 tempos, and experimental requirements. During the familiarization period, participants' 1RM values  
78 for the Back Squat, Front Squat, and Romanian Deadlift were assessed using standardized  
79 procedures. For unilateral and machine-based exercises (i.e., Bulgarian Split Squat, Hip Thrust, Leg  
80 Press, Step-up, and Walking Lunge), training loads were prescribed according to estimated RM  
81 values and adjusted when participants exceeded the prescribed repetitions while maintaining proper  
82 technique. Participants were instructed to avoid strenuous exercise for 48 h before testing, as well as  
83 alcohol, caffeine, and other stimulants for 24 h before each testing session. They were also asked to  
84 maintain their habitual diet and sleep patterns throughout the study. Throughout the intervention, both  
85 groups followed the same overall training programme prescribed by the coaching staff. Supervised  
86 resistance training sessions were conducted three times per week (Monday, Wednesday, and Friday),  
87 with each session lasting approximately 2 h and consisting of a standardized warm-up, resistance  
88 training, and cool-down. Only the lower-body resistance training protocol differed between groups,  
89 whereas canoe-specific training, upper-body resistance training, core training, and technical training

90 were kept consistent throughout the intervention. The resistance training programme included the  
91 Back Squat, Front Squat, Romanian Deadlift, Hip Thrust, Bulgarian Split Squat, Leg Press, Step-up,  
92 and Walking Lunge. Both groups completed the same exercises with identical training frequency,  
93 relative loads, sets, repetitions, rest intervals, and overall training volume. Group allocation differed  
94 only in the prescribed movement tempo of the primary exercises (Back Squat, Front Squat, and  
95 Romanian Deadlift). For the TRT group, the primary exercises followed the triphasic training  
96 protocol. The eccentric contraction phase was applied during Weeks 1–3, followed by the isometric  
97 contraction phase during Weeks 4–6 and the concentric contraction phase during Weeks 7–9. The  
98 TST group completed all exercises using a conventional movement tempo (2-0-2-0) throughout the  
99 intervention. Intervention protocols are shown in Table 1

## 100 **Training Intervention**

101 Two certified strength and conditioning coaches supervised all resistance training sessions  
102 throughout the intervention. Before the study began, the coaches received standardized training to  
103 ensure that they followed the same training procedures and monitoring methods.  
104 The researchers used a digital metronome (60 beats·min<sup>-1</sup>) during every training session to control  
105 the prescribed movement tempo. During the eccentric and isometric phases, the coaches used verbal  
106 counting together with the metronome to help participants maintain the required tempo. The coaches  
107 monitored each session and recorded participants' movement technique, tempo control, and  
108 completion of the planned exercises, sets, and repetitions. When participants failed to maintain the  
109 prescribed tempo for two consecutive repetitions, the coaches reduced the training load by 2.5–5% in  
110 the following set to maintain correct exercise execution and the intended training stimulus.  
111 The coaches recorded attendance, protocol deviations, and load adjustments during the intervention.

**Table 1 Triphasic resistance training program**

|                  | Eccentric phase (Week1-3) |       |         |      | Isometric phase (Week4-6) |       |         |      | Concentric phase(Week7-9) |       |         |      |
|------------------|---------------------------|-------|---------|------|---------------------------|-------|---------|------|---------------------------|-------|---------|------|
|                  | INT                       | S×R   | Tempo   | Rest | INT                       | S×R   | Tempo   | Rest | INT                       | S×R   | Tempo   | Rest |
| <b>Monday</b>    |                           |       |         |      |                           |       |         |      |                           |       |         |      |
| Back Squat       | 75%1R                     | 4 × 5 | 5:0:X:  | 3mi  | 80%1RM                    | 4 × 4 | 0:2:X:  | 3mi  | 75%1R                     | 5 × 3 | 0:0:X:  | 3mi  |
| Romanian DL      | 70%1R                     | 3 × 5 | 5:0:X:  | 3mi  | 72.5%1R                   | 3 × 5 | 0:2:X:  | 3mi  | 70%1R                     | 4 × 4 | 0:0:X:  | 3mi  |
| Bulgarian split  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  |
| leg press        | ~10R                      | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  |
| Step-up          | ~10R                      | 3 × 8 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 8 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 8 | 2:0:2:0 | 90s  |
| <b>Wednesday</b> |                           |       |         |      |                           |       |         |      |                           |       |         |      |
| Front squat      | 70%1R                     | 4 × 5 | 5:0:X:  | 3mi  | 75%1RM                    | 4 × 4 | 0:2:X:  | 3mi  | 70%1R                     | 5 × 3 | 0:0:X:  | 3mi  |
| Hip Thrust       | ~8RM                      | 3 × 8 | 2:0:2:0 | 2mi  | ~8RM                      | 3 × 8 | 2:0:2:0 | 2mi  | ~8RM                      | 3 × 8 | 2:0:2:0 | 2mi  |
| Walking Lunge    | ~10R                      | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  |
| leg press        | ~10R                      | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  |
| Bulgarian split  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  |
| <b>Friday</b>    |                           |       |         |      |                           |       |         |      |                           |       |         |      |
| Back Squat       | 75%1R                     | 4 × 5 | 5:0:X:  | 3mi  | 80%1RM                    | 4 × 4 | 0:2:X:  | 3mi  | 75%1R                     | 5 × 3 | 0:0:X:  | 3mi  |
| Romanian DL      | 70%1R                     | 3 × 5 | 5:0:X:  | 3mi  | 72.5%1R                   | 3 × 5 | 0:2:X:  | 3mi  | 70%1R                     | 4 × 4 | 0:0:X:  | 3mi  |
| Bulgarian split  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  | ~8RM                      | 3 × 8 | 2:0:2:0 | 90s  |
| leg press        | ~10R                      | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  | ~10RM                     | 3 × 1 | 2:0:2:0 | 90s  |
| Hip Thrust       | ~8RM                      | 3 × 8 | 2:0:2:0 | 2mi  | ~8RM                      | 3 × 8 | 2:0:2:0 | 2mi  | ~8RM                      | 3 × 8 | 2:0:2:0 | 2mi  |

113 \*INT intensity, The prescribed tempo was expressed as eccentric:isometric:concentric:pause (e.g., 5-0-X-0), where "X" indicates maximal intended  
114 concentric velocity

## 115 **Participants**

116 The sample size was estimated before the study using G\*Power. The analysis was performed with an  
117 effect size of  $f = 0.40$ , an  $\alpha$  level of 0.05, and a statistical power of 0.80. The analysis indicated that at  
118 least 16 participants were required. Because elite sprint canoe athletes were limited in availability,  
119 the study recruited 20 elite female sprint canoeists from Yunnan Province, China.

120 The participants were  $19.72 \pm 1.45$  years old on average, with a mean height of  $169.78 \pm 3.26$  cm and  
121 a mean body mass of  $65.85 \pm 4.08$  kg. Their average training experience was  $5.55 \pm 1.20$  years.

122 Based on the Chinese National Athlete Grading System, the sample included 4 International Masters

of Sport, 6 National Masters of Sport, and 10 National First-Class Athletes. All participants completed the intervention, and no withdrawals or exclusions occurred. Before the intervention, participants completed the Functional Movement Screen (FMS) to assess movement competency. Participants were required to achieve a score of 3 on the Deep Squat component before performing the loaded squat and deadlift exercises included in the training program. All participants had at least two years of systematic resistance training experience. They had no lower-extremity musculoskeletal injuries within the previous six months and reported no cardiovascular, neurological, or other medical conditions that could interfere with participation. All participants provided written informed consent before taking part in the study and completed the Physical Activity Readiness Questionnaire Plus (PAR-Q+) for health screening[18]. Participants avoided strenuous exercise for 24 h before each testing session and maintained their usual dietary and sleeping habits throughout the study. Before baseline testing, participants completed a two-week familiarization period. During this period, they became familiar with all testing procedures and resistance training exercises. The study protocol received approval from the Ethics Committee of the Affiliated Medical College of Yunnan University (Approval No. KJK#20250825-R1-038). The study was conducted according to the principles of the Declaration of Helsinki. The study was reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines. A completed CONSORT checklist is provided as an additional file.

## **Testing Metrics and Procedures**

### **Lower Limb Isokinetic Strength Test**

The relative peak torque, relative average power, and 50–100 ms rate of torque development (RTD) of the hip, knee, and ankle joints were assessed using an ISOMED 2000 isokinetic dynamometer (D. & R. Ferstl GmbH, Hemau, Germany). The testing protocol included a standardized warm-up, equipment preparation, participant positioning, and joint-specific isokinetic testing procedures.

147 Participants completed a standardized general warm-up before the isokinetic assessment. The  
148 dynamometer was prepared according to the requirements of each joint test, and the participant's  
149 position was adjusted accordingly. Non-elastic straps were used to stabilize the participants during  
150 testing. The rotational axis of the dynamometer was aligned with the anatomical axis of the  
151 corresponding joint, and appropriate adapters were selected. The range of motion was confirmed  
152 before testing, and safety devices were checked to ensure safe operation. Participants then completed  
153 a specific isokinetic warm-up before the formal assessment.

