

Effects of CrossFit training on physical adaptations, strength, and skill development in basketball players

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Abstract

Introduction: Basketball is a sport that requires the female players to have certain physical qualities and physiological skills and technical expertise that will help them to carry out their responsibilities even when they are engaged in strenuous activities. **Purpose:** The research evaluated the effect of an 8 weeks high-intensity functional training (HIFT) program that was based on CrossFit on female basketball players aged 17-20. **Procedure:** The study participants were distributed randomly into two groups: experimental (EG; n = 15) and control groups (CG; n = 15). The experimental (EG) and control (CG) groups underwent supervised CrossFit and traditional basketball conditioning programmes respectively and adapted four times a week respectively; these matched the frequency and time duration respective to the training. **Results:** The experimental group (EG) obtained a higher score than the control group (CG) using all assessment measures that had included reduced BMI of -5.78% and reduced FM of -11.96% and increased FFM of +4.26% and improved vertical jump of +15.04% and medicine ball throw distance of +17.01% and VO 2max of +11.98% and faster footwork of -12.68% and shooting accuracy of +21.88%. In this study, the intervention proved to be effective based on the large effect sizes that ranged between ES = 0.76 and ES = 0.93 and based on the Group x Time interactions which were statistically significant. **Conclusions:** The research proves that the basketball-based CrossFit program can help female athletes to improve body composition and physical performance and sport-specific skills. The application of functional movements along with contextualized skill training achieve efficient entry points through which the athletes can project their training to real games.

Key Words: CrossFit; high-intensity functional training (HIFT); sportswomen; physical performance; body composition; muscular power; VO 2max; shooting accuracy.

Introduction

Basketball is an intermittent activity that is high-intensity and requires a complex combination of anaerobic power, muscular strength, agility, and tactical knowledge, which are required not only to play to the best of their abilities but also to avoid injuries (Milanović, Stojanović, and Scanlan, 2020). Thus, exercise programs must be planned to build these physical capabilities together with ensuring that these capacities are not overuse or overstrain (Cao et al., 2025). High-Intensity Interval Training (HIIT) is a great alternative to this endurance training, in this regard, because it has been found to be better than traditional endurance training on basketball-specific physiological and performance parameters. Research indicates that HIIT can also improve VO 2 max, lactate threshold, sprint speed, and jump performance leading to adaptations that are highly similar to competitive basketball metabolic and biomechanical demands (Cao et al., 2025; Shamim, 2021). However, in spite of the effectiveness of HIIT in terms of enhancing general fitness as well as some physical parameters, the influence of this training on the sport-specific skills including shooting skills is less reliable, which suggests the necessity of additional or combined training modalities (Cao et al, 2025; Cao et al., 2024).

Functional and high-intensity conditioning are increasingly being marketed and guaranteeing that multiple aspects of fitness are enhanced at once. One of them is High-Intensity Functional Training (HIFT), which is the foundational pillar of CrossFit, referred to as one of the most prominent providers of this training model, has turned out to be a viable option due to its emphasis on multi-joint, compound exercises, incessantly

varied stimuli, and elevated metabolic stress (Feito et al., 2018). It has been also shown that HIFT can offer significant improvements in aerobic capacity (VO_2max improvements between 8 and 15%), muscular strength (determination of major lifts improvement between 10 and 20%), and anaerobic power, and all these are achieved in an efficient time-saving fashion (Neto and Kennedy, 2019; Brisebois et al., 2018). The adaptations rank positively to the many requirements on the players in the sport of basketball and thus HIFT has the potential of being effectively implemented as an element in an athlete program. It is better to mention, though, that the research on HIFT remains limited, particularly, when it comes to its direct impacts on the acquisition of basketball specific skills, as well as its usefulness in comparison to more traditional methods, including HIIT. Moreover, the risk of high injuries and programming issues also represent the area of further studies (Feito et al., 2019; Feito et al., 2018).

CrossFit training has been demonstrated to improve a number of important factors related to body composition, VO_2max anaerobic capacity, and muscular strength, which are important for athletes, especially those playing basketball. Findings show that non-specific but structured CrossFit program results in significant decreases in fat mass and increases in lean body mass leading to better general performance in athletes (Moscatelli et al., 2023; Tibana et al., 2018). Concomitant improvements in the aerobic and anaerobic pathways that CrossFit training enables allow for prolonged sustainment of intermittent applications of high-intensity work and adequate rest, including sprints, jumps, critical aspects of play in competition (Mangine et al., 2019). For example, elite CrossFit athletes have significantly lower body fat percentage and have significantly higher peak aerobic capacity when compared to recreational CrossFit athletes leading to the efficiency of CrossFit on physical fitness (Mangine et al., 2019). These adjustments are responsible for not just these specific performance outcomes but also for the general athleticism needed to participate in sports like basketball (Sauvé et al., 2024; Tibana et al., 2018).

