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Transforming performance

The impact of an 8-week complex training program on strength, power, and change of direction in female basketball athletes

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Abstract

Background: This study aimed to investigate the effect of complex training on the strength, power, and change of direction (COD) performance of college female basketball athletes.

Methods: This design used experimental and randomized studies. A total of 32 female basketball players volunteered to participate in this study and were randomly allocated to a complex training group (CT group: n = 16) and a resistance training group (RT group: n = 16). The CT group performed CT and the RT group completed RT for 8 weeks. The CT and RT programs were developed based on the linear periodization theory, which required participants to train 2 times a week in the first 4 weeks and 3 times a week in the following 4 weeks. All participants were tested using the 5-0-5 COD test, Illinois agility test (IAT), one-repetition maximum back squat (1RM BS) test, and countermovement jump (CMJ) test before and after the 8-week training period.

Results: Two-way repeated measure ANOVA showed a significant group × time interaction for the 5-0-5 COD, IAT, 1RM BS, and CMJ results after the intervention compared with that before the intervention ($P < .05$) in the CT group (effect size = 0.86–4.04). CT compared with RT caused remarkably larger enhancements in the IAT ($P < .001$) and CMJ ($P = .040$) scores.

Conclusion: Our findings indicate that the implementation of CT could be a promising and innovative intervention for enhancing the strength, power, and COD performance of female basketball players.

Abbreviations: 1RM = one-repetition maximum, CMJ = countermovement jump, COD = changes of direction, CT = complex training, ES = effect size, IAT = Illinois agility test, PAP = post-activation potentiation, RT = resistance training.

Keywords: COD, complex training, female basketball players, physical training, strength

1. Introduction

Basketball is a dynamic and high-intensity sport, distinguished by its emphasis on speed, physical strength, and strategic court play. The primary objective in basketball is to score points, which is achieved through a combination of rapid jumps, agility maneuvers, effective changes of direction (COD), swift passing, and precise shooting.[1] As an inherently cooperative court sport, basketball necessitates continuous and rapid transitions between offensive and defensive play, encompassing a diverse array of technical movements that frequently change in response to the evolving dynamics of the game.[2] In an average game, athletes perform 40 to 60 high-intensity jumps and 50 to 60 shifts and CODs.[3] The COD ability is a critical determinant of performance in basketball players. Superior leg strength and power are intimately associated with enhanced COD capabilities, representing one of the most effective methods to augment this skill.[4] Effectively enhancing the strength of basketball players is instrumental in improving their COD performance. This strength development is crucial for enabling players to execute various technical and tactical tasks on the court with greater proficiency.

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The complex training (CT) method integrates high-load resistance training (RT) and plyometric exercises within a single training session, alternating between these modalities. This approach is designed to exploit the neuromuscular system's response to varied stimuli, thereby enhancing athletic performance.[5] The CT can induce a post-activation potentiation (PAP) response, enhancing power output in subsequent plyometric exercises among athletes. This is achieved by augmenting neuromuscular connectivity and efficiency, accelerating the phosphorylation of myosin light chains, and increasing limb stiffness. These physiological adaptations collectively contribute to the PAP response, thereby optimizing the athlete's performance in power-centric activities.[6,7] Research has indicated that CT leads to significant enhancements in neuromuscular fitness, strength, and muscle power, as evidenced in studies.[8–10] Cumulatively, CT may have great potential in enhancing the competitive performance of modern pentathlon female athletes by simultaneously improving their strength and power,[11].Furthermore, Hassan et al (2023) have demonstrated the efficacy of a Core Complex Training Program in boosting performance efficiency and muscular strength, thereby positively influencing match outcomes.[12] However, the specific effects of CT on enhancing the COD ability, as well as the strength and power of the lower limbs, in female basketball players have not been adequately examined.

Therefore, the objective of this study was to investigate whether an 8-week CT program, in comparison to an 8-week RT regimen, can enhance the COD ability, as well as the strength and power of the lower limbs in female basketball players. Specifically, we hypothesized that the application of a CT protocol would result in significant improvements in athletic performance parameters related to COD, lower limb strength, and power, outcomes that may not be attainable through RT alone.