154 During the isokinetic test, participants performed concentric flexion and extension movements of the  
155 hip, knee, and ankle joints at an angular velocity of 60°/s. Each joint was tested for six maximal  
156 repetitions. Hip joint testing was performed in a supine position with a range of motion from 10° to  
157 120°, and the rotational axis was aligned with the estimated hip joint center at the greater trochanter.  
158 Knee joint testing was conducted in a seated position with a range of motion from 10° to 90°, with  
159 alignment at the lateral femoral epicondyle. Ankle joint testing was also performed in a seated  
160 position, with a range of motion from -20° to 50° and the lateral malleolus used as the reference axis  
161 [19]. Participants rested for 1 minute between assessments of different joints. Throughout the test,  
162 participants were instructed to exert maximal effort throughout the entire range of motion.

### 163 **Countermovement and Squat jump test**

164 CMJ and SJ performances were assessed using a SmartJump system (Australia). Participants  
165 completed a standardized warm-up before the jump tests. During both assessments, participants kept  
166 their hands on the iliac crests throughout the movement to minimize the influence of arm swing. For  
167 the CMJ test, participants started from a standing position on the jump mat and performed a rapid  
168 countermovement followed immediately by a maximal vertical jump. No pause was allowed between  
169 the eccentric and concentric phases.[20]. For the SJ test, participants maintained a squat position with

170 approximately 90° of knee flexion, which was confirmed using a handheld goniometer. Participants  
171 held this position for 2–3 s before performing a maximal vertical jump to reduce the contribution of  
172 the stretch-shortening cycle [21]. Participants were instructed to achieve maximal jump height in each  
173 trial. Three maximal attempts were completed for each test, and the highest jump height was used for  
174 statistical analysis. A 1-min rest interval was provided between trials [22].

### 175 **Balance Test**

176 Dynamic balance performance was evaluated using the Y-Balance Test kit. Participants completed  
177 the test using both the left and right legs as the supporting limb, with reach distances recorded in the  
178 anterior, posteromedial, and posterolateral directions. The test was used to assess dynamic balance  
179 performance and related lower-limb functional characteristics [23, 24].

### 180 **200-m Sprint Performance Test**

181 The 200-m sprint test was performed on an international-standard canoe sprint course. The course  
182 conditions were checked before each trial. No obvious water current or floating debris was observed  
183 during testing, and the water depth met the requirements for canoe sprint testing. Three experienced  
184 coaches and one national-level canoe referee supervised the testing procedure. Wind conditions were  
185 recorded using a handheld anemometer during each test session. The average wind speed was  
186 approximately 0.05 m·s<sup>-1</sup>, suggesting that environmental effects from wind were minimal. Sprint  
187 time was measured using photocell timing gates (accuracy: 0.01 s), which were placed at the start and  
188 finish points of the 200-m course. Boat velocity was obtained by dividing the 200-m distance by the  
189 corresponding sprint time. The calculated value was expressed as m·s<sup>-1</sup>.

### 190 **Statistical Analysis**

191 All statistical analyses were performed using SPSS software (version 27.0; IBM Statistics, Chicago,  
192 IL, USA). The distribution of continuous variables was checked using the Shapiro–Wilk test, and

Levene's test was applied to examine the equality of variances. Data are reported as mean  $\pm$  standard deviation ( $M \pm SD$ ). A two-way repeated-measures ANOVA was used to evaluate the effects of group, time, and the group  $\times$  time interaction. When a significant interaction was identified, Sidak-adjusted simple effects analyses were conducted for further comparisons. The magnitude of ANOVA effects was reported using partial eta-squared ( $\eta^2$ ), with values of 0.01, 0.06, and 0.14 considered small, moderate, and large effects, respectively. Additional analyses were performed using change scores (post – pre). Independent-samples t-tests and Cohen's d were calculated to further examine between-group differences. Cohen's d values were interpreted as trivial ( $<0.20$ ), small ( $0.20-0.49$ ), moderate ( $0.50-0.79$ ), and large ( $\geq 0.80$ ). The significance level was set at  $p < 0.05$ .

## Results

All participants completed the intervention without dropout or injury (Supplementary S1). During the intervention, coaches monitored compliance with the prescribed contraction tempo. When participants failed to maintain the prescribed tempo for two consecutive repetitions, the external load was reduced by 2.5 – 5% according to the predefined protocol. All adjusted sets were completed successfully. No major protocol deviations or training-related injuries occurred during the intervention. The test results for lower limb maximal strength, rapid strength, explosive power, balance ability, and competitive performance between the experimental group and the control group are shown in Table 2. Training tempo fidelity and temporary load adjustments are summarized in Supplementary Table S2, Individual load adjustment record in Supplementary Table S3, and The results of the t-test for the differences between the TRT group and the TST group before and after the intervention in Supplementary Table S4.

**Table 2. Difference between TRT and TST**

| Variable                     |       | TRT (n=10) | TST (n=10) | F           | P      | ES ( $\eta^2$ ) |
|------------------------------|-------|------------|------------|-------------|--------|-----------------|
| Relative Peak Torque (Nm/kg) |       |            |            |             |        |                 |
| Left hip flexors             | Pre   | 1.44±0.15  | 1.44±0.20  | 0.000       | 0.990  | 0.00            |
|                              | Post  | 1.64±0.14  | 1.47±0.19  | 5.481       | 0.031* | 0.233           |
|                              | Δ (%) | 15.18      | 2.41       |             |        |                 |
|                              |       |            | effect     | interaction | group  | Time            |
|                              | P     | 0.000*     | 0.478      | 0.014*      | 0.227  | 0.001*          |
|                              | ES    | 0.540      | 0.028      | 0.294       | 0.080  | 0.440           |
| Left hip extensors           | Pre   | 4.29±0.33  | 4.18±0.32  | 0.606       | 0.447  | 0.033           |
|                              | Post  | 4.62±0.18  | 4.20±0.33  | 12.202      | 0.003* | 0.404           |
|                              | Δ (%) | 7.15       | 0.50       |             |        |                 |
|                              |       |            |            | interaction | group  | Time            |
|                              | P     | 0.000*     | 0.715      | 0.002*      | 0.049  | 0.001*          |
|                              | ES    | 0.632      | 0.008      | 0.428       | 0.199  | 0.494           |
| Right hip flexors            | Pre   | 1.43±0.16  | 1.43±0.13  | 0.000       | 1.000  | 0.000           |
|                              | Post  | 1.71±0.21  | 1.45±0.13  | 11.322      | 0.003* | 0.386           |
|                              | Δ (%) | 15.75      | 1.57       |             |        |                 |
|                              |       |            |            | interaction | group  | Time            |
|                              | P     | 0.000*     | 0.573      | 0.000*      | 0.062  | 0.000*          |
|                              | ES    | 0.731      | 0.018      | 0.533       | 0.180  | 0.613           |
| Right hip extensors          | Pre   | 4.28±0.39  | 4.12±0.46  | 0.680       | 0.420  | 0.036           |
|                              | Post  | 4.63±0.36  | 4.14±0.46  | 6.974       | 0.017* | 0.279           |
|                              | Δ (%) | 8.38       | 0.44       |             |        |                 |
|                              |       |            |            | interaction | group  | Time            |
|                              | P     | 0.000*     | 0.744      | 0.000*      | 0.096  | 0.000*          |
|                              | ES    | 0.697      | 0.006      | 0.509       | 0.147  | 0.560           |
| Left knee flexors            | Pre   | 1.35±0.11  | 1.39±0.18  | 0.315       | 0.582  | 0.017           |
|                              | Post  | 1.58±0.18  | 1.41±0.17  | 4.622       | 0.045* | 0.204           |
|                              | Δ (%) | 16.82      | 1.28       |             |        |                 |
|                              |       |            |            | interaction | group  | Time            |
|                              | P     | 0.000*     | 0.682      | 0.001*      | 0.351  | 0.000*          |
|                              | ES    | 0.650      | 0.010      | 0.444       | 0.048  | 0.516           |
|                              | Pre   | 2.61±0.34  | 2.40±0.21  | 2.703       | 0.117  | 0.131           |