Development of strength and power is essential for basketball performance, as a prerequisite for actions such as sprinting and rebounding. It has been demonstrated that the training lifting cost of Olympic lifting derivatives, plyometric training (PT) and bodyweight gymnastics may be able to increase lower-body power and maximum strength. Notably, Lamas et al. (2012) reported superior improvements in jump height for power training (PT) over strength training (ST) despite both interventions noticeably enhancing vertical jump performance possibly due to the greater effect of PT on rate of force development. Moreover, players-specific strength and plyometric training protocols have been reported to improve performance of sports specific movements, i.e. vertical jumps and sprints, after only four weeks (Barrera-Domínguez et al., 2023). In addition, complex strength training (CST), integrating both resistance and plyometric training, has been demonstrated to effectively improve lower limb strength and explosive power, which are critical components of athletic performance (Samsudin et al., 2025). In general, these training modalities stimulate neuromuscular adaptations that lead to improved performance variables pertinent to the game of basketball (Velasco, 2022).

CrossFit training, with its focus on functional movement patterns, can increase physical fitness and skill-related performance in basketball players. Prior research notes CrossFit training's unique combination of circuit-based and plyometric exercises enhances agility, change-of-direction speed, and general movement efficiency, all of which are important for basketball (Li et al., 2024). In particular, an improvement of 2.34% to 6.79% in agility variables was reported after plyometric training in basketball players (Wang et al., 2024). Also similar to CrossFit, functional training has been shown to positively impact muscle strength, linear speed, and balance, but the evidence on change-of-direction speed is equivocal (Cao et al., 2024). The results of the study by Gong et al. (2025) propose that training with CrossFit might be particularly beneficial for developing certain essential basketball skills, especially for youth athletes.

CrossFit programming in athletic training needs to come out on top in terms of care and consideration - mainly because of the sheer intensity and impact of the training, which has a proven track record of a significant risk of musculoskeletal injuries - and its particular hotspots tend to be the shoulders, lower back and knees. A couple of studies in particular - Giansina & Kassotaki in '19, and Veronez et al. a bit more recently - have shown that when CrossFit training is on the cards, these three body parts are the ones at the greatest risk. You might expect that given that, to be fair Klimek et al in 2017 found that the overall injury rate in CrossFit isn't that different - and in some cases even slightly lower - than what you would see in other high-intensity sports like Olympic weightlifting. However, injury rates in CrossFit are still pretty high - and particularly in new athletes - and those who are exercising without the right level of supervision. And then of course there are the more extreme cases of exertional rhabdomyolysis - a condition which results from extreme muscle breakdown - which have been reported in CrossFit - like Meyer et al found back in 2017, it just goes to show how important proper individualized programming, teaching sound technique and keeping a close eye on the athlete during high-intensity sessions is. A few recent studies (Van den Tillaar and Gibson in 2021, for instance) suggest that adjusting CrossFit approaches to make them more relevant to whatever sport you're after can result in a better balance of safety and effectiveness. For example - Giansina & Kassotaki (2019) and Veronez et al (2025)) have recommended that youth basketball players in particular should look to incorporate moves that are specific to

basketball - like vertical jumps, and lateral sprints and the like - into their modified CrossFit programs - and in doing so they should be able to boost their functional performance and cut down on the risk of injury

In summary, the current research shows that basketball players need complete physical capabilities which include strength power speed and agility to achieve their best performance. Traditional training methods treat fitness components as separate elements but recent studies show that high-intensity functional training (HIFT) methods like CrossFit provide a better training approach which enables athletes to improve multiple fitness areas at once (Feito et al., 2018; Neto & Kennedy, 2019). The existing research about HIFT effects on athletic populations remains scarce especially about how HIFT affects sports-related abilities such as shooting accuracy and defensive responsiveness and reactive decision making (Cao et al., 2025; Cao et al., 2024). The researchers will conduct this study to determine how an 8-week CrossFit training program affects physical changes and lower-body strength and power and basketball abilities. The researchers aim to establish how CrossFit functions as supplemental training for basketball while linking general fitness improvements to specific athletic skills through evidence-backed training programs.

Materials and Methods

Participants

The population of interest was small and well-defined; therefore, researchers used standard infinite population sample size estimation methods that work at 95 percent confidence ($Z = 1.96$) with a 5 percent margin of error ($d = 0.05$) and the conservatively estimated proportion of $p = 0.5$ to determine the sample size. The study required a final sample of 30 female basketball players, who were randomly assigned into two equal groups; however, the researchers needed to follow practical study requirements. The researchers used random allocation methods to create groups with equal baseline characteristics before starting the intervention (Table 1).