2. Materials and methods

2.1. Subjects

The study utilized a sample size of 24 participants, determined through calculations conducted with GPower (version 3.1.9.7; Franz Faul, University of Kiel, Kiel, Germany). These calculations were based on an α error probability of 0.05, a power (1-β error probability) of 0.8, an effect size (ES) of 0.4, and a test family encompassing F-tests and analysis of variance (ANOVA), specifically focusing on repeated measures and within-between interaction.[13] A total of 33 female college basketball players volunteered to participate in this study. Participants were randomly assigned into a CT group (n = 17, age: 19.7 ± 3.9 years, height: 176.4 ± 6.1 cm, weight: 70.87 ± 6.4 kg, and training experience: 4.4 ± 1.4 years) and an RT group (n = 16, age: 19.9 ± 2.1 years, height: 178.8 ± 4.6 cm, weight: 70.2 ± 3.9 kg, and training experience: 4.4 ± 1.3 years) using a computer-generated randomization list (See Figure 1 for recruitment process details). Study subjects were recruited from April 1 to May 30, 2023, and the experiment was conducted from June 1 to August 1. The inclusion criteria were college basketball athletes who were female (quarterfinalists of the Chinese University Basketball Association), who were versed in resistance and plyometric training skills, and who had the capability and intention to complete the 8-week training program including the exercise and testing. The exclusion criteria were participants who had suffered serious injuries to their lower limbs, such as the anterior cruciate ligament, hamstring, meniscus, and ankle, or had suffered from any medical or orthopedic problems in the last 3 years and who were unable to perform plyometric training. Participants provided written informed consent after being informed about the potential benefits and risks associated with data collection. They were instructed to maintain their regular diet, avoid additional nutritional supplements, and consume caffeine-free beverages during the study. The study received approval from the Shandong Normal University Institutional Research Commission (Approval number: 2023053) and adhered to the Declaration of Helsinki's guidelines.

2.2. Procedures

The study integrated a weekly technical training schedule alongside the specific exercise programs for both the CT and RT groups. These groups underwent an 8-week training program, executed separately. Table 1 delineates a comprehensive

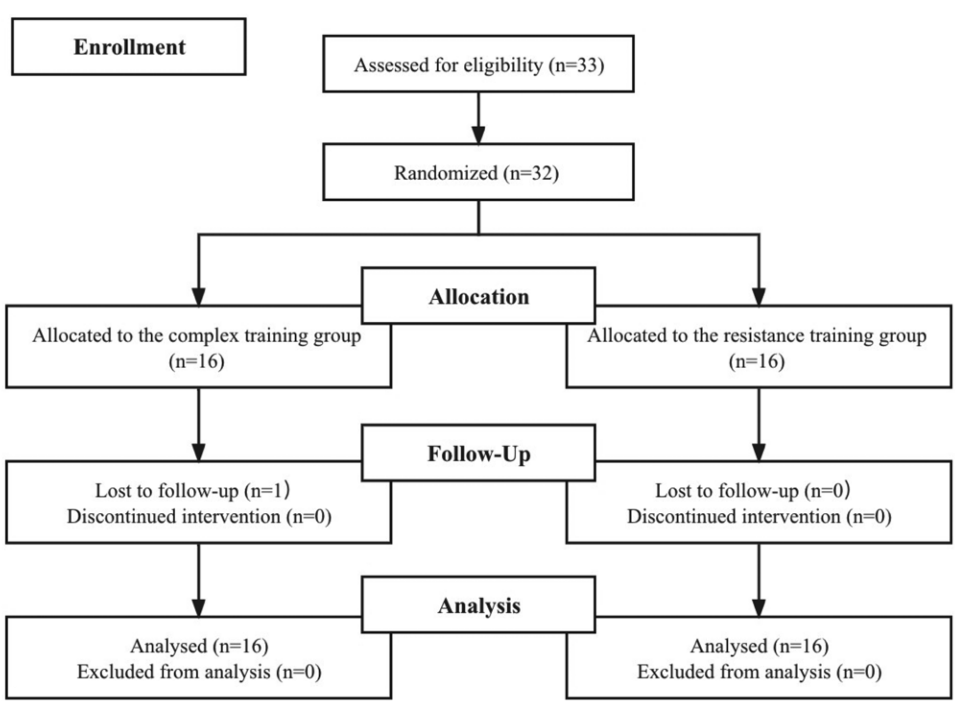

Figure 1. Flow chart of the study process according to the CONSORT statements.