|                      |       |           |           |             |        |        |
|----------------------|-------|-----------|-----------|-------------|--------|--------|
| Left knee extensors  | Post  | 2.87±0.29 | 2.42±0.22 | 15.777      | 0.001* | 0.467  |
|                      | Δ (%) | 10.93     | 0.61      |             |        |        |
|                      |       |           |           | interaction | group  | Time   |
|                      | P     | 0.000*    | 0.765     | 0.002*      | 0.010  | 0.001* |
|                      | ES    | 0.613     | 0.005     | 0.414       | 0.315  | 0.470  |
| Right knee flexors   | Pre   | 1.31±0.12 | 1.31±0.12 | 0.003       | 0.956  | 0.000  |
|                      | Post  | 1.51±0.16 | 1.31±0.13 | 8.967       | 0.008* | 0.333  |
|                      | Δ (%) | 14.95     | -0.58     |             |        |        |
|                      |       |           |           | interaction | group  | Time   |
|                      | P     | 0.000*    | 0.766     | 0.000*      | 0.106  | 0.000* |
| Right knee extensors | ES    | 0.751     | 0.005     | 0.621       | 0.139  | 0.582  |
|                      | Pre   | 2.53±0.23 | 2.43±0.25 | 0.929       | 0.348  | 0.049  |
|                      | Post  | 2.76±0.19 | 2.44±0.26 | 9.579       | 0.006* | 0.347  |
|                      | Δ (%) | 9.56      | 0.60      |             |        |        |
|                      |       |           |           | interaction | group  | Time   |
| Left ankle flexors   | P     | 0.000*    | 0.767     | 0.007*      | 0.048  | 0.003* |
|                      | ES    | 0.537     | 0.005     | 0.336       | 0.200  | 0.397  |
|                      | Pre   | 1.80±0.32 | 1.80±0.15 | 0.000       | 0.986  | 0.000  |
|                      | Post  | 1.81±0.32 | 1.80±0.15 | 0.014       | 0.907  | 0.001  |
|                      | Δ (%) | 0.81      | 0.15      |             |        |        |
| Left ankle extensors |       |           |           | interaction | group  | Time   |
|                      | P     | 0.531     | 0.923     | 0.707       | 0.947  | 0.609  |
|                      | ES    | 0.022     | 0.001     | 0.008       | 0.000  | 0.015  |
|                      | Pre   | 0.47±0.10 | 0.46±0.12 | 0.051       | 0.824  | 0.003  |
|                      | Post  | 0.50±0.08 | 0.47±0.12 | 2.64        | 0.613  | 0.014  |
| Right ankle flexors  | Δ (%) | 7.72      | 3.56      |             |        |        |
|                      |       |           |           | interaction | group  | Time   |
|                      | P     | 0.060     | 0.284     | 0.533       | 0.712  | 0.041  |
|                      | ES    | 0.182     | 0.064     | 0.022       | 0.008  | 0.212  |
|                      | Pre   | 1.74±0.24 | 1.72±0.34 | 0.010       | 0.922  | 0.001  |
| Right ankle flexors  | Post  | 1.77±0.22 | 1.77±0.31 | 0.000       | 0.994  | 0.000  |
|                      | Δ (%) | 2.01      | 2.89      |             |        |        |
|                      |       |           |           | interaction | group  | Time   |
|                      | P     | 0.316     | 0.166     | 0.774       | 0.956  | 0.097  |

|                                       |       |           |           |             |        |       |
|---------------------------------------|-------|-----------|-----------|-------------|--------|-------|
|                                       | ES    | 0.056     | 0.104     | 0.005       | 0.000  | 0.145 |
|                                       | Pre   | 0.45±0.10 | 0.42±0.07 | 0.735       | 0.403  | 0.039 |
|                                       | Post  | 0.49±0.13 | 0.44±0.10 | 1.323       | 0.265  | 0.068 |
| Right ankle extensors                 | Δ (%) | 9.30      | 2.93      |             |        |       |
|                                       |       |           |           | interaction | group  | Time  |
|                                       | P     | 0.040     | 0.418     | 0.341       | 0.304  | 0.045 |
|                                       | ES    | 0.214     | 0.037     | 0.050       | 0.059  | 0.204 |
| <b>Relative Average Power (Nm/kg)</b> |       |           |           |             |        |       |
|                                       | Pre   | 1.14±0.15 | 1.05±0.24 | 1.014       | 0.327  | 0.053 |
|                                       | Post  | 1.33±0.09 | 1.11±0.23 | 7.799       | 0.012* | 0.302 |
| Left hip flexors                      | Δ (%) | 17.28     | 5.66      |             |        |       |
|                                       |       |           | effect    | interaction | group  | Time  |
|                                       | P     | 0.000*    | 0.064     | 0.004*      | 0.075  | 0.000 |
|                                       | ES    | 0.709     | 0.178     | 0.374       | 0.166  | 0.672 |
|                                       | Pre   | 3.27±0.47 | 3.16±0.50 | 0.240       | 0.630  | 0.013 |
|                                       | Post  | 3.70±0.54 | 3.19±0.49 | 5.033       | 0.038* | 0.218 |
| Left hip extensors                    | Δ (%) | 14.05     | 0.93      |             |        |       |
|                                       |       |           |           | interaction | group  | Time  |
|                                       | P     | 0.000*    | 0.769     | 0.005*      | 0.164  | 0.002 |
|                                       | ES    | 0.562     | 0.005     | 0.361       | 0.105  | 0.420 |
|                                       | Pre   | 1.07±0.11 | 1.11±0.13 | 0.523       | 0.479  | 0.028 |
|                                       | Post  | 1.32±0.18 | 1.13±0.13 | 7.149       | 0.015* | 0.284 |
| Right hip flexors                     | Δ (%) | 23.81     | 2.19      |             |        |       |
|                                       |       |           |           | interaction | group  | Time  |
|                                       | P     | 0.000*    | 0.457     | 0.000*      | 0.226  | 0.000 |
|                                       | ES    | 0.797     | 0.031     | 0.619       | 0.080  | 0.700 |
|                                       | Pre   | 3.11±0.31 | 3.19±0.34 | 0.281       | 0.603  | 0.015 |
|                                       | Post  | 3.60±0.48 | 3.20±0.32 | 4.872       | 0.041  | 0.213 |
| Right hip extensors                   | Δ (%) | 15.81     | 0.45      |             |        |       |
|                                       |       |           |           | interaction | group  | Time  |
|                                       | P     | 0.000*    | 0.893     | 0.001*      | 0.001  | 0.001 |
|                                       | ES    | 0.630     | 0.001     | 0.447       | 0.438  | 0.472 |
| Left knee flexors                     | Pre   | 1.15±0.08 | 1.10±0.18 | 0.592       | 0.451  | 0.032 |
|                                       | Post  | 1.29±0.06 | 1.14±0.20 | 5.105       | 0.037* | 0.221 |

|                      |              |           |           |             |        |       |
|----------------------|--------------|-----------|-----------|-------------|--------|-------|
|                      | $\Delta$ (%) | 13.19     | 4.17      |             |        |       |
|                      |              |           |           | interaction | group  | Time  |
|                      | P            | 0.000*    | 0.037     | 0.003*      | 0.133  | 0.000 |
|                      | ES           | 0.735     | 0.221     | 0.391       | 0.121  | 0.707 |
| Left knee extensors  | Pre          | 1.82±0.20 | 1.66±0.25 | 2.539       | 0.128  | 0.124 |
|                      | Post         | 1.96±0.19 | 1.68±0.22 | 9.712       | 0.006* | 0.350 |
|                      | $\Delta$ (%) | 8.16      | 1.57      |             |        |       |
|                      |              |           |           | interaction | group  | Time  |
|                      | P            | 0.000*    | 0.476     | 0.005*      | 0.030  | 0.001 |
|                      | ES           | 0.601     | 0.029     | 0.358       | 0.236  | 0.495 |
| Right knee flexors   | Pre          | 1.02±0.12 | 1.01±0.13 | 0.011       | 0.916  | 0.001 |
|                      | Post         | 1.12±0.07 | 1.04±0.09 | 4.953       | 0.039* | 0.216 |
|                      | $\Delta$ (%) | 10.58     | 3.07      |             |        |       |
|                      |              |           |           | interaction | group  | Time  |
|                      | P            | 0.000*    | 0.225     | 0.017*      | 0.353  | 0.000 |
|                      | ES           | 0.579     | 0.081     | 0.278       | 0.048  | 0.519 |
| Right knee extensors | Pre          | 1.71±0.23 | 1.63±0.20 | 0.751       | 0.398  | 0.040 |
|                      | Post         | 1.92±0.20 | 1.67±0.21 | 7.416       | 0.014* | 0.292 |
|                      | $\Delta$ (%) | 12.72     | 2.78      |             |        |       |
|                      |              |           |           | interaction | group  | Time  |
|                      | P            | 0.000*    | 0.123     | 0.000*      | 0.089  | 0.000 |
|                      | ES           | 0.765     | 0.127     | 0.502       | 0.152  | 0.704 |
| Left ankle flexors   | Pre          | 1.11±0.25 | 1.11±0.19 | 0.001       | 0.976  | 0.000 |
|                      | Post         | 1.29±0.23 | 1.12±0.17 | 3.249       | 0.088  | 0.153 |
|                      | $\Delta$ (%) | 17.96     | 1.89      |             |        |       |
|                      |              |           |           | interaction | group  | Time  |
|                      | P            | 0.000*    | 0.599     | 0.002*      | 0.378  | 0.000 |
|                      | ES           | 0.636     | 0.016     | 0.417       | 0.044  | 0.512 |
| Left ankle extensors | Pre          | 0.37±0.07 | 0.38±0.08 | 0.047       | 0.832  | 0.003 |
|                      | Post         | 0.42±0.05 | 0.39±0.09 | 1.359       | 0.259  | 0.070 |
|                      | $\Delta$ (%) | 16.88     | 2.64      |             |        |       |
|                      |              |           |           | interaction | group  | Time  |
|                      | P            | 0.000*    | 0.370     | 0.018*      | 0.634  | 0.001 |
|                      | ES           | 0.540     | 0.045     | 0.273       | 0.013  | 0.458 |

