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Research article

A Comparative Study of High-Intensity Flywheel Eccentric Training and Traditional Barbell Training on Athletic Performance in Female Basketball Players

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Abstract
Flywheel eccentric training is a type of training that combines concentric and eccentric contractions by creating inertial resistance with a flywheel device. This study compared the effects of high-intensity flywheel eccentric training and traditional barbell training on the anaerobic capacity and lower-limb strength of female college basketball players. Sixteen female Chinese University Basketball League (CUBAL) athletes from a university were recruited and randomly divided into flywheel eccentric training and traditional barbell training groups, with eight athletes in each group. They underwent two training sessions per week for 8 weeks. The athletes were assessed for their anaerobic capacity (blood lactate concentrations, peak anaerobic power, mean anaerobic power, fatigue index, 30-m sprint, T-test, and 17×15-m shuttle run), and lower-limb strength (1RM back squat, CMJ, peak power output (PPO), and isokinetic muscle strength) before and after the training intervention. After the training intervention, there was a significant difference between the flywheel eccentric training and traditional barbell training groups in each test index when compared to before and after the within-group experiment ($P < 0.05$). Between groups, there were significant differences in 3 min blood lactate concentrations ($P < 0.05$, $d = 1.09$), peak anaerobic power ($P < 0.05$; $d = 1.10$), mean anaerobic power ($P < 0.05$; $d = 1.21$), fatigue index ($P < 0.05$; $d = 1.20$), 30-m sprint ($P < 0.05$; $d = 1.38$), T-test ($P < 0.05$; $d = 1.12$), 17×15-m shuttle run ($P < 0.05$; $d = 1.31$), 1RM back squat ($P < 0.05$; $d = 1.08$), CMJ ($P < 0.05$; $d = 1.11$), peak power output (PPO) ($P < 0.05$; $d = 1.26$), and isokinetic muscle strength ($P < 0.05$). This study revealed that high-intensity flywheel eccentric training significantly enhanced the players' anaerobic capacity and lower-limb strength and led to better performance than traditional barbell training across all measures.

Key words: Lower-limb strength; anaerobic capacity; isokinetic muscle strength; sports performance; flywheel training.

Introduction

Basketball is a high-intensity intermittent team sport requiring activities with maximal or near-maximal efforts (Garcia et al., 2020). The game is characterized by high anaerobic glycolytic and aerobic oxidative demands, repeated changes in direction (CODs) that challenge the neuromuscular system, accelerations, decelerations, short-distance sprints, jumps, physical contacts, and sport-specific skills (Chimera et al., 2004; Garcia et al., 2020; Sekine et al., 2019). High-intensity activities during the game rely on anaerobic energy metabolism, while low-intensity actions like jogging, walking, and standing are predominantly sustained by aerobic energy metabolism (Heishman et al., 2020; Song et al., 2023). Hence, improving the anaerobic metabolic system is crucial for enhancing performance in basketball. Strength, speed, and change in direction are essential skills for this game and improving them will enhance athletic performance (Montgomery et al., 2010).In particular, muscle strength, especially in the lower limbs, is critical for directional change performance in basketball (Ramirez-Campillo et al., 2022).Recent reviews and experimental studies have indicated that flywheel eccentric training, which targets the lower extremities, is associated with improvements in muscle function, sprinting ability, change in direction performance, jump performance, muscle mass, and strength (Beato and Dello Iacono, 2020; de Hoyo et al., 2015a; Maroto-Izquierdo et al., 2017; Raya-González et al., 2021). Both strength and power training programmes for basketball players should focus on improving the performance of explosive movements.

Anaerobic capacity is the ability of the body to perform high-intensity exercise in a state of anaerobic energy metabolism, and it is an integral and critical factor in improving athletic performance (Ben Abdelkrim et al., 2007). In basketball, basketball players perform an average of 105 high-intensity runs with short duration (2 - 6 seconds) with 21 seconds rest intervals (Figueira et al., 2022). The contributing sources of anaerobic energy include the phosphagen system (ATP-PCr system) and the anaerobic lactic system (glycolysis) (Shalom et al., 2023). Aerobic capacity aids in the resynthesis of creatine phosphate between efforts. Supported by aerobic metabolism, repetitive sprinting ability can be improved by enhancing anaerobic capacity and promoting the storage and recovery of creatine phosphate (Girard et al., 2011). The Wingate test is currently used as an important measure of anaerobic metabolic capacity in basketball players because of the high short-term peak power and high anaerobic capacity required in basketball (Bar-Or, 1987). The Wingate test is a non-invasive, objective test that does not directly measure muscle performance, but rather provides an indirect estimate of anaerobic power and capacity (Zupan et al., 2009). It has been found that the reference values of the peak and mean anaerobic power indexes and fatigue index in the Wingate test have the capacity to measure anaerobic capacity in

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basketball players, as these measurements can reflect with actions that occur during a game, such as peak power and explosiveness, average power and sustained sprint, fatigue index and late game performance, and anaerobic capacity and high-intensity movements (Coppin et al., 2012; Franco et al., 2012). In addition, the anaerobic capacity (peak anaerobic power, mean anaerobic power, and the fatigue index) can be improved using high-intensity interval training (Tabata et al., 1996). Post-exercise peak blood lactate indicates the body's maximum tolerance to lactate and also reflects the body's maximum capacity for anaerobic fermentation for energy supply (Bishop et al., 2002; Mero, 1988). Although blood lactate clearance is more closely related to aerobic capacity, especially during the recovery phase, it is also closely related to anaerobic capacity. Based on the high intensity and intermittent nature of basketball, effective lactic acid removal is critical to basketball performance, and better blood lactate clearance enables athletes to reduce muscle fatigue, prolong exercise, and shorten recovery time (Thomas et al., 2004). The rapid clearance of lactic acid contributes to an athlete's ability to repeat sprints, thus contributing prominently to their performance in frequent sprints during competitions (Tabka, 2007). Therefore, we will compare the differences in athletes' altered anaerobic capacity between high-intensity flywheel eccentric training and traditional barbell training.

The greater force under eccentric load and muscle damage potential are the key reasons as to why eccentric training promotes strength and hypertrophy (Friedmann-Bette et al., 2010). CMJ, COD, and sprinting ability are applicable to the evaluation of quick reactions and jumping height in basketball (Gu et al., 2025). Eccentric training has been shown to improve the conduction velocity of the nervous system, the synchronization of muscle activation, and the optimization of movement patterns by improving neural adaptations, altering motor unit discharge rates, enhancing motor unit synchronization, and increasing motor unit recruitment, thus improving the CMJ, COD, and sprinting ability of basketball players (O Brien et al., 2020; Younes-Egana et al., 2023). Additionally, eccentric training facilitates muscle toughness and reduces the risk of muscle strains (Hinks et al., 2021). It has been noted that flywheel eccentric training effectively stimulates neuromuscular improvement and coordination, enhances neuromuscular adaptation (Fiorilli et al., 2020), and allows for altered patterns of neural activation during stretch-shortening cycles (SSCs) (Chimera et al., 2004). Flywheel eccentric training has the following unique characteristics: 1. Eccentric overload: this is triggered by the generation of inertial torque and the storage of kinetic energy during the concentric contraction phase of the muscle (Norrbrand et al., 2008), has an ameliorating effect on athletes' ability to accelerate and change direction after braking in basketball games (Xie et al., 2024); 2. Adaptive loading: this phenomenon, where the athlete's self-subjective level of exertion is positively correlated with flywheel resistance, dynamically adjusts resistance based on the athlete's power output, speed, and fatigue level, matching resistance and effort in real time to ensure progressive overload and thereby allowing the trainee to perform at their optimal level every time they train (Chiu and Salem, 2006); and 3. A selection of loads: the disk of inertia is selected between the 0.05 and 0.125 $kg{\cdot}m^2$ moments of inertia, wherein a lower moment of inertia results in higher concentric peak power outputs, whereas higher inertial loads are more likely to produce higher eccentric peak power outputs (Sabido et al., 2018). Flywheel eccentric training imposes 125% of the resistance in the eccentric phase compared to that in the concentric phase (Norrbrand et al., 2008), and this proportion remains stable until the end of training.