outline of the CT and RT programs, including detailed descriptions and progression strategies. In adherence to the principles of linear strength training sessions, each program consisted of the following 3 phases. Phase 1, lasted for 1 week and focused on improving muscular adaptations; Phase 2, spanned 3 weeks and aimed to enhance muscular hypertrophy; and Phase 3, lasted 4 weeks with the goal of maximizing strength and power. During Phases 1 and 2, the participants were instructed to complete training sessions twice a week. In Phase 3, they were required to perform 3 training sessions per week, with a recovery period of 48 to 72 hours between each session. RT methods primarily emphasized structural exercises that targeted large muscle groups such as squat, deadlift, and hip thrust. Within a single session of RT, linear periodization (e.g., pyramid training method) was used for load arrangement to enhance both nerve function and lower extremity strength. Certified strength and conditioning coaches provided participants with consistent instructions on precise skills for resistance and plyometric exercises throughout each phase. All protocols were designed and supervised by a researcher who was proficient in the strength and conditioning field as well as the fitness field.

2.3. Test program

The test was conducted before and after the 8-week training period in both the CT and RT groups. The tests included the 5-0-5 COD test, Illinois agility test (IAT), one-repetition maximum (1RM) of back squat test, and vertical jump test. The participants performed a standardized warm-up routine before the test sessions.[14]

2.3.1. 5-0-5 change of direction test. The 5-0-5 COD test is used to assess an athlete's COD capacity in a variety of sports, particularly in short-distance acceleration and COD sports, such as basketball and football.[15] Figure 2 in the study depicts the setup used for a specific agility test involving cone buckets and the Smart Speed system. The arrangement was as follows: Two cone buckets, labeled as A, were symmetrically placed at the starting line; An additional pair of cone buckets, labeled as B, were positioned 3 meters to the right of the parallel point A; Another cone bucket, labeled as C, was placed 3 meters to the left of the parallel point A. The Smart Speed system (Fusion Sport, Coopers Plains, Australia), a precise timing mechanism, was stationed behind each pair of cones to automatically record the start and end times of the test. The test procedure was as follows: Upon hearing the command "Ready, go!," participants began at point A and were instructed to perform a quick right turn, followed by a sprint to point B; Upon reaching point B, they were asked to swiftly turn around and sprint to point C; Then, immediately after arriving at point C, they had to turn around again and run back to point A.

Table 1

Resistance training and plyometric training program.

Phase	Period	RT	CT
Phase 1	1 wk	65% 1RM × 15RM × 6–8 sets × 60s	(65% 1RM × 15RMS + 3–5RMP) × 6–8 group × 60 s
Phase 2	3 wk	70–85% 1RM × 6–12RM × 6–8 group × 90 s	(70–85% 1RM × 6–12RMS + 5–10RMP) × 6–8 group × 90 s
Phase 3	4 wk	80–100% 1RM × 1–8RM × 68 group × 180–240 s	(80–100% 1RM × 1–8RMS + 5–10RMP) × 6–8 group × 18–240 s

% 1RM = percentage of 1RM maximum load intensity, CT = complex training, P = plyometric exercise, RM = maximum repetitions, RT = resistance training, S = regular strength training.

Each participant completed 3 trials of this test. The final valid score for each participant was recorded as the highest (fastest) time out of the 3 attempts. To ensure adequate recovery and prevent fatigue, there was a rest period of 5 to 10 minutes between each trial. This setup and procedure were designed to accurately assess the agility and COD ability of the participants in a controlled and repeatable manner.