|                                            |       |            |            |             |        |       |
|--------------------------------------------|-------|------------|------------|-------------|--------|-------|
| Right ankle flexors                        | Pre   | 1.10±0.10  | 1.09±0.13  | 0.003       | 0.956  | 0.000 |
|                                            | Post  | 1.21±0.08  | 1.10±0.13  | 5.424       | 0.032* | 0.232 |
|                                            | Δ (%) | 10.93      | 0.64       |             |        |       |
|                                            |       |            |            | interaction | group  | Time  |
|                                            | P     | 0.000*     | 0.750      | 0.001       | 0.260  | 0.000 |
|                                            | ES    | 0.678      | 0.006      | 0.486       | 0.070  | 0.539 |
| Right ankle extensors                      | Pre   | 0.35±0.08  | 0.35±0.07  | 0.000       | 1.000  | 0.000 |
|                                            | Post  | 0.40±0.07  | 0.36±0.07  | 1.847       | 0.191  | 0.093 |
|                                            | Δ (%) | 16.72      | 3.30       |             |        |       |
|                                            |       |            |            | interaction | group  | Time  |
|                                            | P     | 0.000*     | 0.398      | 0.025*      | 0.505  | 0.002 |
|                                            | ES    | 0.510      | 0.004      | 0.250       | 0.025  | 0.429 |
| <b>50-100ms Rate of torque development</b> |       |            |            |             |        |       |
| Left hip flexors                           | Pre   | 7.79±0.90  | 7.94±0.89  | 0.139       | 0.714  | 0.008 |
|                                            | Post  | 8.86±0.73  | 8.00±0.88  | 5.755       | 0.027  | 0.242 |
|                                            | Δ (%) | 14.23      | 0.84       |             |        |       |
|                                            |       |            | effect     | interaction | group  | Time  |
|                                            | P     | 0.000*     | 0.548      | 0.000*      | 0.352  | 0.000 |
|                                            | ES    | 0.886      | 0.020      | 0.741       | 0.048  | 0.782 |
| Left hip extensors                         | Pre   | 19.58±4.01 | 19.74±2.95 | 0.010       | 0.920  | 0.001 |
|                                            | Post  | 23.01±3.51 | 19.52±2.98 | 5.747       | 0.028* | 0.242 |
|                                            | Δ (%) | 19.77      | -1.08      |             |        |       |
|                                            |       |            |            | interaction | group  | Time  |
|                                            | P     | 0.000*     | 0.753      | 0.001*      | 0.263  | 0.003 |
|                                            | ES    | 0.593      | 0.006      | 0.451       | 0.069  | 0.390 |
| Right hip flexors                          | Pre   | 7.67±1.36  | 7.67±0.72  | 0.000       | 0.994  | 0.000 |
|                                            | Post  | 8.87±1.51  | 7.72±0.77  | 4.566       | 0.047* | 0.202 |
|                                            | Δ (%) | 16.33      | 0.63       |             |        |       |
|                                            |       |            |            | interaction | group  | Time  |
|                                            | P     | 0.000*     | 0.777      | 0.000*      | 0.264  | 0.000 |
|                                            | ES    | 0.701      | 0.005      | 0.517       | 0.069  | 0.561 |
| Right hip extensors                        | Pre   | 18.28±3.23 | 18.55±4.57 | 0.024       | 0.878  | 0.001 |
|                                            | Post  | 22.57±4.31 | 18.34±4.38 | 4.727       | 0.043  | 0.208 |
|                                            | Δ (%) | 24.25      | -0.99%     |             |        |       |

|                      |       |            |           | interaction | group  | Time  |
|----------------------|-------|------------|-----------|-------------|--------|-------|
|                      | P     | 0.000*     | 0.752     | 0.000*      | 0.286  | 0.000 |
|                      | ES    | 0.696      | 0.006     | 0.558       | 0.063  | 0.509 |
| Left knee flexors    | Pre   | 6.87±0.72  | 6.89±0.89 | 0.006       | 0.941  | 0.000 |
|                      | Post  | 7.85±1.06  | 6.90±0.96 | 4.472       | 0.049* | 0.199 |
|                      | Δ (%) | 14.50      | -0.01     |             |        |       |
|                      |       |            |           | interaction | group  | Time  |
|                      | P     | 0.000*     | 0.971     | 0.001*      | 0.253  | 0.000 |
|                      | ES    | 0.667      | 0.000     | 0.498       | 0.072  | 0.504 |
| Left knee extensors  | Pre   | 9.30±2.41  | 9.41±1.22 | 0.017       | 0.899  | 0.001 |
|                      | Post  | 11.11±1.96 | 9.40±1.16 | 5.609       | 0.029* | 0.238 |
|                      | Δ (%) | 23.53      | 0.04      |             |        |       |
|                      |       |            |           | interaction | group  | Time  |
|                      | P     | 0.000*     | 0.989     | 0.000*      | 0.311  | 0.000 |
|                      | ES    | 0.696      | 0.000     | 0.535       | 0.057  | 0.533 |
| Right knee flexors   | Pre   | 6.65±0.59  | 6.83±0.36 | 0.667       | 0.425  | 0.036 |
|                      | Post  | 7.42±0.40  | 6.82±0.34 | 13.053      | 0.002* | 0.420 |
|                      | Δ (%) | 12.31      | -0.14     |             |        |       |
|                      |       |            |           | interaction | group  | Time  |
|                      | P     | 0.000*     | 0.940     | 0.001*      | 0.217  | 0.002 |
|                      | ES    | 0.615      | 0.000     | 0.451       | 0.083  | 0.437 |
| Right knee extensors | Pre   | 9.39±1.59  | 9.14±1.01 | 0.180       | 0.676  | 0.01  |
|                      | Post  | 10.96±1.15 | 9.01±0.92 | 17.542      | 0.001* | 0.494 |
|                      | Δ (%) | 18.51      | -1.28     |             |        |       |
|                      |       |            |           | interaction | group  | Time  |
|                      | P     | 0.000*     | 0.633     | 0.000*      | 0.040  | 0.001 |
|                      | ES    | 0.652      | 0.013     | 0.524       | 0.213  | 0.441 |
| Left ankle flexors   | Pre   | 4.67±0.56  | 4.62±0.62 | 0.043       | 0.839  | 0.002 |
|                      | Post  | 5.33±0.75  | 4.72±0.50 | 4.606       | 0.046* | 0.204 |
|                      | Δ (%) | 14.56      | 2.74      |             |        |       |
|                      |       |            |           | interaction | group  | Time  |
|                      | P     | 0.000*     | 0.448     | 0.008*      | 0.213  | 0.001 |
|                      | ES    | 0.580      | 0.032     | 0.330       | 0.085  | 0.480 |