Table 1. Descriptive Statistics of Demographic and Training Variables

Variable	EG		CG					
	Mean	Std.	Min	Max	Mean	Std.	Min	Max
Age	18.73	0.81	17.00	20.00	18.87	0.76	17.00	20.00
Height	170.42	1.95	167.00	174.00	170.68	2.03	167.00	174.00
WIGHT	68.24	3.12	62.00	75.00	68.56	2.98	62.00	75.00
Training	4.62	0.85	3.00	6.00	4.58	0.82	3.00	6.00

The experimental group (EG) and control group (CG) demographic data and training information were analyzed through descriptive statistics which Table 1 displays. The groups were equivalent at the beginning of the study because researchers found no significant age or height or weight or basketball training experience differences between the two groups. The participants in the EG had a mean age of 18.73 years ($SD = 0.81$) while the CG had a mean age of 18.87 years ($SD = 0.76$), which resulted in a similar age distribution that matched the study's requirement for participants between 17 and 20 years. The mean height of the EG was 170.42 cm ($SD = 1.95$) and the CG was 170.68 cm ($SD = 2.03$) and was within the normal range of female basketball players with a height of 167 to 174 cm. The body mass of the two groups was 68.24kg ($SD = 3.12$) and 68.56kg ($SD = 2.98$), which was in line with the expected range of body weight of between 62 and 75kg. Both sample groups had a similar training experience, and the average training experience of the EG group was 4.62 ($SD = 0.85$) and the average training experience of the CG group was 4.58 ($SD = 0.82$). The study findings revealed that the two groups were fully similar in the beginning of the experiment which minimized the impact of external factors on study results.

Procedure

The group exchange of the research team was carried out by a three-day test which determined the equality of the groups at the start of the research. The inclusion criteria applied in the study meant that the individuals were to have all of these four factors: (a) female sex, (b) at least five years of regular basketball training and competition, (c) able to attend training sessions at least three times a week, and (d) no chronic medical conditions or medications that might affect the physiological responses or performance results. To guard the scientific integrity, the research team used exclusion criteria to exclude those participants with cardiovascular or respiratory conditions that might decrease their exercise capacity, those participants who did not train, or non-adherence to testing procedures.

Study Design

The intervention was carried out in Basketball Club in Minya Governorate in Egypt. The evaluation conducted between January 20-22 of 2025 provided the baseline information in the form of standardized tests of all the participants of the study. The experimental population then underwent a CrossFit-based training program that was provided over a period of eight weeks; between January 26 and March 20, 2025. The control group had parallel training program that was comparable in terms of frequency and length of training

but followed their own unique program structure and content. Measures on both groups were taken after the intervention, according to the same conditions as the pre-tests, between March 22 and 24, 2025. The test involved giving the players full information regarding the possible risks and they signed the consent form. The King Faisal University Ethics Committee approved the research protocol after reviewing it (Reference: Minia- -2024-Dec-ETHICS4220).

Instrument

Anthropometric and Body Composition Assessment

Anthropometry was done through standardized and validated procedures to determine baseline body composition and track down possible changes after the intervention. The Martin anthropometric stadiometer (GPM, Switzerland) was used to measure height, with a range of 0.1 cm and which was selected on the basis of reliability and accuracy (Hassan, 2025; Kolachahi, Elmieh, and Talebi, 2020). The participants were made to stay standing with their feet together, arms crossed across the chest, and heels, buttocks and upper back in complete contact with the vertical stadiometer. The participants were requested to close their eyes and take deep breathing in order to achieve the best posture alignment.

The measurements of body weight and overall body composition including Body Mass Index (BMI), Fat Mass (FM), Fat-Free Mass (FFM using the assistance of InBody 720 bioelectrical impedance analyzer (InBody Co., Ltd., Seoul, South Korea). This tool has been found to be highly valid and test-retest reliability of measuring the body composition of the various populations (Gonzalez, Orlandi, and Santos, 2019; Stanković, Čaprić, Đorđević et al., 2023). To enhance the accuracy of the measurement, the following pre-assessment instructions were implied on the participants; (1) they were to fast at least four hours prior to the test, (2) to avoid caffeine and alcohol consumption and (3) avoid intense physical exercises within the 12 hours before the test. Measurements were made at the same conditions of the environment and at a similar time of the day (morning hours) to minimise the diurnal variation. This had been done since such measurements were done at the end and pre-training to determine the changes in body composition due to training.