2.3.2. Illinois agility test. The agility zone of the IAT had 4 conical barrels (Fig. 3).[16] In this agility test, the course and timing mechanism for the athletes were structured as follows: Upon receiving the start command, each athlete commenced by running a distance of 9.20 meters, after which they turned around and returned to the starting point. At the start, the athlete executed a shuttle run, moving between 4 markers, and this included completing two 9.20-meter sprints to finalize the agility test course. The participants' scores were accurately recorded using an electronic timing system, specifically the Smart Speed system by Fusion Sport, Coopers Plains, Australia. Infrared timing gates, about 100 cm in height, were positioned at both the starting and finishing lines. To ensure adequate recovery, the athletes underwent 3 consecutive tests, with each test separated by a rest interval of 5 to 10 minutes. The highest score out of the 3 trials was recorded for analysis. This setup was designed to precisely evaluate the athletes' agility, speed, and change of direction (COD) abilities in a controlled and quantifiable manner, with the advanced timing technology providing reliable and exact measurements of performance.[3]

2.3.3. One-repetition maximum back squat. To assess maximum leg strength per individual, the back squat exercise was used.[17] The 1RM test, a measure of the maximum weight an individual can lift through a complete joint range (specifically at 90° knee flexion), follows a structured procedure. Initially, participants perform a warm-up with 5 to 6 repetitions at a low load (about 40% of their previous 1RM test load). This is followed by 3 to 4 repetitions with a heavier load (approximately 70% of the estimated 1RM) to prepare the muscles for maximum effort. Then, a single repetition with 95% of the estimated 1RM is performed as a near-maximum effort. The actual 1RM attempt involves lifting a load equivalent to the participant's perceived maximum capacity. If successful, the weight is incrementally increased by 1.0 to 2.5 kg for further attempts. The test is considered a failure if the participant cannot complete a lift through the full range of motion on at least two attempts, with a 2-minute rest interval between each trial. Typically, 4 to 5 trials are needed to accurately determine the 1RM, ensuring a precise assessment of maximum strength capacity, which is vital for customizing strength training programs.[18]

2.3.4. Vertical jump test. The vertical jump test, including the countermovement jump (CMJ) height, was used to evaluate lower extremity strength.[19] Participants in the study performed a series of cCMJs 3 times on a force platform (Kistler 9281CA; KISTLER, Winterthur, Switzerland) designed to precisely measure their jumping performance. Each participant was required to complete 3 jumps, with the highest jump height from each series being selected for analysis. Strict control was maintained over the take-off procedure, prohibiting any preparatory steps or maneuvers to ensure consistency and accuracy in the measurements. The force platform was instrumental in accurately capturing both take-off and landing times. This data facilitated the assessment of the flight phase duration of each jump. The calculation of the CMJ height was then conducted using an equation developed by Bosco et al, which leverages the measured flight phase duration. This methodological approach provided a detailed and accurate assessment of the participants' explosive leg power, as reflected in their CMJ performance.[20]

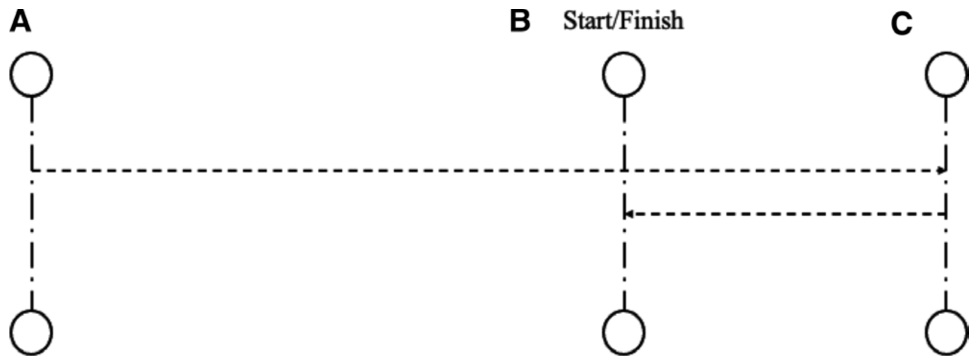

Figure 2. The 5-0-5 COD test.