|                         |       |            |            |             |        |       |
|-------------------------|-------|------------|------------|-------------|--------|-------|
| Left ankle extensors    | Pre   | 1.61±0.31  | 1.61±0.34  | 0.003       | 0.956  | 0.000 |
|                         | Post  | 1.91±0.28  | 1.63±0.30  | 4.587       | 0.046* | 0.203 |
|                         | Δ (%) | 20.18      | 1.42       |             |        |       |
|                         |       |            |            | interaction | group  | Time  |
|                         | P     | 0.000*     | 0.811      | 0.001*      | 0.318  | 0.001 |
|                         | ES    | 0.634      | 0.003      | 0.442       | 0.055  | 0.486 |
| Right ankle flexors     | Pre   | 4.86±0.56  | 4.77±0.55  | 0.144       | 0.709  | 0.008 |
|                         | Post  | 5.49±0.70  | 4.84±0.50  | 5.709       | 0.028* | 0.241 |
|                         | Δ (%) | 13.38      | 1.73       |             |        |       |
|                         |       |            |            | interaction | group  | Time  |
|                         | P     | 0.000*     | 0.567      | 0.006*      | 0.146  | 0.001 |
|                         | ES    | 0.577      | 0.019      | 0.347       | 0.114  | 0.460 |
| Right ankle extensors   | Pre   | 1.71±0.55  | 1.71±0.29  | 0.000       | 1.000  | 0.000 |
|                         | Post  | 1.95±0.61  | 1.72±0.23  | 1.246       | 0.279  | 0.065 |
|                         | Δ (%) | 14.82      | 0.83       |             |        |       |
|                         |       |            |            | interaction | group  | Time  |
|                         | P     | 0.001*     | 0.931      | 0.010*      | 0.564  | 0.008 |
|                         | ES    | 0.489      | 0.000      | 0.315       | 0.019  | 0.333 |
| <b>Jump Performance</b> |       |            |            |             |        |       |
| CMJ height (cm)         | Pre   | 42.85±2.79 | 42.49±2.58 | 0.090       | 0.768  | 0.005 |
|                         | Post  | 45.44±2.89 | 42.82±2.46 | 4.774       | 0.042  | 0.210 |
|                         | Δ (%) | 6.09       | 0.81       |             |        |       |
|                         |       |            |            | interaction | group  | Time  |
|                         | P     | 0.000*     | 0.303      | 0.000*      | 0.223  | 0.000 |
|                         | ES    | 0.794      | 0.059      | 0.595       | 0.081  | 0.710 |
| SJ height (cm)          | Pre   | 38.87±2.38 | 38.85±2.53 | 0.000       | 0.986  | 0.000 |
|                         | Post  | 39.38±2.12 | 39.39±2.40 | 0.000       | 0.992  | 0.000 |
|                         | Δ (%) | 1.40       | 1.43       |             |        |       |
|                         |       |            |            | interaction | group  | Time  |
|                         | P     | 0.169      | 0.147      | 0.953       | 0.996  | 0.051 |
|                         | ES    | 0.102      | 0.113      | 0.000       | 0.000  | 0.195 |
| EUR                     | Pre   | 1.10±0.02  | 1.09±0.03  | 0.688       | 0.418  | 0.037 |
|                         | Post  | 1.15±0.04  | 1.09±0.02  | 20.882      | 0.000* | 0.537 |
|                         | Δ (%) | 4.72       | -0.59      |             |        |       |

|                            |       |             |             |             |       |       |
|----------------------------|-------|-------------|-------------|-------------|-------|-------|
|                            |       |             |             | interaction | group | Time  |
|                            | P     | 0.000*      | 0.541       | 0.001*      | 0.001 | 0.010 |
|                            | ES    | 0.553       | 0.021       | 0.442       | 0.455 | 0.318 |
| <b>1RM Test</b>            |       |             |             |             |       |       |
| Back Squat 1RM             | Pre   | 94.25±9.28  | 91.75±11.55 | 0.285       | 0.600 | 0.016 |
|                            | Post  | 98.75±9.15  | 92.95±12.01 | 1.476       | 0.240 | 0.076 |
|                            | Δ (%) | 4.90        | 1.30        |             |       |       |
|                            |       |             |             | interaction | group | Time  |
|                            | P     | 0.000*      | 0.239       | 0.029*      | 0.387 | 0.001 |
|                            | ES    | 0.537       | 0.076       | 0.238       | 0.042 | 0.482 |
| Deadlift 1RM               | Pre   | 109.75±9.16 | 108.25±9.28 | 0.132       | 0.720 | 0.007 |
|                            | Post  | 116.50±8.83 | 110.30±9.81 | 2.206       | 0.155 | 0.109 |
|                            | Δ (%) | 6.24        | 1.94        |             |       |       |
|                            |       |             |             | interaction | group | Time  |
|                            | P     | 0.000*      | 0.094       | 0.010*      | 0.356 | 0.000 |
|                            | ES    | 0.654       | 0.148       | 0.314       | 0.047 | 0.616 |
| <b>Y-Balance Test (cm)</b> |       |             |             |             |       |       |
| Left ANT                   | Pre   | 62.70±4.69  | 60.20±3.29  | 1.902       | 0.185 | 0.096 |
|                            | Post  | 62.70±4.88  | 60.60±3.50  | 1.223       | 0.283 | 0.064 |
|                            | Δ (%) | -0.01       | 0.66        |             |       |       |
|                            |       |             |             | interaction | group | Time  |
|                            | P     | 1.000       | 0.227       | 0.388       | 0.228 | 0.388 |
|                            | ES    | 0.000       | 0.080       | 0.042       | 0.080 | 0.042 |
| Left PL                    | Pre   | 108.30±2.83 | 107.00±1.70 | 1.550       | 0.229 | 0.079 |
|                            | Post  | 108.80±3.01 | 107.80±1.62 | 0.856       | 0.367 | 0.045 |
|                            | Δ (%) | 0.46        | 0.76        |             |       |       |
|                            |       |             |             | interaction | group | Time  |
|                            | P     | 0.237       | 0.066       | 0.610       | 0.276 | 0.037 |
|                            | ES    | 0.077       | 0.175       | 0.015       | 0.066 | 0.219 |
| Left PM                    | Pre   | 105.50±3.54 | 105.20±2.94 | 0.043       | 0.839 | 0.002 |
|                            | Post  | 106.10±4.15 | 105.60±2.46 | 0.108       | 0.747 | 0.006 |
|                            | Δ (%) | 0.56        | 0.40        |             |       |       |
|                            |       |             |             | interaction | group | Time  |
|                            | P     | 0.109       | 0.276       | 0.696       | 0.788 | 0.062 |

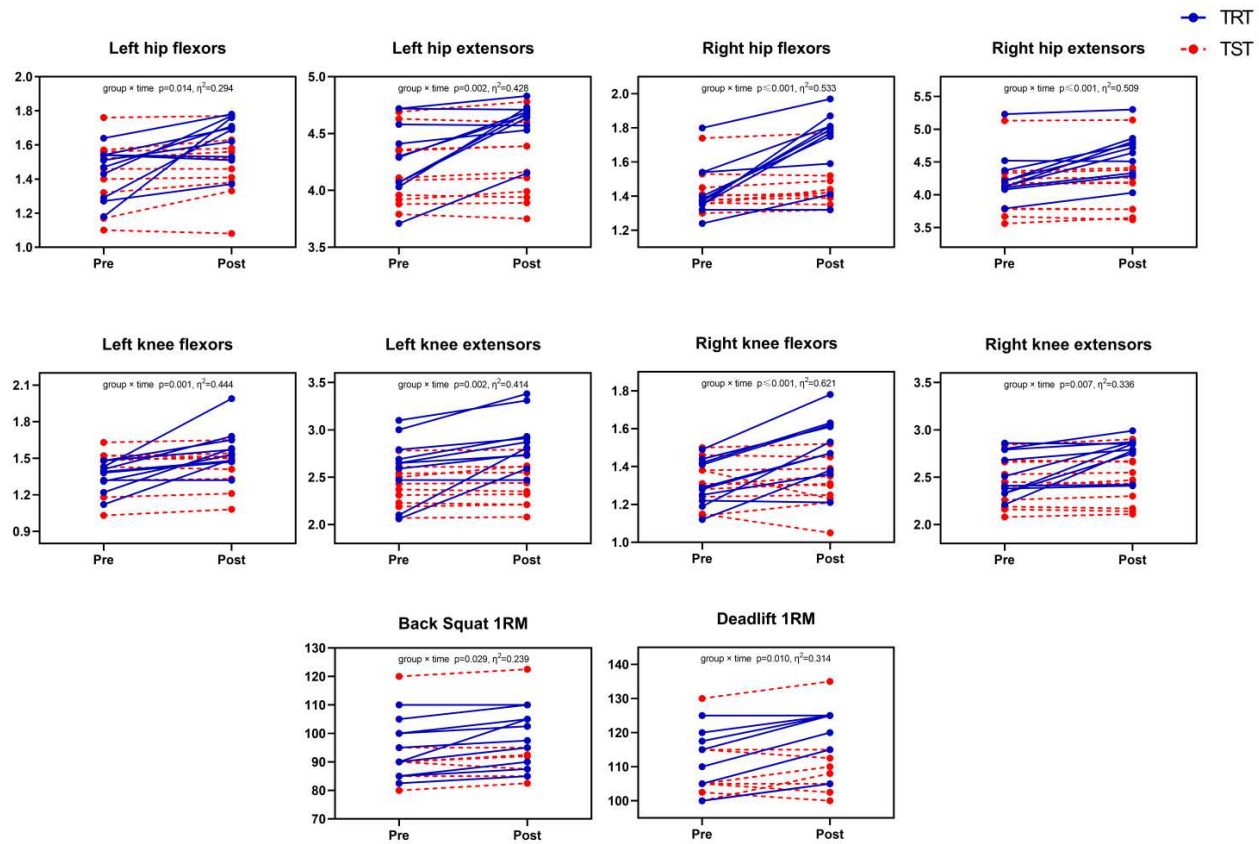
|                                      |                     |               |               |             |       |       |
|--------------------------------------|---------------------|---------------|---------------|-------------|-------|-------|
|                                      | ES                  | 0.136         | 0.066         | 0.009       | 0.004 | 0.180 |
| Left composite scores                | Pre                 | 101.62%±3.86% | 100.76%±3.37% | 0.284       | 0.600 | 0.016 |
|                                      | Post                | 102.02%±3.81% | 101.35%±3.59% | 0.163       | 0.691 | 0.009 |
|                                      | Δ (%)               | 0.40          | 0.59          |             |       |       |
|                                      |                     |               |               | interaction | group | Time  |
|                                      | P                   | 0.114         | 0.024         | 0.579       | 0.644 | 0.009 |
|                                      | ES                  | 0.133         | 0.253         | 0.284       | 0.600 | 0.016 |
| Right ANT                            | Pre                 | 63.70±4.83    | 62.30±2.45    | 0.668       | 0.425 | 0.036 |
|                                      | Post                | 63.80±4.21    | 62.50±2.46    | 0.710       | 0.410 | 0.038 |
|                                      | Δ (%)               | 0.24          | 0.33          |             |       |       |
|                                      |                     |               |               | interaction | group | Time  |
|                                      | P                   | 0.770         | 0.561         | 0.836       | 0.413 | 0.538 |
|                                      | ES                  | 0.005         | 0.019         | 0.002       | 0.037 | 0.021 |
| Right PL                             | Pre                 | 108.30±2.41   | 107.90±2.08   | 0.158       | 0.695 | 0.009 |
|                                      | Post                | 108.30±2.16   | 107.70±1.70   | 0.475       | 0.499 | 0.026 |
|                                      | Δ (%)               | 0.01          | -0.17         |             |       |       |
|                                      |                     |               |               | interaction | group | Time  |
|                                      | P                   | 1.000         | 0.689         | 0.777       | 0.574 | 0.777 |
|                                      | ES                  | 0.000         | 0.009         | 0.005       | 0.018 | 0.005 |
| Right PM                             | Pre                 | 105.80±2.90   | 106.10±2.28   | 0.066       | 0.800 | 0.004 |
|                                      | Post                | 106.00±3.40   | 106.50±2.68   | 0.134       | 0.719 | 0.007 |
|                                      | Δ (%)               | 0.19          | 0.37          |             |       |       |
|                                      |                     |               |               | interaction | group | Time  |
|                                      | P                   | 0.641         | 0.355         | 0.741       | 0.750 | 0.328 |
|                                      | ES                  | 0.012         | 0.048         | 0.006       | 0.006 | 0.053 |
| Right composite scores               | Pre                 | 102.12%±4.45% | 102.23%±4.06% | 0.003       | 0.956 | 0.000 |
|                                      | Post                | 102.22%±3.85% | 102.37%±4.00% | 0.007       | 0.933 | 0.000 |
|                                      | Δ (%)               | 0.12          | 0.14          |             |       |       |
|                                      |                     |               |               | interaction | group | Time  |
|                                      | P                   | 0.765         | 0.664         | 0.923       | 0.945 | 0.605 |
|                                      | S (η <sup>2</sup> ) | 0.005         | 0.011         | 0.001       | 0.000 | 0.015 |
| <b>200-m sprint performance Tset</b> |                     |               |               |             |       |       |
|                                      | Pre                 | 4.28±0.06     | 4.29±0.06     | 0.348       | 0.563 | 0.019 |
|                                      | Post                | 4.29±0.08     | 4.29±0.06     | 0.013       | 0.911 | 0.001 |