To the best of our knowledge, there are no studies that combined high-intensity interval training with flywheel eccentric training. Additionally, a large number of studies exploring the relationship between anaerobic capacity and lower extremity strength have only focused on male basketball players. According to the literature, female basketball players demonstrate lower fatigue accumulation and faster recovery compared to male basketball players, as well as differences in muscle mass, substrate utilization, and muscle morphology (Astorino et al., 2011; Laurent et al., 2010). No analyses have previously been conducted to determine if there is an effect of high-intensity flywheel eccentric training on the improvement in anaerobic capacity and lower-limb strength in female basketball players. This study introduces a mode of high-intensity interval training on the basis of flywheel eccentric training, which abandons the interval mode of traditional strength training and exerts the eccentric overload of flywheel training to a greater extent (Fiorilli et al., 2020) and high-intensity interval training stimulates the body's muscle adaptation and enhancement (Cao et al., 2025), thus forming a new training mode: high-intensity flywheel eccentric training. Therefore, we will directly compare high-intensity flywheel eccentric training with traditional barbell training. We hypothesize that high-intensity flywheel eccentric training will be more effective in improving anaerobic capacity and lower extremity strength in female basketball players compared to traditional barbell training.

Methods

Participants

The Institutional Review Board and Ethical Committee of Hunan Normal University approved this study (approval no. 229; 2020). Before participating in the study, the athletes were informed of the experiment and signed an informed consent form.

The subjects included 16 high-level CUBAL female basketball players who volunteered to participate in this study. The 16 players were divided into guard, forward, and center groups according to their position on the field. A stratified randomized grouping statistic was used to classify them into flywheel eccentric training (n = 8, age: 21.00 ± 1.69 years, height: 176.88 ± 5.22 cm, weight: 72.39 ± 8.38 kg) and traditional barbell training groups (n = 8, age: 21.13 ± 1.89 years, height: 175 ± 8.25 cm, weight: 71.35 ± 10.30 kg). To identify a suitable sample size for this study, a preliminary power analysis was carried out using the G*Power software (version 3.1.9, which is freely accessible from the University of Düsseldorf, Germany), which determined a minimum total sample size of 16, with an effect size (ES) of 0.8, an α level of 0.05, and a power ($1-\beta$)

of 0.80 for intergroup comparisons. The participants were all national-level basketball players, who were highly experienced in basketball skills and physical fitness and participated in tournaments and activities organized by the Chinese Basketball Association (CBA) and the Federation of University Sports of China (FUSC) every year. Prior to this study, no subjects had experience of flywheel eccentric training, and the subjects participated in a week of theoretical study and technique practice before they were tested.

Study design

All participants trained daily for 8 weeks as part of the intervention. A one-week washout period was enforced to prevent pre-laboratory familiarization training from biasing the test results. Throughout the study period, the participants were prohibited from any training other than regular technical and tactical training and restricted from consuming alcohol, caffeinated beverages, and other stimulants. Regular technical and tactical training was strictly controlled in terms of intensity, duration, and frequency to ensure that consistency was maintained between the two groups. During the intervention experiment, the flywheel eccentric training and traditional barbell training groups underwent the same program in terms of training intensity, duration, movements, intervals, and number of sets. A standardized 10-minute warm-up was performed before the start of the intervention, as detailed in Table 1.

Table 1. Arrangement of flywheel eccentric training and traditional barbell training manoeuvres.

Name	No. of sets	No. of reps	Time (min)
Bug Crawl	1	6	1
The Greatest Stretch	1	6	1
Lunge Back Pull Plus Turn	1	6	1
Swallow Balance	1	6	1
High Leg Raise	2	6	1
Deep Squat Jumps	1	6	1
Cross Lunge Squat	1	6	1
Jogging	1	1	3

Procedures

The experiment was conducted after a one-week washout period. The two groups of athletes, the flywheel eccentric training group and the traditional barbell training group, were numbered for participant identification, and the intensity of exercise in both groups was monitored via a SUUNTO team heart-rate monitor. The minimum target heart rate was 85% of the maximum heart rate, reducing errors and allowing both groups of athletes to maintain the same intensity under a specific load. According to the force–velocity curve, the speed of movement is inversely proportional to the external load; as external load increases, the movement velocity decreases. However, the external load is positively proportional to the force generated. According to the literature, there is a significant relationship between the flywheel training load and the peak and average speed of barbell training, which can be used as a basis to develop a reasonable load arrangement (Martín-Rivera et al., 2022). To match loading between the two training modes, the flywheel group performed deep squats using different inertia loads. Since velocity is closely related to the mechanical (e.g., acceleration, deceleration) and physiological loads (e.g., heart rate, lactate levels) of the exercise, matching velocities enables load equivalence between the two training modalities (Suchomel et al., 2015). These were compared with traditional barbell squats performed at 80% 1RM using speed-based testing. First, the flywheel group completed four barbell squats at 80% 1RM and recorded the average speed of each using the GYMAWARE speed tester as a reference for comparison. Next, subjects in the flywheel group were tested three times using different counterweight plates ($0.010kg·m^2$, $0.025kg·m^2$, and $0.050kg·m^2$) with an interval of 2-3 minutes between each set to ensure that the athletes completed the four squat repetitions with the same best effort in each set. Meanwhile, the average speed was recorded during movement using a GYMAWARE speed tester. Finally, by comparing and analyzing the speeds of the two modalities, a flywheel load was selected for the flywheel set that was relatively equal to the average speed of the barbell set. Three training movements were selected: back squat, hard pulls, and single-leg squats, and were carried out using selected loads. A 10-minute warm-up routine was performed, as per usual, before the formal experimental intervention, as detailed in Table 1. The formal experimental intervention is detailed in Table 2.

The following indicators were measured once at the end of the elution period and once 48 hours after the experiment: 1. anaerobic capacity—blood lactate concentrations (mmol/L) at 3min, 5min, and 10min after exercise (Bishop and Martino, 1993; Carter et al., 1999; Chen et al., 2020), blood lactate clearance (%) at 3-10min and 5-10min, peak anaerobic power (W), mean anaerobic power (W), fatigue index (%), 30-m sprint (s) (Gu et al., 2025), T-test (s) (Vera-Assaoka et al., 2020), and 17×15-m shuttle run (s); 2. lower-limb strength: countermovement jump (CMJ),

Table 2. Training program schedule for the flywheel eccentric training and traditional barbell training exercise intervention trial.

Group	Flywheel eccentric training	Traditional barbell training
Training movements	Flywheel Eccentric Back Squat Flywheel Eccentric Hard Pull Flywheel Eccentric Single-Leg Squat	Barbell Back Squat Barbell Hard Pull Barbell Single-Leg Squat
Number of rounds	6 times	
Interval between rounds	20s	
Number of training rounds	3 rounds	
Interval time	3-4mim	
Number of sets	4 groups	
Intensity	80%1RM	
Training frequency	Secondary/round	
Training cycle	8 weeks	

(Vera-Assaoka et al., 2020), and 17×15-m shuttle run (s); 2. lower-limb strength: countermovement jump (CMJ), peak power output (PPO), 1RM back squat, and isokinetic muscle strength.