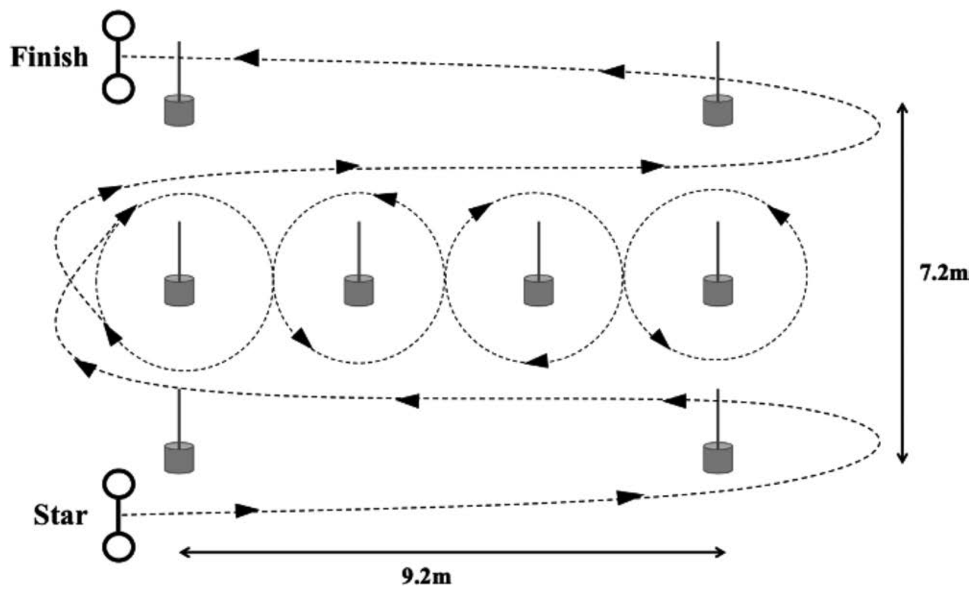

Figure 3. The IAT test. IAT = Illinois agility test.

2.4. Statistical analysis

All experimental data were analyzed using the IBM SPSS statistical software package (version 25.0; IBM, Chicago). The results are expressed as means ± standard deviations, with a level of significance of $P < .05$ for all tests. The Shapiro–Wilk test was used to assess the normality of data distribution. The nonparametric Friedman test was used for data that was not normally distributed. The two-way repeated-measures ANOVA test (group × time) was performed to evaluate the impact of exercise training (i.e., RT and CT) on the COD and power performance. The dependent variables analyzed for each model were the 5-0-5 COD, IAT, 1RM BS, and CMJ results, where the model factors considered were group, time, and interaction. Upon observing the notable interactions, LSD post hoc correction was performed to assess significant interactions. We assessed the influence of training (i.e., RT or CT) on performance within each group using separate one-way ANOVA models; the modeling element was time. The ES for within-group comparisons, expressed as Cohen's d,[21] was calculated using the absolute value of each test result. ES values were interpreted based on the following thresholds: <0.2 as trivial, 0.2 to 0.6 as small, 0.6 to 1.2 as moderate, 1.2 to 2.0 as large, and > 2.0 as very large.[22]

3. Results

All participants completed the prescribed training and assessment, and their data was included in subsequent analysis. All the data were normally distributed. There was no obvious difference between the groups in terms of demographic characteristics, strength and power outcomes, and performance ($P > .05$). Table 2 shows the demographic information of the study participants (Fig. 4).

3.1. Change of direction performance

The fundamental two-way repeated measures ANOVA models indicated remarkable interactions between group and time on the IAT ($P < .001$) but not on the 5-0-5 COD ($P = .147$) results. post hoc analysis confirmed that IAT scores ($F = 8.610$, $P = .005$, Partial $\eta^2 = 0.125$) significantly increased after the CT intervention compared with the scores before the intervention and after RT.

In addition, the one-way ANOVA test indicated that the 5-0-5 COD test scores significantly increased after the CT intervention compared with the pre-intervention scores ($P = .005$), while no clear difference was observed in the RT group ($P = 0.394$).