|                                  |              |                  |                  |             |       |       |
|----------------------------------|--------------|------------------|------------------|-------------|-------|-------|
| 200M average boat<br>speed (M/S) | $\Delta$ (%) | 0.28             | 0.01             |             |       |       |
|                                  |              |                  |                  | interaction | group | Time  |
|                                  | P            | 0.415            | 0.990            | 0.568       | 0.730 | 0.556 |
|                                  | ES           | 0.037            | 0.000            | 0.018       | 0.007 | 0.020 |
| 200M result (s)                  | Pre          | 46.78 $\pm$ 0.65 | 46.61 $\pm$ 0.64 | 0.345       | 0.564 | 0.019 |
|                                  | Post         | 46.65 $\pm$ 0.83 | 46.61 $\pm$ 0.70 | 0.015       | 0.903 | 0.001 |
|                                  | $\Delta$ (%) | -0.27            | 0                |             |       |       |
|                                  |              |                  |                  | interaction | group | Time  |
|                                  | P            | 0.434            | 0.998            | 0.580       | 0.725 | 0.578 |
|                                  | ES           | 0.034            | 0.000            | 0.017       | 0.007 | 0.018 |

215 **Lower Limb Maximum Strength**

216 Significant group  $\times$  time interactions were observed for the relative peak torque of the bilateral hip  
217 and knee flexors and extensors, as well as for the 1RM back squat and 1RM deadlift (all  $p < 0.05$ ,  
218 partial  $\eta^2 = 0.238$ – $0.621$ ). No significant between-group differences were observed at baseline (all  
219  $p > 0.05$ ). Post hoc simple effects analyses demonstrated that only the TRT group exhibited  
220 significant improvements in all lower-limb maximal strength variables following the intervention (all  
221  $p < 0.05$ ), with percentage increases ranging from 4.90% to 16.82%, corresponding to large effect  
222 sizes (Cohen's  $d = 1.060$ – $2.428$ ). No significant pre- to post-intervention changes were observed in  
223 the TST group (all  $p > 0.05$ ) (Figure 1).

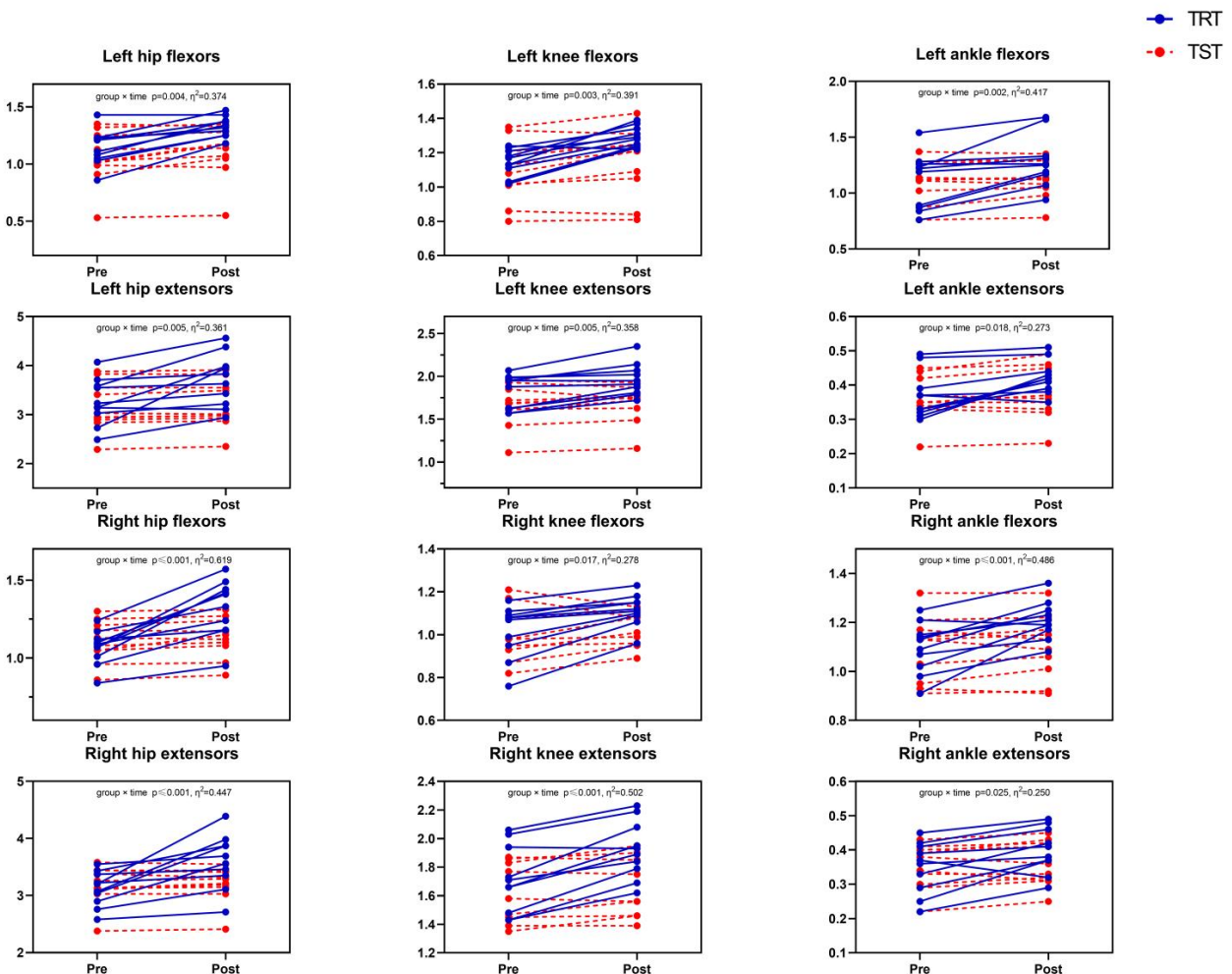
224 **FIGURE 1**



## Lower Limb Muscle Power

Significant group  $\times$  time interactions were observed for the average relative power of the bilateral hip, knee, and ankle flexors and extensors (all  $p < 0.05$ ,  $\eta^2 = 0.250$ – $0.619$ ). No significant between-group differences were observed at baseline (all  $p > 0.05$ ). Post hoc simple effects analyses demonstrated that only the TRT group exhibited significant improvements across all lower-limb explosive strength measures, with percentage increases ranging from 8.16% to 23.81% and large effect sizes (Cohen's  $d = 1.095$ – $2.417$ ). In contrast, no significant changes were observed in the TSR group (all  $p > 0.05$ ). No significant between-group differences were found at baseline for any outcome (all  $p > 0.05$ )(Figure 2).