Anaerobic capacity

The Wingate anaerobic power test (Bar-Or, 1987) was performed using a Monark 894E Anaerobic Power Bike. Athletes warmed up by slowly riding the power bike for 2-5 minutes, and upon starting the test, the athletes pedaled at maximum speed, attempting to reach full power in less than 30 seconds. At the end of the session, the peak anaerobic power, the mean anaerobic power, and the fatigue index metrics were recorded. Blood lactate was measured via an EKF lactate analyzer (Biosen S_line, EKF Diagnostic, Magdeburg, Germany). Blood collection was scheduled after the Wingate test, and we used a blood collection needle, alcohol, and cotton swabs. The athlete's finger was sterilized, and blood was collected in a minimally invasive manner and then placed into an instrument for analysis. Blood was collected 3, 5, and 10 min after the Wingate test. The peak and minimum values of blood lactate were also analyzed and calculated, from which the clearance rate of blood lactate was calculated. The formula for the clearance rate was expressed as follows:

$$\text{Blood lactate clearance\%} = \frac{(\text{Maximum Bla} - \text{Minimum Bla})\ \text{mmol/L}}{\text{Maximum mmol/L}} \times 100\%$$

The specific procedure for the sensitivity T-test was as follows: The stopwatch was started at A, as shown in the figure, and rapid movement was performed in accordance with the order A–B–C–D–B–A. Once the athlete was back in the starting position, the stopwatch was stopped and the total time required to complete the test was recorded. It is worth noting that the body was always facing forward, dependent on the direction of the different forms of movement. The test was performed three times with 3-minute intervals, and the results were recorded in units of "S". The best result was taken as the final test result.

The 30-m sprint was performed on a standard basketball court using a Brower Timing wireless infrared timing system, with a standing start. After a sufficient warm-up, two tests were conducted with an interval of 4 - 5 minutes, and the final test result was the best score of the two tests.

The 17×15-m shuttle run involved athletes standing behind the left and right sidelines of the basketball court to prepare for the test, and after hearing the command, they started running quickly. The sidelines had to be stepped over on each trip to complete the 17×15-m shuttle run. The clock was stopped at the end of the test, i.e., when the athlete completed the 17th trip and their torso crossed the sideline. Each athlete performed two tests, and the final result was the better of the two tests.

Lower-extremity strength

A Smart Jump portable jump test system was chosen for the CMJ test. During the test, the athlete stands on the jumping mat with their hands on their waist. Their body had to remain upright, with eyes to the front, and upon the light signal, the athlete quickly performed a squat jump. Athletes in the CMJ test performed a total of three tests: we used consistent rest intervals, with an interval of 10 minutes for each test, to prevent performance decrements affecting the results. The best of the three tests was taken as the final result.

For the 1RM back squat tests, after the athlete warmed up according to Table 1, followed by a 30% - 50% 1RM weight warm-up, six to eight repetitions of each exercise were performed to ensure the full activation of the lower-limb muscles. The load was then adjusted, guided by the athlete, and then gradually increased to 80% 1RM. The athletes were expected to be able perform this test at this level three times with ease, with an interval of 4 - 5 minutes between sets. After this, a gradual increase in weight to 1RM was initiated, with several single repetitions, each with an increase in weight of about 5%. The 1RM was usually determined over six to eight trials. We exercised strict control over fatigue during this process, using consistent rest intervals to prevent a drop in performance from affecting the results.

Athletes performed the isokinetic muscle strength test using a U.S. Biodex isokinetic muscle strength evaluation training system (System4), testing the lower limbs of the knee joint, hip joint peak moments, and average power test. The test method was as follows: 1. The full static pull and dynamic activation of the lower limbs was tested to ensure the athletes could efficiently and scientifically perform the test. 2. The isokinetic muscle strength test evaluation system was debugged, the activity range of the knee joint was set as 0 ~ 90°, the activity range of hip joint was set as 90 ~ 180°, the angular velocity of knee joint was set as 60°/s and 180°/s, and the angular velocity of hip joint was set as 30°/s and 180°/s. When the angular velocity was set at 30°/s and 60°/s, the athletes performed hip and knee joint tests, respectively, as well as five flexion and extension movements at full strength. When the angular velocity was set at 180°/s, the athlete performed tests on the knee and hip joints, respectively, as well as 15 flexion and extension exercises at full strength. 3. The maximum peak moment and average power of concentric and eccentric muscle contraction were recorded for 5 and 15 repetitions, respectively.

Statistical analyses

After recording and organizing the data, they were imported into SPSS 27.0 software for processing. A paired samples t-test was used to assess the differences within groups before and after the intervention, and an independent samples t-test was used to compare the differences between the two groups. The data are expressed as the means ± standard deviation (M ± SD). Cohen's d was used as a measure of effect size for these comparisons. The following classification was used to interpret Cohen's d: trivial, <0.20; small, 0.20 - 0.50; medium, 0.5 - 0.80; large, 0.8-1.30; and very large, >1.30 (Seitz et al., 2014). Both groups of pre-experimental test data conformed to a normal distribution (Shapiro–Wilk test, $p > 0.05$), and neither group of pre-experimental test data was significantly different ($p > 0.05$) from the other, in line with previous research. An analysis of covariance was then used to compare the two different training modes by plotting scatter plots to visually determine the existence of a linear relationship between the pre- and post-experimental data within the two groups. The regression lines for the covariates and dependent variables within the two groups were parallel, and the Shapiro–Wilk test result was p > 0.05. The residuals for the dependent variables within/between groups were found to be equivariant after observing the scatter plots and performing Levene's test. In addition, the standardized residuals of the data in this study were less than 3, with no significant outliers. One-way analyses of covariance were performed to gain further inferences about the differences between the two training methods. For a better interpretation of the results, partial eta squared (η^2) was calculated as an indicator of effect size: η^2 values below 0.01, 0.06, and 0.14 were considered to be small, medium, and large effect sizes, respectively (Grice and Barrett, 2014). Significance was set at an alpha level of 0.05 for all statistical tests.

Results

All participants exhibited full compliance during the entire study period. There were no test- or training-related injuries during this study. In addition, all participants attended all training sessions. None of the participants dropped out from this study.

Effect of Functional Training (FT) vs. Traditional-Based Training (TBT) on anaerobic capacity

Anaerobic capacity: As shown in Figure 1, the peak anaerobic power improved significantly within groups, demonstrating a significant difference and a medium effect size for traditional barbell training ($P < 0.05$; d = 0.80) and a highly significant difference and large effect size for flywheel eccentric training ($P < 0.01$; d = 1.23). The between-group analysis revealed a significant difference and large effect size ($P < 0.05$; d = 1.10) between flywheel eccentric training and traditional barbell training for the post-intervention measurements. The ANCOVA confirmed a significant difference between the two groups (F = 9.084; p = 0.010; η^2 = 0.411), with a large effect size.

In the post-intervention within-group comparisons of mean anaerobic power, a significant difference and a small effect size were found for traditional barbell training ($P < 0.05$, d = 0.31) and an extremely significant difference and large effect size were found for flywheel eccentric training ($P < 0.001$, d = 1.16). There was also a highly significant difference in the fatigue index between the flywheel eccentric training and traditional barbell training groups ($P < 0.01$), which showed large effect sizes (d = 1.16 and 0.84, respectively). The between-group analysis demonstrated a significant difference (P < 0.05) between the mean anaerobic power and the fatigue index post-intervention, with the mean anaerobic power and the fatigue index showing large effect sizes (d = 1.21 and 1.20, respectively). The ANCOVA confirmed a significant difference and large effect size in the mean anaerobic power and the fatigue index between the two groups (F = 12.691, p = 0.003, and η^2 = 0.494; and F = 14.197, p = 0.002, and η^2 = 0.522, respectively) (Figure 1).

Blood lactate concentration and lactate clearance: As shown in Figure 2, the results of within-group increases in the 3min, 5min, and 10min blood lactate concentration of both flywheel eccentric training and traditional barbell training athletes showed that both groups showed significant differences at the 3-minute time point ($P < 0.05$); the flywheel eccentric training group had a very large effect size (d = 1.57), and the traditional barbell training group had a large effect size (d = 0.82). The between-group analysis revealed significant differences and large effect sizes at the 3-minute time point ($P < 0.05$, d = 1.09), but no significant differences were found at 5 or 10 minutes.

The results of the pre- and post-tests of blood lactate clearance at 3 to 10 minutes and 5 to 10 minutes in both flywheel eccentric training and traditional barbell training athletes showed that there was a highly significant difference ($P < 0.01$) between the flywheel eccentric training and traditional barbell training groups at the 3 to 10 min interval, with both the flywheel eccentric training and traditional barbell training groups demonstrating very large effect sizes (d = 2.35 and 1.82, respectively). The between-group analysis also found no significant differences (Figure 2).