3.2. Strength and power

The fundamental two-way repeated-measures ANOVA test indicated remarkable interactions between group and time on CMJ ($P = .040$) but not on 1RM BS ($P = .809$).

post hoc analysis confirmed that the CMJ scores ($F = 86.781$, $P < .001$, Partial $\eta^2 = 0.591$) significantly increased after the CT intervention compared with the scores before the intervention and after the RT intervention. For the 1RM BS test, the secondary one-way ANOVA test showed a significant improvement in both the CT (P = .001) and RT (P = .004) groups.

4. Discussion

The results of this study revealed that CT is a notably effective method for improving lower limb strength and COD ability in female basketball athletes. This conclusion was drawn from observing significant enhancements in IAT and CMJ heights in the CT group, as compared to those noted in the RT group. These findings underscore the potential benefits of integrating CT into the regular training regimens of female basketball players. The integration of CT could serve as a valuable strategy for optimizing their athletic performance, particularly in the realms of lower limb strength and COD ability, which are critical competencies in basketball. This suggests that CT offers a more holistic approach to developing key athletic skills necessary for success in this sport, especially for female athletes.

After completing the CT program, there were notable enhancements in both strength and power among the participants, as evidenced by significant improvements in the 1RM squat test and CMJ performance. These improvements are particularly critical for basketball performance, considering the pivotal role that lower limb muscles play in key movements essential to the sport. These movements include jumping, running, and changing direction on the court, all of which are fundamental to basketball play. The enhanced strength and power in the lower limbs, as demonstrated by improved 1RM squat and CMJ results, suggest that CT effectively develops the muscular capabilities required for these dynamic and explosive movements, thereby contributing significantly to the overall athletic performance of basketball players.[23] In this study, the traditional RT protocol focused on isometric contractions with slow velocity movements, leading to longer transition times between eccentric and concentric contractions. In contrast, the CT protocol was tailored to enhance both strength and speed. This was achieved by incorporating exercises with larger loads (above 75% of 1RM) to improve the strength-speed aspect of the force-velocity curve, and exercises with lower loads (below

Table 2

Assessment results of the CT and RT groups before and after 8 weeks of training.

	RT group				CT group			
	Pre	Post	P	Cohen's d	Pre	Post	P	Cohen's d
IAT(s)	19.74 ± 1.00	19.89 ± 1.16	.828	0.14	19.83 ± 1.13	17.68 ± 0.95*	.000	2.06
505 test (s)	3.06 ± 51	2.92 ± 0.50	.394	0.28	3.10 ± 0.43	2.64 ± 0.37*	.005	0.86
1RM BS (kg)	109.89 ± 7.93	118.24 ± 7.86*	.004	1.06	111.98 ± 7.00	121.28 ± 8.33*	.001	1.21
CMJ (cm)	41.82 ± 1.66	45.60 ± 2.19*	.000	1.95	41.75 ± 1.44	47.29 ± 1.30*	.000	4.04

1RM = one repetition of maximum, CMJ = countermovement jump, CT = complex training, IAT = Illinois agility test, RT = resistance training.
*Statistically significant difference between pre- and post-test results, $P < .05$.