FIGURE 2

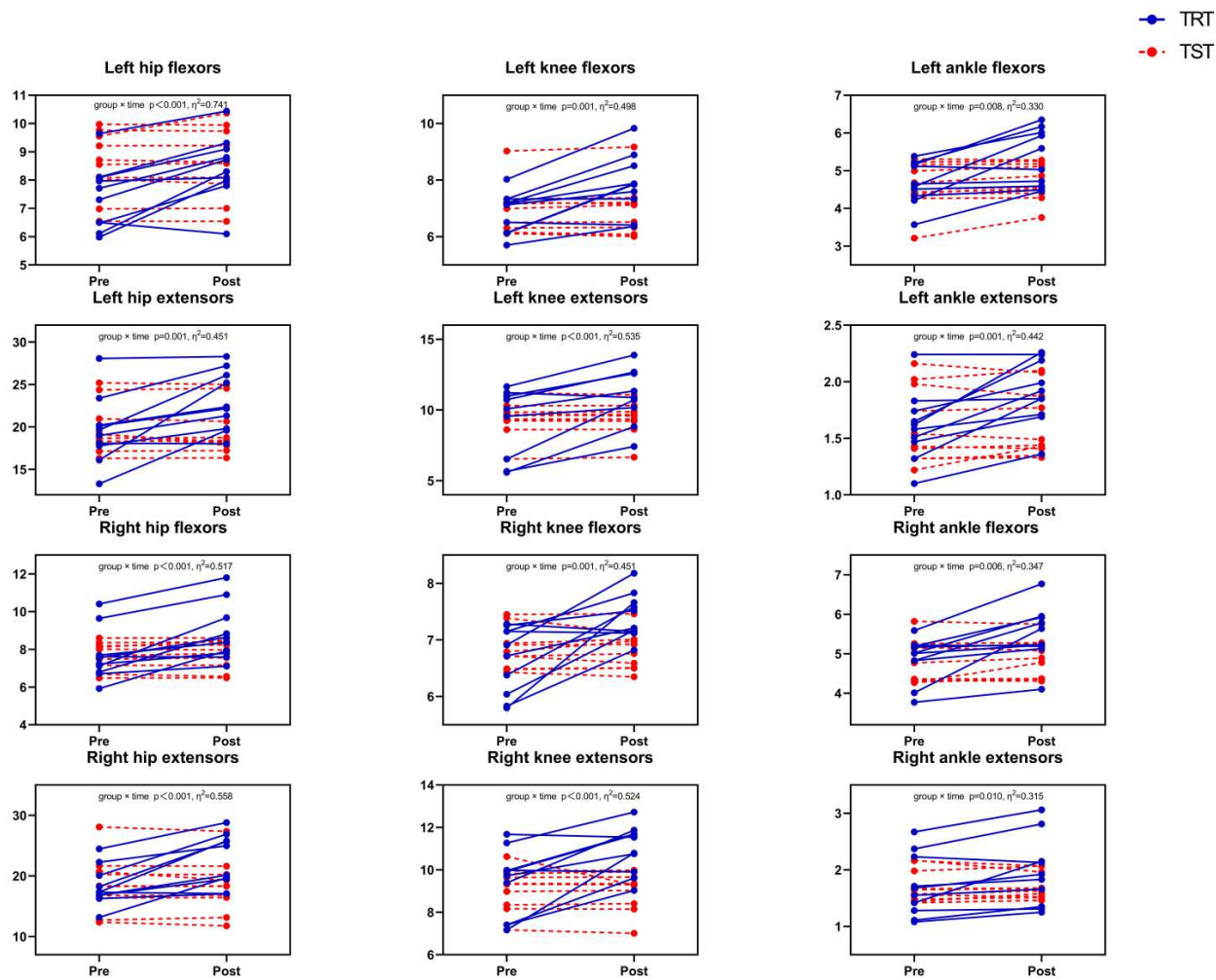


237 **Lower Limb Explosive Strength**

238 Significant group  $\times$  time interactions were observed for the torque development slope during the 50–  
239 100 ms interval of the bilateral hip, knee, and ankle flexors and extensors, as well as for CMJ height  
240 and EUR (all  $p < 0.05$ ,  $\eta^2 = 0.315\text{--}0.741$ ). No significant between-group differences were observed  
241 at baseline (all  $p > 0.05$ ). Post hoc simple effects analyses demonstrated that only the TRT group  
242 exhibited significant improvements across all lower-limb explosive strength measures, with  
243 percentage increases ranging from 4.72% to 24.25% and large effect sizes (Cohen's  $d = 1.286\text{--}$   
244 3.212). In contrast, no significant changes were observed in the TSR group (all  $p > 0.05$ ). No  
245 significant between-group differences were found at baseline for any outcome (all  $p > 0.05$ )(Figure

246 3).

247 FIGURE 3



248

## **Lower Limb balance ability and 200-m sprint performance**

No significant group  $\times$  time interactions were observed for dynamic balance or 200-m sprint performance. For dynamic balance, both groups demonstrated anterior reach asymmetry of  $<4$  cm and posteromedial and posterolateral reach asymmetries of  $<6$  cm under both left and right stance conditions at pre- and post-intervention assessments. Accordingly, no participants in either group were classified as being at elevated risk of injury before or after the intervention.

## **Discussion**

This study examined the effects of a 9-week triphasic resistance training program on lower-limb strength, dynamic balance, and sport performance in elite female sprint canoe athletes. The results showed that triphasic resistance training produced greater improvements than traditional resistance training in lower-limb strength outcomes, including maximal strength, muscle power, and explosive strength,. However, neither group showed significant changes in dynamic balance, 200-m sprint performance, or average boat velocity after the intervention.

## **Maximal Strength**

The 9-week triphasic resistance training program significantly improved 1RM squat, 1RM deadlift, and relative peak torque of the hip and knee flexor muscles in the present study. Previous studies have reported that eccentric, isometric, and concentric resistance training can increase muscle cross-sectional area (CSA) and maximal strength, which may contribute to improvements in lower-limb strength [25-27].The 1RM test reflects overall lower-limb strength but does not provide information on muscle function at specific joints. Therefore, combining 1RM testing with relative peak torque assessment may provide a more complete evaluation of lower-limb maximal strength [28].

The TRT program applied different movement tempos across the three training phases, with an emphasis on eccentric, isometric, and concentric muscle actions. Both groups completed the same exercises and followed similar training volume, relative intensity, training frequency, and rest

intervals. Therefore, the main difference between the two programs was the prescribed movement tempo. The greater improvements observed in the TRT group may be related to the phase-specific manipulation of movement tempo, which represents the main feature of the triphasic resistance training model compared with traditional resistance training.

The present study found no significant changes in bilateral ankle flexor or extensor relative peak torque after the triphasic resistance training intervention. This result may be related to the characteristics of the training program, which mainly included lower-body multi-joint resistance exercises. During these exercises, the hip and knee joints usually receive greater mechanical loading within the kinetic chain, while the ankle joint mainly contributes to force transmission and dynamic stabilization [29, 30]. Therefore, the ankle muscles may have received a smaller training stimulus, which could explain the lack of improvement in ankle maximal strength. The results also indicate that ankle strength adaptations may depend on exercise specificity and may require additional targeted ankle resistance training [29, 31]. In sprint canoeing, force production during the catch, drive, and recovery phases mainly involves the hip and knee joints. The relatively limited ankle range of motion may reduce the training stimulus received by the ankle musculature [32].

### **Muscle Power and Explosive Strength**

The TRT group showed greater improvements in relative average power, RTD50–100, CMJ height, and EUR compared with the TST group in elite female sprint canoe athletes. Previous studies have also shown that resistance training, isometric training, and plyometric training can improve muscle power and explosive strength in athletes [2, 33].