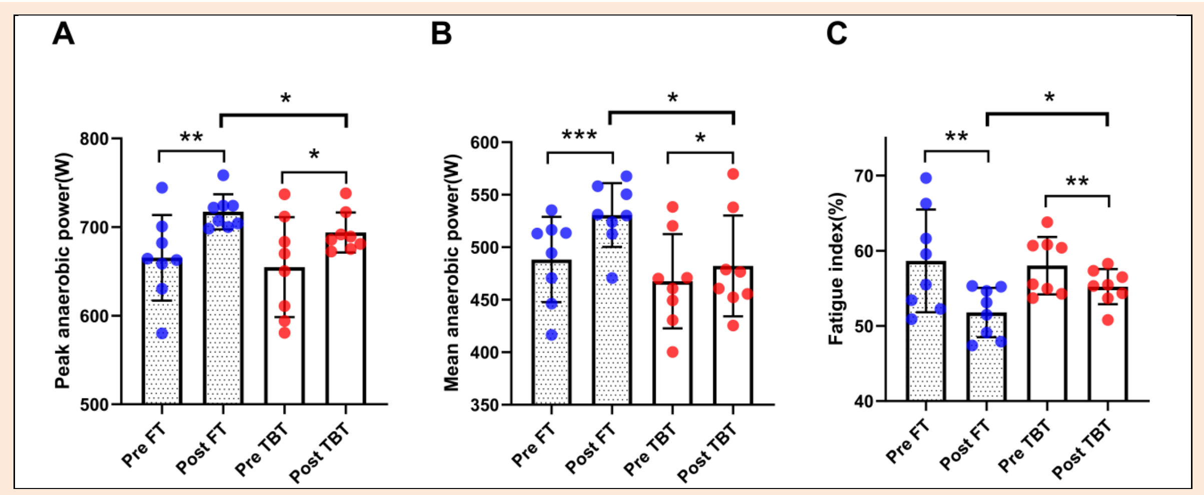

Figure 1. The graphs compare the pre- and post-intervention anaerobic capacity within the flywheel eccentric training and traditional barbell training groups, respectively, as well as the post-experimental significance of the two groups. Flywheel eccentric training is shown in blue and traditional barbell training in red, with each point corresponding to an individual athlete. Panel A is the peak anaerobic power, Panel B is the mean anaerobic power, and Panel C is the fatigue index. Data are presented as means ± standard deviation (M ± SD).

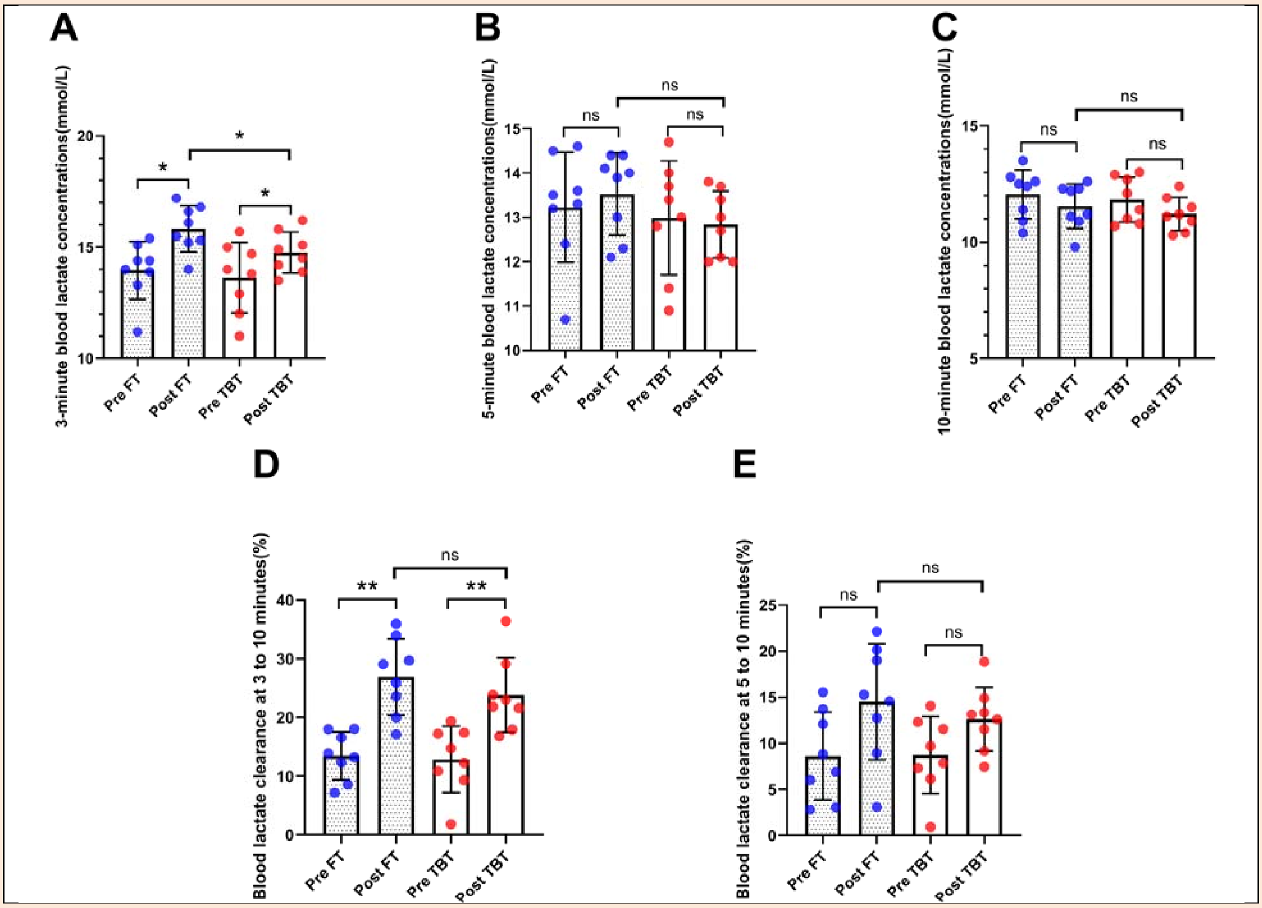

Figure 2. The graphs compare the pre- and post-intervention blood lactate concentration within the flywheel eccentric training (blue) and traditional barbell training (red) groups, respectively, as well as the post-intervention significance of the two groups. Each point corresponds to an individual athlete. Panels A, B, and C show the blood lactate concentration at 3, 5, and 10 minutes, respectively. Panels D and E display blood lactate clearance at 3-10 and 5-10 minutes. Data are presented as means ± standard deviation (M ± SD).

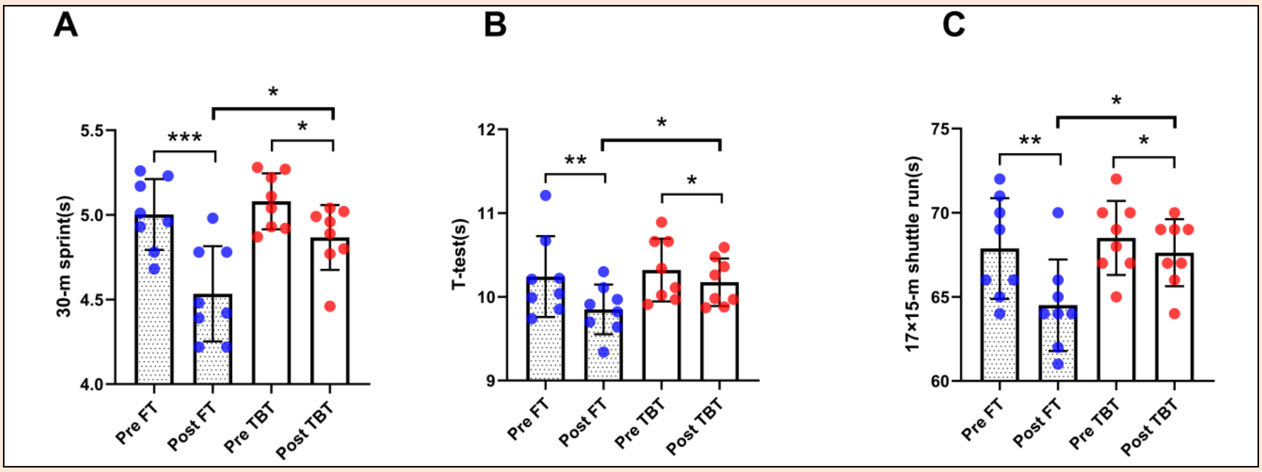

Figure 3. The graphs compare the pre- and post-intervention performance within the flywheel eccentric training and traditional barbell training groups, respectively, as well as the post-experimental significance of the two groups. The flywheel eccentric training group is shown in blue and the traditional barbell training group is shown in red, with each point corresponding to an individual athlete. Panel A is the 30 m sprint, Panel B is the T-test, and Panel C is the 17×15 m shuttle run. Data are presented as means ± standard deviation (M ± SD).