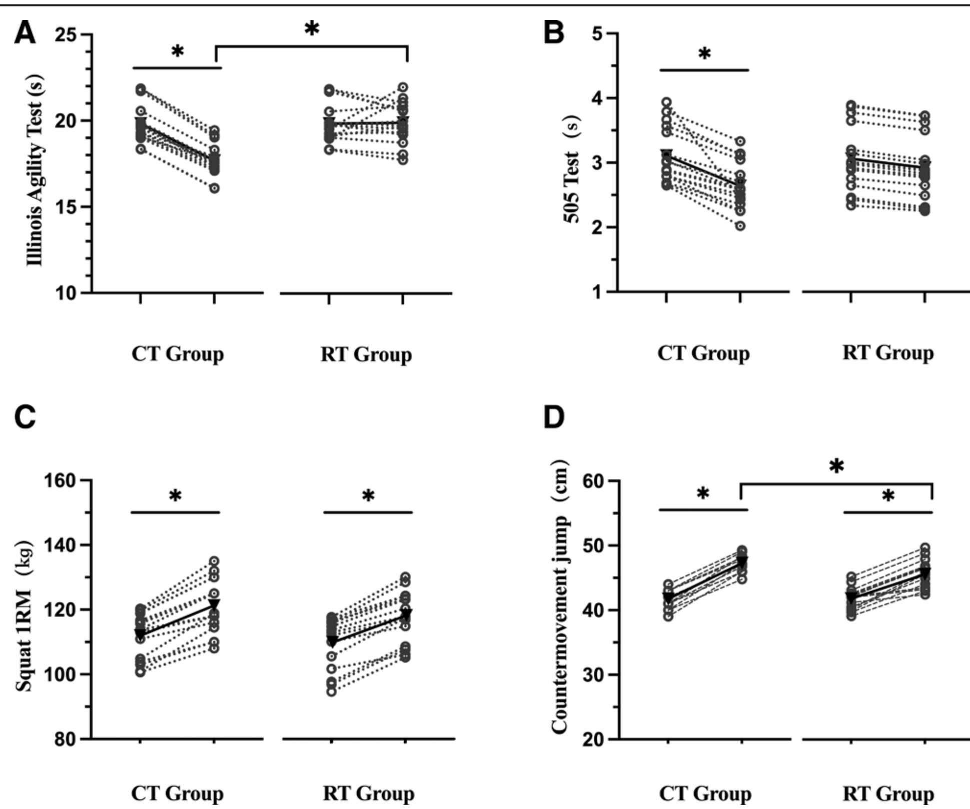

Figure 4. Results of the CT and RT groups before and after 8 weeks of training. *Statistically significant difference between all the pre- and post-interventions results, $P < .05$. Dashed lines are individual values, and solid lines are mean values. CT =complex training, RT = resistance training.

50% of 1RM) to enhance maximum velocity capabilities. The CT approach, therefore, provided a more holistic training regimen, crucial for the dynamic and rapid movements essential in basketball.[24] Maximizing strength is imperative for basketball athletes to excel in crucial actions like capitalizing on opportunities, and in skills such as handling, shooting, and stealing the ball.[25] In this study, the CT intervention incorporated RT exercises with heavier loads and faster velocities, aimed at improving lower limb strength by enhancing the force-velocity curve.[26] The findings suggest that CT may effectively lead to significant improvements in 1RM squat performance, a key indicator of lower limb strength. Considering the multifaceted nature of lower limb power, comprehensive assessments encompassing various aspects of this physical attribute are warranted. This would include exploring underlying physiological factors, such as electromyogram activity, to gain a deeper understanding of how they contribute to overall power output in basketball athletes. Such detailed analyses are essential for developing targeted training strategies that optimally enhance the specific power and strength demands of the sport.

The results of this study indicated significant improvements in the IAT and 5-0-5 test scores following the CT protocol. These enhancements in COD ability are crucial for basketball players, aiding in quickly evading defenders, seizing opportunities, stealing the ball, and breaking through defenses, thereby highlighting the effectiveness of CT in enhancing essential basketball skills.[27,28] As established in prior research, movements involving COD are among the most frequently observed patterns in basketball. Consequently, performance evaluations like the IAT and the 5-0-5 COD test are valuable tools for assessing an athlete's COD ability in a game context. These tests effectively measure agility and quickness in directional changes, which are key components of a basketball player's skill set and directly impact their performance during a game.[29] Despite existing research indicating positive changes in the change of direction (COD) abilities of basketball players following plyometric training,[4] our study suggests that CT interventions might yield even more significant improvements in this physical attribute. These findings align with the results reported by Bouteraa et al,[2] further supporting the potential superiority of CT in enhancing COD capabilities in basketball athletes. The COD is a vital athletic skill that allows athletes to rapidly alter their movement direction during gameplay. For basketball players, the ability to swiftly change direction is crucial for evading and outmaneuvering opponents. Beyond its impact on game performance, achieving high levels of maximum strength, explosiveness, and COD ability plays a significant role in injury prevention among athletes. As highlighted in previous research, athletes with high-level maximum strength typically have a more robust muscular and skeletal system. This enhanced strength provides better support and protection, reducing the risk of injuries. Thus, training that develops these attributes is essential not only for improving performance but also for ensuring athlete safety and longevity in sports.[30] Similarly, the capacity to generate explosive power and efficiently change direction plays a crucial role in injury prevention. Athletes who possess these physical attributes are typically better at controlling their movements, which significantly reduces the risk of injuries that can arise from physical impairments. Moreover, enhancing maximum strength, explosive power, and COD ability contributes substantially to improving overall physical fitness. This improvement in physical fitness not only elevates athletic performance but also fortifies the body's resilience against potential injuries, making it an essential aspect of training for athletes, particularly in sports requiring quick and agile movements like basketball.[31] This study demonstrated that an 8-week CT program was more effective than an 8-week RT regimen in enhancing maximal strength, explosive power, and COD abilities among female basketball players. The development of these physical attributes is crucial not only for improving the overall game performance of athletes but also for advancing their physical fitness. Additionally, this training contributes to a reduced risk of injuries. The findings highlight the multifaceted benefits of CT, underscoring its value in athletic training programs, particularly in sports like basketball where strength, power, and agility are key determinants of success.