Previous research has shown a strong positive relationship between maximal strength and explosive strength [34]. Explosive strength is also influenced by maximal strength and muscle contraction velocity [35, 36]. In the present study, the improvements in maximal strength were accompanied by

296 similar improvements in explosive strength. The increase in relative average power further suggests  
297 that TRT improved the athletes' ability to generate mechanical power during dynamic muscle  
298 contractions.

299 The triphasic resistance training model uses different movement tempos to emphasize eccentric,  
300 isometric, and concentric muscle actions across separate training phases. Previous studies have  
301 reported that eccentric training may improve muscle hypertrophy and force production [37, 38].  
302 Isometric training has also been associated with changes in tendon structure and improvements in  
303 explosive power [39, 40]. In addition, concentric training with explosive movements may enhance  
304 muscle activation, recruit high-threshold motor units, and promote muscle fiber hypertrophy [41-  
305 43]. These training characteristics may help explain the greater improvements in maximal strength,  
306 muscle power, and explosive strength observed in the TRT group compared with the TST group.

307 Although RTD50–100 of the hip, knee, and ankle flexor and extensor muscles, as well as CMJ height  
308 and EUR, significantly increased after the intervention, SJ height did not show a significant change.  
309 Kozinc et al. [44] reported a significant negative correlation between EUR, SJ height, and RFD ( $r =$   
310  $-0.41$ ) in a cross-sectional study involving 313 athletes. Their findings suggested that a higher EUR  
311 may be related to lower concentric strength during the SJ rather than improved SSC function.

312 Another possible explanation is that CMJ and SJ may respond differently to the same training  
313 stimulus. Suchomel et al. [45] also observed different response patterns between SJ and CMJ during  
314 a 10-week training intervention. Wlodarczyk et al. [46] reported that SJ and CMJ height significantly  
315 increased from the preparation phase to the competition phase in 10 elite sprinters, whereas EUR  
316 remained unchanged. These findings indicate that SJ, CMJ, and EUR may have different adaptive  
317 responses following training. In addition, the increase in EUR observed in the present study may be  
318 explained by the calculation method of EUR. Because EUR is calculated from CMJ height  
319 (numerator) and SJ height (denominator), an increase in CMJ height without a corresponding change

320 in SJ height can result in a higher EUR. This interpretation is consistent with previous research [44,  
321 47, 48].

### 322 **Dynamic Balance**

323 Neither the TRT group nor the TST group showed significant changes in balance performance after  
324 the intervention. This result differs from previous studies that reported improvements in balance  
325 following resistance training programs [49]. Systematic reviews and meta-analyses have also  
326 suggested that lower-limb resistance training may improve both strength and dynamic balance  
327 performance [50, 51].

328 The difference between the present findings and previous reports may be related to several factors.  
329 Balance performance involves the interaction of multiple components, such as neuromuscular  
330 control, muscular strength, attentional demands, trunk muscle fatigue, and visual regulation [52, 53].  
331 Previous studies have also shown that knee muscle strength explains only a small proportion of the  
332 variation in postural stability (13%-30%), indicating that strength alone may not determine balance  
333 performance [54]. In addition, balance ability is highly dependent on the specific task, and the transfer  
334 of training effects may be influenced by the similarity between the training exercises and the  
335 assessment conditions [55, 56].

336 Previous studies have shown that resistance training can improve strength and sprint performance,  
337 but it may not always result in improvements in balance ability [57, 58]. The participants in the  
338 present study were elite canoe athletes who already demonstrated high baseline levels of balance  
339 performance and postural stability. Therefore, further improvements may have been difficult to detect  
340 due to a possible ceiling effect. The Y-Balance Test, which has been validated for evaluating lower-  
341 limb injury risk in athletes [59], showed that all participants remained within the established  
342 normative ranges throughout the intervention. Specifically, anterior reach asymmetries were below 4

cm, posteromedial and posterolateral asymmetries were below 6 cm, and composite scores remained above 95% at both pre- and post-testing [60]. Although triphasic resistance training did not produce measurable improvements in dynamic balance, it maintained postural stability without increasing lower-limb asymmetry or functional risk indicators.

#### **200-m sprint performance**

Although the TRT group showed greater improvements in lower-limb maximal strength, muscle power, and explosive strength compared with the TST group, neither group showed significant changes in 200-m sprint performance or average boat velocity. The improvements in lower-limb strength observed after triphasic resistance training were not changes in 200-m sprint performance during the 9-week intervention period.

Sprint canoe performance is influenced by multiple factors, including lower-limb propulsion, trunk force transmission, upper-limb paddling capacity, paddling technique, boat stability, energy metabolism, and pacing strategy, rather than relying solely on lower-limb strength [61-63]. Therefore, the improvement in lower-limb strength following TRT may not directly translate into better competitive performance because performance outcomes also depend on technical proficiency and overall athletic capacity.

The strength improvements observed in the present study mainly reflect changes in physical capacity, whereas improvements in competitive performance require the transfer of these adaptations to sport-specific actions. In the current study, the increase in lower-limb strength was not accompanied by measurable improvements in 200-m sprint performance under the experimental conditions. Previous research has suggested that effective transfer of strength adaptations to sport performance may require longer periods of sport-specific practice, which may help athletes further develop neuromuscular control, intermuscular coordination, and canoe-specific movement patterns [12, 64,

65]. Therefore, the improvements in lower-limb strength following TRT may not have been fully converted into more effective paddling propulsion during the 9-week intervention period.

The participants in the present study were elite female sprint canoe athletes with high levels of technical proficiency and competitive ability developed through long-term systematic training. Previous studies have reported that highly trained athletes often show smaller improvements in competitive performance after short-term training interventions compared with less-trained individuals [66, 67]. Thus, although the present intervention improved several physical performance variables, the magnitude of these changes may not have been enough to result in significant improvements in 200-m sprint performance.

Both groups continued the same canoe-specific training program throughout the intervention period. Resistance training was only one part of the overall training program and mainly aimed to improve athletes' physical capacity. However, improvements in competitive performance require the long-term combination of strength development and sport-specific technical training [13, 68]. Previous research has indicated that changes in neuromuscular function may occur before improvements in sport-specific performance [69]. In contrast, meaningful changes in competitive performance often require a longer period of sport-specific training [70]. Therefore, the lack of significant improvements in 200-m sprint performance does not necessarily mean that TRT has limited practical value for sprint canoe athletes. The current findings may instead reflect that the transfer of improved physical capacity to sport-specific performance requires additional time.

Overall, TRT improved lower-limb strength and explosive performance in elite female sprint canoe athletes. However, the 9-week intervention period used in the present study may not have been long enough for these physical improvements to result in measurable changes in 200-m sprint performance.

## **Limitations of the Study**

This study has several limitations. Although the inclusion of elite female canoe athletes is valuable, the relatively small sample size should be considered. Because the intervention was primarily based on manipulating training tempo, blinding of athletes and coaches was not feasible. In addition, multiple outcome measures were assessed, and the possibility of type I error resulting from multiple comparisons should be considered. Given that triphasic training enhanced lower-body strength characteristics (maximal strength, muscle power, and explosive power) in canoe athletes, it may also be applicable to strength- and power-oriented sports, such as track cycling, speed skating, sprinting, and rugby.

## **Conclusion**

Compared with traditional strength training, a 9-week triphasic resistance training was more effective in improving lower-limb maximal strength (1RM back squat, 1RM deadlift, and the relative peak torque of the hip and knee muscles), muscle power (relative average power of the hip, knee, and ankle muscles), and explosive strength (50-100 ms RTD of the hip, knee, and ankle muscles) in elite female sprint canoe athletes. However, no significant improvements were observed in dynamic balance or 200-m sprint performance.

## **Data availability**

The records that were generated and analyzed during the current study are not publicly available due to confidential information about the participants, however, the corresponding author can provide it upon reasonable request.

## **Abbreviations**

TRT:triphasic resistance training

TST:traditional strength training

RTD:Rate of torque development

413 CMJ:Countermovement Jump

414 SJ:Squat Jump

415 EUR:Eccentric Utilization Ratio

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## 627 **Contributions**

628 T.H. and Y.C. designed the study, performed data testing and analysis, and drafted the  
629 manuscript.L.N.,J.L., L.R. and F.R.participated in data analysis, manuscript writing and evaluation.  
630 All authors jointly interpreted the research findings, read and approved the final manuscript, and  
631 agreed to take responsibility for all aspects of this work..

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634 **Ethics declarations**

635 The study protocol received approval from the Ethics Committee of the Affiliated Medical College of  
636 Yunnan University (Approval No. KJK#20250825-R1-038). All participants were familiarized with  
637 the experimental procedures, and players provided written informed consent prior to study  
638 participation. The study was conducted according to the principles of the Declaration of Helsinki.

639 **Consent for publication**

640 Not applicable.

641 **Competing interests**

642 The authors declare no competing interests.

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