Sprint performance

As shown in Figure 3, for the 30 m sprint, within-group improvements showed a significant difference and large effect size for the traditional barbell training group ($P < 0.05$; d = 1.19) and a highly significant difference and very large effect size for the flywheel eccentric training group ($P < 0.01$; d = 1.85). The between-group analysis revealed a significant difference and very large effect size ($P < 0.05$; d = 1.38) between the flywheel eccentric training and traditional barbell training groups post-intervention. The ANCOVA showed a significant difference and large effect size between the two groups (F = 6.841; p = 0.021; η^2 =

0.345).

For the T-test, the within-group comparisons showed a significant difference and small effect size for the traditional barbell training group ($P < 0.05$; d = 0.43) and a highly significant difference and large effect size for the flywheel eccentric training group ($P < 0.01$; d = 0.93). The between-group analysis revealed a significant difference and large effect size ($P < 0.05$; d = 1.12) between the flywheel eccentric training and traditional barbell training groups post-intervention. The ANCOVA showed a significant difference and large effect size between the two groups (F = 14.069; p = 0.002; η^2 = 0.520) (Figure 3).

For the 17×15 m shuttle run, the within-group comparisons showed a significant difference and small effect size for the traditional barbell training group ($P < 0.05$; d = 0.42) and a highly significant difference and large effect size for the flywheel eccentric training group ($P < 0.01$; d = 1.18). The between-group analysis revealed a significant difference and very large effect size ($P < 0.05$; d = 1.31) between the flywheel eccentric training and traditional barbell training groups post-intervention. The ANCOVA showed a significant difference and large effect size between the two groups (F = 15.364; p = 0.002; η^2 = 0.542) (Figure 3).

Effect of Functional Training (FT) vs. Traditional-Based Training (TBT) on Lower Limb Strength

Lower body strength and explosiveness: As shown in Figure 4, for 1RM back squat, the within-group comparisons showed a highly significant difference and trivial effect size for the traditional barbell training group ($P < 0.01$; d = 0.15) and an extremely significant difference and large effect size for the flywheel eccentric training group ($P < 0.001$; d = 0.85). The between-group analysis revealed a significant difference and large effect size ($P < 0.05$; d = 1.08) between the flywheel eccentric training and traditional barbell training groups post-intervention. The ANCOVA showed a significant difference and large effect size between the two groups (F = 55.705; p < 0.001; η^2 = 0.811).

For countermovement jump (CMJ), the within-group comparisons showed a significant difference and small effect size for the traditional barbell training group ($P < 0.05$; d = 0.29) and an extremely significant difference and very large effect size for the flywheel eccentric training group ($P < 0.001$; d = 1.41). The between-group analysis revealed a significant difference and large effect size ($P < 0.05$; d = 1.11) between the flywheel eccentric training and traditional barbell training groups post-intervention. The ANCOVA showed a significant difference and large effect size between the two groups (F = 71.703; p < 0.001; η^2 = 0.847) (Figure 4).

For peak power output (PPO), the within-group comparisons showed an extremely significant difference and large effect size for the traditional barbell training group ($P < 0.001$; d = 1.07) and an extremely significant difference and very large effect size for the flywheel eccentric training group ($P < 0.001$; d = 1.33). The between-group analysis revealed a significant difference and large effect size ($P < 0.05$; d = 1.26) between the flywheel eccentric training and traditional barbell training groups post-intervention. The ANCOVA showed a significant difference and large effect size between the two groups (F = 5.399; p = 0.037; η^2 = 0.293) (Figure 4).

Isokinetic muscle strength: As shown in Table 3, for the isokinetic muscle power right knee 60°/s (flexion) test, the within-group comparisons showed a highly significant enhancement in peak torque (PT) for the flywheel eccentric training and traditional barbell training groups, respectively (flywheel eccentric training: $P = 0.001$, d = 2.33, very large effect size; traditional barbell training: $P = 0.003$, d = 0.34, small effect size). An extremely significant difference in average power (AP) was found for both groups, respectively (flywheel eccentric training: $P < 0.001$, d = 2.05, very large effect size; traditional barbell training: $P < 0.001$, d = 0.55, medium effect size). The between-group analysis revealed a significant difference (peak torque (PT): $P = 0.048$, d = 1.09, large effect size; average power (AP): $P = 0.038$, d = 1.14, large effect size) between peak torque (PT) and average power (AP) in both the flywheel eccentric training and traditional barbell training groups post-intervention.

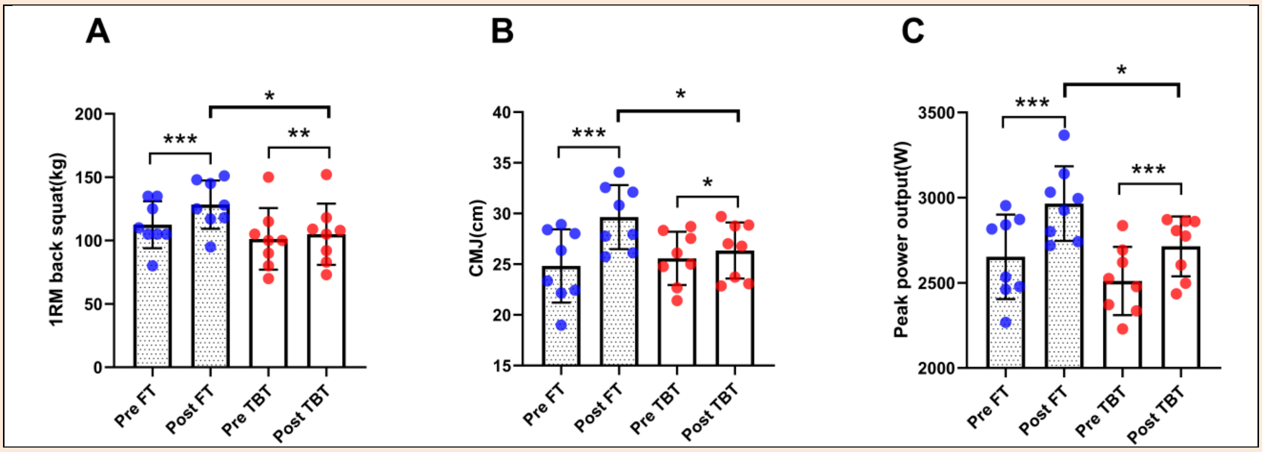

Figure 4. The graphs compare the pre- and post-intervention lower limb strength within the flywheel eccentric training and traditional barbell training groups, respectively, as well as the post-experimental significance of the two groups. The flywheel eccentric training group is shown in blue and the traditional barbell training group is shown in red, with each point corresponding to an individual athlete. Panel A is the 1RM back squat, Panel B is the CMJ, and Panel C is the peak power output. Data are presented as means ± standard deviation (M ± SD).

Table 3. Comparison of results of isokinetic muscle strength testing of right knee.