Traditional RT exercises like bench presses, squats, and deadlifts typically involve slow isotonic contractions, requiring longer periods to transition between muscle lengthening and shortening phases. This characteristic of RT is more focused on building muscle strength and endurance rather than rapid, explosive movements.[32] Several studies assessing the speed of bench press movements in maximal strength training, including those involving weightlifters, have found the average speed to be around 0.17 meters per second (m/s), highlighting the slow nature of this traditional strength exercise.[33] Carter and Greenwood noted that strength exercises involving slower muscle contraction velocities might not adequately fulfill the specific explosive power requirements of female basketball players. This observation underscores the need for training that aligns more closely with the high-speed and dynamic demands of the sport.[34] Traditional strength training cycles usually follow a linear pattern, increasing intensity from 65% to 100% of 1RM and decreasing volume as the intensity grows.[8] Experts suggest that for high-level athletes, the development of maximal strength and explosive power should follow a non-linear cycle pattern, whereas low to medium-level athletes may benefit more from a traditional linear cycle training pattern.[25,35] The CT combines RT with augmentation exercises and is notably effective in enhancing athletes' explosive power, likely due to the PAP effect. PAP, triggered by high-load training, increases muscle responsiveness and strength during contractions, making CT a valuable approach for athletic training.[36] Previous studies have shown post activation performance enhancement in basketball players after training with squats.[37] Moreover, CT optimizes force transmission to the tendon by decreasing the penultimate angle between the tendon and muscle fibers. As force is transmitted, this reduced angle enhances efficiency in force transmission and activates more motor units. This activation recruits additional muscle fibers, leading to increased force output during augmented exercises that follow. This process is key to the effectiveness of CT in enhancing athletic performance, particularly in activities requiring explosive strength.[8,36,38] Conversely, the implementation of CT has been shown to improve an athlete's ability to rapidly transition from the centrifugal (muscle lengthening) to the centripetal (muscle shortening) phase of muscle contraction, effectively utilizing the stretch-shortening cycle. This rapid transition is crucial for activities requiring explosive power and agility.[39]

The study presents several limitations. First, the small sample size of 32 elite female participants raises concerns about potential placebo or practice effects. To validate the study's findings, future research should involve randomized control groups and larger, more diverse, and gender-balanced samples. Additionally, long-term follow-up assessments with various CT protocols are necessary to evaluate the durability of CT benefits and determine the optimal intensity and frequency of CT sessions for maximizing these benefits. Addressing these factors in future studies is crucial for a more accurate interpretation of results and understanding the potential implications for athletic performance outcomes.

5. Conclusions

This study demonstrated that CT effectively managed the intensity of strength training loads among elite athletes. Moreover, as a pilot randomized study, it offers preliminary evidence that CT could significantly enhance lower limb strength, power, and change of direction (COD) performance in elite female basketball athletes. This suggests the potential of CT as a valuable training approach in this specific athletic context.

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