Norm	Norm	Time	Flywheel eccentric training	Traditional barbell training	P	d
60°/s (flexion)	PT (N·m)	Pre-test	105.25 ± 16.03	105.38 ± 30.49		
		After the test	138.25 ± 10.70	115.38 ± 27.75	0.048	1.09
		P	0.001	0.003		
		d	2.33	0.34		
	AP (W)	Pre-test	97.00 ± 14.60	95.38 ± 19.32		
		After the test	123.13 ± 9.13	106 ± 19.13	0.038	1.14
		P	< 0.001	< 0.001		
		d	2.05	0.55		
60°/s (extension)	PT (N·m)	Pre-test	169.38 ± 19.13	155.88 ± 29.78		
		After the test	199.13 ± 21.17	167.5 ± 29.37	0.027	1.24
		P	0.009	0.003		
		d	1.47	0.39		
	AP (W)	Pre-test	143.75 ± 18.16	129.88 ± 18.40		
		After the test	172.5 ± 16.17	137 ± 27.07	0.007	1.59
		P	< 0.001	0.248		
		d	1.67	0.30		
180°/s (flexion)	PT (N·m)	Pre-test	85.5 ± 7.60	79.88 ± 18.10		
		After the test	102.25 ± 7.89	84 ± 17.47	<0.001	1.35
		P	< 0.001	< 0.001		
		d	2.16	0.23		
	AP (W)	Pre-test	120 ± 13.21	111.25 ± 23.83		
		After the test	145.38 ± 12.72	124.25 ± 24.27	0.047	1.09
		P	< 0.001	< 0.001		
		d	1.96	0.54		
180°/s (extension)	PT (N·m)	Pre-test	111.75 ± 12.73	103.63 ± 23.46		
		After the test	129.25 ± 22.33	104.38 ± 18.24	0.029	1.22
		P	0.006	0.857		
		d	0.90	0.04		
	AP (W)	Pre-test	162.5 ± 15.00	151.13 ± 17.69		
		After the test	190.25 ± 12.74	168.75 ± 21.22	0.028	1.23
		P	< 0.001	< 0.001		
		d	1.98	0.89		

Data presented as mean ± SD. PT, peak torque. AP, average power. Paired samples t-tests were used pre-test and after the test within the group. Independent samples t-tests were used after the intergroup test. Cohen's d was used as a measure of effect size for these comparisons.

For the isokinetic muscle power right knee 60°/s (extension) test, the within-group comparisons showed a highly significant enhancement in peak torque (PT) for the flywheel eccentric training and traditional barbell training groups, respectively (flywheel eccentric training: $P = 0.009$, d = 1.47, very large effect size; traditional barbell training: $P = 0.003$, d = 0.39, small effect size). An extremely significant difference in average power (AP) was found for the flywheel eccentric training group ($P < 0.001$, d = 1.67, very large effect size). However, no significant difference was found within the traditional barbell training group post-intervention ($P > 0.05$). The between-group analysis revealed significant differences (peak torque (PT): $P = 0.027$, d = 1.24, large effect size; average power (AP): $P = 0.007$, d = 1.59, very large effect size) between peak torque (PT) and average power (AP) in both the flywheel eccentric training and traditional barbell training groups post-intervention (Table 3).

For the isokinetic muscle strength right knee 180°/s (flexion) test, the within-group comparisons showed that both the flywheel eccentric training and traditional barbell training groups showed extremely significant ($P < 0.001$) increases in peak torque (PT) and average power (AP). Among them, the peak torque (PT) of the flywheel eccentric training group showed a very large effect size (d = 2.16); the peak torque (PT) of the traditional barbell training group showed a small effect size (d = 0.23); the average power (AP) of the flywheel eccentric training group showed a very large effect size (d = 1.96); and the average power (AP) of the traditional barbell training group showed a medium effect size (d = 0.54). The between-group analysis revealed significant differences (peak torque (PT): $P < 0.001$, d = 1.35, very large effect size; average power (AP): $P = 0.047$, d = 1.09, large effect size) between peak torque (PT) and average power (AP) for both the flywheel eccentric training and traditional barbell training groups post-intervention (Table 3).

For the isokinetic muscle power right knee 180°/s (extension) test, the within-group comparisons showed a highly significant enhancement in peak torque (PT) for the flywheel eccentric training group ($P = 0.006$, d = 0.90, large effect size). However, no significant difference was found within the traditional barbell training group post-intervention ($P > 0.05$). Additionally, an extremely significant difference in average power (AP) was found for both groups (flywheel eccentric training: $P < 0.001$, d = 1.98, very large effect size; traditional barbell training: $P = 0.001$, d = 0.89, large effect size). The between-group analysis revealed significant differences (peak torque (PT): $P = 0.029$, d = 1.22, large effect size; average power (AP): $P = 0.028$, d = 1.23, large effect size) between peak torque (PT) and average power (AP) in both the flywheel eccentric training and traditional barbell training groups post-intervention (Table 3).

Table 4. Comparison of results of isokinetic muscle strength testing of right hip.

Norm	Norm	Time	Flywheel eccentric training	Traditional barbell training	P	d
30°/s (flexion)	PT (N·m)	Pre-test	89.63 ± 18.17	83.38 ± 10.56		
		After the test	121.00 ± 23.80	96.25 ± 6.86	0.013	1.41
		P	< 0.001	< 0.001		
		d	1.46	1.39		
	PT (N·m)	Pre-test	100.63 ± 24.20	97.63 ± 23.82		
		After the test	133.13 ± 25.78	104.50 ± 25.71	0.043	1.11
		P	< 0.001	0.002		
		d	1.30	0.28		
30°/s (extension)	PT (N·m)	Pre-test	151.50 ± 29.71	145.88 ± 25.44		
		After the test	190.50 ± 30.17	155.25 ± 26.38	0.026	1.24
		P	< 0.001	< 0.001		
		d	1.30	0.36		
	AP (W)	Pre-test	184.88 ± 34.90	169.63 ± 41.47		
		After the test	237.25 ± 46.57	189.88 ± 34.48	0.036	1.16
		P	< 0.001	0.005		
		d	1.25	0.53		
180°/s (flexion)	PT (N·m)	Pre-test	68.88 ± 12.56	64.00 ± 9.17		
		After the test	89.00 ± 11.70	71.13 ± 8.08	0.004	1.78
		P	< 0.001	< 0.001		
		d	1.66	0.82		
	AP (W)	Pre-test	74.00 ± 10.24	75.63 ± 14.04		
		After the test	102.50 ± 15.82	86.25 ± 13.98	0.047	1.09
		P	< 0.001	< 0.001		
		d	2.05	0.76		
180°/s (extension)	PT (N·m)	Pre-test	108.13 ± 18.30	98.13 ± 24.85		
		After the test	144.00 ± 33.78	110.50 ± 24.21	0.039	1.14
		P	< 0.001	< 0.001		
		d	1.22	0.50		
	AP (W)	Pre-test	129.00 ± 26.97	122.38 ± 45.28		
		After the test	171.38 ± 29.92	128.63 ± 46.41	0.012	1.09
		P	< 0.001	0.002		
		d	1.48	0.14		

Data presented as mean ± SD. PT, peak torque. AP, average power. Paired samples t-tests were used pre-test and after the test within the group. Independent samples t-tests were used after the intergroup test. Cohen's d was used as a measure of effect size for these comparisons.

As shown in Table 4, for the isokinetic muscle power right hip 30°/s (flexion) test, the within-group comparisons showed an extremely significant enhancement in peak torque (PT) for both the flywheel eccentric training and traditional barbell training groups (flywheel eccentric training: $P < 0.001$, d = 1.46, very large effect size; tradetional barbell training: $P < 0.001$, d = 1.39, very large effect size), as well as a highly significant difference in average power (AP) for both groups (flywheel eccentric training: $P < 0.001$, d = 1.30, large effect size; traditional barbell training: $P = 0.002$, d = 0.28, small effect size). The between-group analysis revealed significant differences (peak torque (PT): $P = 0.013$, d = 1.41, very large effect size; average power (AP): $P = 0.043$, d = 1.11, large effect size) between peak torque (PT) and average power (AP) in both the flywheel eccentric training and traditional barbell training groups post-intervention.

For the isokinetic muscle power right hip 30°/s (extension) test, the within-group comparisons showed an extremely significant enhancement in peak torque (PT) for both the flywheel eccentric training and traditional barbell training groups (flywheel eccentric training: $P < 0.001$, d = 1.30, large effect size; traditional barbell training: $P < 0.001$, d = 0.36, small effect size). A highly significant difference in average power (AP) was also found for both groups (flywheel eccentric training: $P < 0.001$, d = 1.25, large effect size; traditional barbell training: $P = 0.005$, d = 0.53, medium effect size). The between-group analysis revealed significant differences (peak torque (PT): $P = 0.026$, d = 1.24, large effect size; average power (AP): $P = 0.036$, d = 1.16, large effect size) between peak torque (PT) and average power (AP) in both the flywheel eccentric training and traditional barbell training groups post-intervention (Table 4).

For the isokinetic muscle strength right hip 180°/s (flexion) test, the within-group comparisons showed an extremely significant increase in peak torque (PT) for both groups (flywheel eccentric training: $P < 0.001$, d = 1.66, very large effect size; traditional barbell training: $P < 0.001$, d = 0.82, large effect size). An extremely significant difference in average power (AP) was also found for both groups (flywheel eccentric training: $P < 0.001$, d = 2.05, very large effect size; traditional barbell training: $P < 0.001$, d = 0.76, medium effect size). The between-group analysis revealed significant differences (peak torque (PT): $P = 0.004$, d = 1.78, very large effect size; average power (AP): $P = 0.047$, d = 1.09, large effect size) between peak torque (PT) and average power (AP) in both the flywheel eccentric training and traditional barbell training groups post-intervention (Table 4).

For the isokinetic muscle strength right hip 180°/s (extension) test, the within-group comparisons showed an extremely significant difference in peak torque (PT) for the flywheel eccentric training and traditional barbell training groups (flywheel eccentric training: $P < 0.001$, d = 1.22, large effect size; traditional barbell training: $P < 0.001$, d = 0.50, medium effect size), as well as a highly significant difference in average power (AP) for both groups, respectively (flywheel eccentric training: $P < 0.001$, d = 1.48, very large effect size; traditional barbell training: $P = 0.002$, d = 0.14, trivial effect size). The between-group analysis revealed significant differences between peak torque (PT) and average power (AP) in both the flywheel eccentric training and traditional barbell training groups post-intervention (peak torque (PT): $P = 0.039$, d = 1.14, large effect size; average power (AP): $P = 0.012$, d = 1.09, large effect size) (Table 4).

Discussion

The purpose of this study was to compare the effects of high-intensity flywheel eccentric training and traditional barbell training on anaerobic capacity (peak anaerobic power, mean anaerobic power, fatigue index, blood lactate concentration, blood lactate clearance, 30-m sprint, T-test, and 17×15-m shuttle run) and lower-limb strength (1RM back squat, CMJ, peak power output, and isokinetic muscle strength) in female basketball players. The main results showed that both interventions improved anaerobic capacity and lower-limb strength in female basketball players after an eight-week intervention, but flywheel eccentric training outperformed traditional barbell training in peak blood lactate, anaerobic power, sprinting, change-of-direction (COD), and 1RM back squat, CMJ, peak power output, and isokinetic muscle strength test.

Flywheel eccentric training is during the concentric phase of muscle contraction, pulling a strap connected to the device's rotational axis causes the flywheel to spin, generating inertial torque and storing kinetic energy, which results in eccentric overload (Kompf and Arandjelovic, 2016; Norrbrand et al., 2008). Traditional barbell training involves fixed external loads and primarily concentric/eccentric contractions at specific resistances; while traditional barbell training is not limited to specific joints or angles, it is less adaptable to continuous resistance across all joint angles compared to flywheel eccentric training. Flywheel loading is independent of gravity and creates inertial resistance via rotation, which is independent of joint angles, helping produce optimal muscular training at all angles of movement (Tesch et al., 2017). When training on flywheel equipment, the muscles are constantly engaged in a cyclic concentric -eccentric - concentric- eccentric contraction pattern (SSC). This improves the athlete's nervous system and improves the speed of the muscle's force generation and its ability to generate force (Komi, 1986). In contrast, the eccentric phase in traditional barbell training is limited by the same fixed load as the concentric phase, the characteristics of which may influence the long-term development of muscle strength and explosive power in athletes (Davies et al., 2016), unlike the eccentric overload in flywheel eccentric training. Consistent with our previous findings (Xie et al., 2024), reference's Figure 3 and Figure 4, comparing flywheel eccentric training and traditional barbell training in the present study resulted in significant differences ($P < 0.05$) in terms of 1RM back squat, CMJ, 30-m sprint, and change-of-direction (COD) ability. This study demonstrated that flywheel eccentric training is more effective than concentric training in enhancing muscle elasticity and stability in lower-extremity multi-joint movements (Elmer et al., 2012) and is more effective in increasing the level of explosive muscle power. Existing research proves that flywheel eccentric training effectively enhances the glycolytic energy and phosphagen supplies of the athletes, thus contributing to the enhancement of their anaerobic capacity level of the athletes (Friedmann-Bette et al., 2010; Pousson et al., 1990). The ATP produced by the glycolytic system can be estimated by the accumulation of lactate in the blood (Watanabe et al., 2024); therefore, peak blood lactate plays a significant positive role in anaerobic power improvement. This is consistent with the results of the present study, where flywheel eccentric training was found to improve the athletes' anaerobic power compared with traditional barbell training. With increases in training level and years of experience, the movement patterns of traditional barbell training have been in plateaued adaptations in experienced athletes to a certain extent; compared to flywheel eccentric training variable resistance, prolonged traditional barbell training with its fixed resistance design can lead to the adaptive stagnation of the neuromuscular system (Schoenfeld, 2010), allowing for only limited gains.

According to the results of this study (e.g., Figure 1 and Figure 2), flywheel eccentric training led to an increase in peak anaerobic power, mean anaerobic power, and fatigue index by 7.80%, 8.67%, and 11.71%, respectively; an increase in peak blood lactate by 13.43%; and a large effect size for the 3 - 10-minute blood lactate clearance (d = 1.16). Meanwhile, traditional barbell training led to an increase in peak anaerobic power, mean anaerobic power, and fatigue index by 6.00%, 3.11%, and 4.83%, respectively; an increase in peak blood lactate by 8.25%; and a large effect size for the 3 - 10-minute blood lactate clearance (d = 0.84). According to the literature, the increased storage and utilization of elastic muscle power after flywheel eccentric training can effectively enhance athletes' lower-extremity anaerobic explosive power (Taipale et al., 2010), thereby improving peak anaerobic power (Fu et al., 2023). Flywheel eccentric training results in higher peak power production during the eccentric overload phase, thereby enhancing motor unit synchronization (Skarabot et al., 2021) and stimulating higher EGM activity (Norrbrand et al., 2010), which can effectively improve the mean anaerobic power of athletes (Cormier et al., 2024) (e.g., Figure 1). In addition, the glycolytic capacity as an indicator of anaerobic capacity correlates with blood lactate concentration. According to the results in the literature (Caruso et al., 2006), the blood lactate reaches a peak value in 3min, and flywheel eccentric training improved the peak blood lactate concentration of the athletes after the exercise (e.g., Figure 2). This indicated the body's improved buffering capacity, and this also reflected the maximal capacity of the body's glycolytic capacity for energy supply (Bishop et al., 2002; Mero, 1988). Blood lactate clearance effectively reduces the fatigue index by reducing lactic acid accumulation and accelerating muscle recovery (Hostrup and Bangsbo, 2017; Martin et al., 2015). As shown in Figure 2, the blood lactate clearance increased and the fatigue indices decreased after flywheel eccentric training, thus delaying the onset of fatigue and accelerating the athletes' ability to recover (Bishop and Martino, 1993). Flywheel eccentric training enhances peak anaerobic power, mean anaerobic power, fatigue index, peak blood lactate, and blood lactate clearance in female basketball players through improvements in the glycolytic and phosphagen systems and blood lactate (e.g., Figure 1 and Figure 2).

As shown in Figure 3, the findings of this study indicate that flywheel eccentric training reduced the measured times of completion by 9.37%, 3.83%, and 4.24% in the 30-m sprint, T-test, and 17×15-m shuttle run, respectively. On the other hand, traditional barbell training reduced the measured times of completion by 4.21%, 1.42%, and 1.27% in the 30 m sprint, T-test, and 17×15-m shuttle run, respectively. Flywheel eccentric training results in improved motor unit recruitment and neural drive (O Brien et al., 2020; Yetter and Moir, 2008; Younes-Egana et al., 2023), contributing to the 30-m sprint (d = 1.85), CMJ (d = 1.41), and isokinetic muscle strength test results (Table 3 and Table 4) in this study. According to previous research, athletes undergoing flywheel eccentric training have shown an increase in individual lower-extremity power output, with significant gains in the ability to perform linear sprints (e.g., 30-m sprint) (Askling et al., 2003; Gual et al., 2016). Numerous studies have demonstrated that flywheel eccentric training results in a significant enhancement of the athlete's change-of-direction (COD) ability and that flywheel eccentric training effectively increases the crosstalk of the myotome, thereby increasing muscle fiber diameters, muscle bundle lengths, and eccentric muscle strength (Franchi et al., 2014). Flywheel eccentric training also increases the tendon stiffness and elasticity of the stretch reflex (Martinez-Aranda and Fernandez-Gonzalo, 2017), strengthening the athlete's ability to store energy during SSCs, and enabling them to show more speed in the concentric phase after eccentric braking, prompting improvements in the T-test (d = 0.93), 30-m sprint, and CMJ tests (e.g., Figure 3 and Figure 4). Flywheel eccentric training improves the athlete's running economy by enhancing muscle explosiveness and neuromuscular function, promoting improved 17×15-m shuttle run performance (Weng et al., 2022). Flywheel eccentric training can effectively enhance athletes' ability to sprint, perform CODs, and reaccelerate after braking, which is consistent with the constant and continuous offensive and defensive transition scenarios of female basketball players in high-intensity games. In addition, sprint and COD ability are more related to differences in anaerobic capacity (Losnegard et al., 2012), which flywheel eccentric training was able to effectively enhance (Beato et al., 2024; di Cagno et al., 2020; Foster et al., 2015), indirectly promoting the athletes' sprint and COD abilities.

The results of this study showed that flywheel eccentric training improved 1RM back squat, CMJ, and peak power output (PPO) results by 14.11%, 19.39%, and 11.78%, respectively, while traditional barbell training improved 1RM back squat, CMJ, and peak power output (PPO) results by 3.70%, 3.03%, and 8.10%, respectively (e.g., Figure 4). The isokinetic muscle power tests for the flywheel eccentric training group, compared to those of the traditional barbell training group, found significantly different results ($P < 0.05$) for the peak torque (PT) and average power (AP) for every tested angle of flexion and extension; high effect sizes were also reported (Table 3 and Table 4). Flywheel eccentric training can elicit athletes to apply greater force during the eccentric phase, emphasizing rapid muscle contraction during the concentric phase to enhance elasticity. Stimulating maximal muscular strength gains through the high-speed rotation of the flywheel and regulated resistance (Douglas et al., 2017), may have benefits specific to flywheel movements (Petré et al., 2018). In experiments with athletes performing barbell half squats, it was found that the flywheel eccentric training group facilitated greater force production, and such athletic performance was associated with greater ground reaction force and strength in their vertical jumping ability and explosive power (Papadopoulos et al., 2014), as shown in Figure 4, which is consistent with the improvements in CMJ found in our study. Numerous studies have demonstrated the existence of a more significant effect of flywheel eccentric training on CMJ than that of traditional barbell training of equal intensity (de Hoyo et al., 2015b; Stojanović et al., 2021; Xie et al., 2022); this is consistent with the results of the present study, which showed a large effect size for CMJ. At the same power, eccentric training is more effective in enhancing muscle elasticity and stability in lower-limb multi-joint movements, as well as more effective in increasing the level of explosive muscle power compared to concentric training (Elmer et al., 2012). In elite sports, isokinetic testing is widely used as a standard for muscular strength (peak torque) and muscular endurance (average power) (van Dyk et al., 2019). The more significant gains in flywheel eccentric training, as demonstrated by the peak torque value and average power, may be related to the overall effect of eccentric training on muscle growth and development (Vetter et al., 2023). Flywheel eccentric training enables female basketball players to better compete for favorable positions and maintain body balance in high-intensity, high-confrontation games by improving maximal muscle strength, jumping ability, and explosive power. Furthermore, it can intuitively improve athletes' speed, traverse ability, and bouncing height.

There are some limitations to this study. There were potential influences of external factors during the intervention, such as nutrition intake, dietary habits, and sleep quality, and, although we used standardized instructions and monitoring to attempt to control for these variables and maintain consistency among the participants, we cannot rule out the influence of these factors on the results. In the future, stricter control measures, such as closed intensive training, scientific nutritional intake, and dietary logs, are recommended to minimize the interference of external factors. Secondly, the training movements used during flywheel eccentric training in this study were mainly focused on the lower limbs (back squat, hard pull, and single-leg squat); in future studies, researchers may focus on the upper limbs to selectively train them according to the technical movements of basketball, so that the training benefits can be positively transferred. Finally, this study has a limited sample size, namely a team of 16 CUBAL female basketball players, who are all elite college athletes; therefore, the results of this study may not be applicable to non-professionally trained sports enthusiasts.

Conclusion

Our findings clearly demonstrate that flywheel eccentric training results in greater improvement in anaerobic capacity and lower-limb strength in female basketball players compared to traditional barbell training. In particular, as shown in Figure 1, Figure 2, Figure 3, Figure 4, Table 3, and Table 4, the flywheel eccentric training led to greater improvements ($P < 0.05$) in peak anaerobic power, mean anaerobic power, fatigue index, peak blood lactate concentration, 30-m sprint, T-test, 17×15-m shuttle run, 1RM back squat, CMJ, peak power output (PPO), and isokinetic muscle strength. Flywheel eccentric training has a special mechanism that is independent of joint angles and gravity. This mechanism promotes anaerobic power, sprinting, COD ability, strength, and explosiveness by rotating the flywheel to produce greater force during the eccentric phase, which can be better adapted to and enhance athletic performance relative to traditional barbell training. Given these findings, coaches and athletes should incorporate flywheel eccentric training into their training regimens in the future. Back squat, hard pull, and single-leg squat were chosen as the three training movements to be trained in two sessions per week for a total of eight weeks (Table 2), to improve the sprinting, COD ability, vertical jump, strength, and explosiveness of college female basketball players. This paper is a study of a collegiate female basketball team consisting of 16 elite players, which may have some limitations. It is recommended that future research be conducted to validate flywheel eccentric training among professional basketball players or non-professional basketball enthusiasts.

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Key points

- Both flywheel eccentric training and traditional barbell training improved anaerobic capacity and lower-limb strength in female basketball players.
- Improvements from flywheel eccentric training were shown to be more significant than traditional barbell training through statistical significance and effect size values.
- Flywheel eccentric training significantly improved anaerobic capacity, blood lactate concentration, blood lactate clearance, sprint performance and lower-limb strength in female basketball players through a specific mechanism of eccentric overload.
- Extending the model of high-intensity flywheel eccentric training to trained female basketball players allows athletes and coaches to optimize the quality and efficiency of their training programs.

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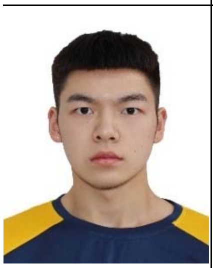

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