Maximal Oxygen Uptake (VO₂max) Assessment

An exercise test (GO 2) was aimed at determining maximal oxygen consumption (VO₂ max) in a motorized treadmill (Lode Valiant Ultra 300, Lode B.V., Groningen, The Netherlands) with a breath-by-breath cardiopulmonary analysis system (Cortex MetaMax 3B, Cortex Biophysik GmbH, Leipzig, Germany). This technique has been valid and reliable to measure the oxygen uptake (VO₂) and the production of carbon dioxide (VCO₂) during dynamic exercise (Schutte et al., 2016; Zhang et al., 2023). It started at a personalized rate of 712 km/h (it depends on the initial level of fitness of the participant) at a 1 percent inclination, according to the recommendation of the American College of Sports Medicine (ACSM, 2021). The treadmill velocity was modified at a rate of 1km/h per 3 min until volitional exhaustion. During the test, heart rate was continuously monitored using a Polar H10 chest strap (Polar Electro Oy, Finland), perceived exertion was measured using the Borg 620 Rating of Perceived Exertion (RPE) scale (Borg, 1998), and real-time respiratory gas exchange was measured. The average values of VO₂ were taken during the last 60 s of each stage, and VO₂max was determined as the maximum average values of VO₂ in the last 30 s before the termination of the test (Goenarjo et al., 2021; Midgley et al., 2007).

To achieve data validity, the following pre-test procedures were followed: (1) the participants were required to stop consuming caffeine, alcohol, and stimulants at least 12 hours before the testing procedure; (2) the subjects were asked to maintain a post-absorptive condition (at least 4 hours fasting) before the test. The assessments were all done before 11:30 AM to check the circadian variation of physiological performance (Atkinson and Reilly, 1996). The ambient temperature was maintained at 18-24 °C and relative humidity at 30-60, and environmental conditions during the testing were monitored constantly. VO₂ max test was considered valid when at least two of the following criteria were met: (1) VO₂ plateau (<150 mL/min to -1) despite a rising workload, (2) respiratory exchange ratio (RER 1.10 or above), or (3) a maximal heart rate achieved within a range of positive and negative variation of 10 beats/min -1 of its age-predicted maximum (220 -age) (ACSM, 2021; Midgley et al., 2007).

Physical performance and skill performance tests.

All participants were given a standardized 10 min warm-up procedure before testing, which involved 5 min of jogging and walking followed by 5 min of dynamic stretching. With skill-specific tests (free-throw shooting and footwork), 5 more minutes of sport-specific activity, involving dribbling, passing, and rebounding, were added (see Appendix A). All tests were performed under the same environmental conditions and were led by qualified exercise scientists.

Lower-Body Power: Vertec Vertical Jump Test (VJ).

The explosive power of the lower body was assessed using the Vertec-Vertical jump device (Jump USA, Sunnyvale, CA, USA), which is a field-based measure that was repeatedly tested for jump height and demonstrated a high level of validation in athletic groups (Buckthorpe, Morris, and Folland, 2012; Yingling et al., 2024). The participants were in a standing position with their feet flat on the ground and at a distance of

approximately 10 cm in front of the apparatus facing the vanes. The participants were asked to use a countermovement jump (CMJ) technique, where the knee and hip flexion were rapid, and the extension was forceful, with arm swinging in coordination with the motion to displace the highest possible vane with the dominant hand. Every respondent was allowed to go through three trials separated by a period of 30 s of rest to reduce the effects of fatigue. The maximum displacement (in cm) was measured and analyzed. It shows a high test-retest reliability ($ICC = 0.92-0.96$) and a high correlation with force plate-derived power values ($r = 0.87$), which proves that it is a valid measure of lower body power in basketball scenarios (Buckthorpe et al., 2012).

Upper body power: Medicine Ball Javelin Quadrathlon Test (MBQJ).

The Medicine Ball Javelin Throw, a functional test that is based on an imitation of a javelin-like overhand throw in a standing position or limited-steps position, was used to measure upper body explosive strength and kinetic chain coordination (Zhao et al., 2023; Hassan, 2025). The participants were positioned with a 2-kg medicine ball at the chest level, took a staggered position (shoulder-to-shoulder distance, with their lead foot facing the target), and performed a full-body throw made of sequential rotation of the hips, trunk extension, and propulsion of the arm. No more than two preparation measures were allowed prior to being released. The distance at which the ball was thrown was recorded from the front foot (at release) to the point of first contact with the ground using a calibrated tape measure. Three experiments were conducted, separated by 60 s of rest between trials, and the maximum valid throw was used in the analysis. The test has shown a great degree of reliability ($ICC = 0.94$) and construct validity as an indicator of upper body strength in team sport athletes (Hassan, 2025; Zhao et al., 2023).

Basketball-Specific Footwork (FW): Modified Reactive Component T-test.

Agility and multidirectional footwork were evaluated using a modified T-test combined with the FITLIGHT Trainer System (FITLIGHT Sports Corp., Canada), which includes a visual stimulus reactive component to increase the ecological validity of basketball-specific motions (Hassan et al., 2022). The course was made up of four cones in a T-shape, each Cone A set as follows: Cone A (start), Cone B (5 yd/4.57 m (right) of A), Cone C (10 yd/9.14 m (forward) of A), and Cone D (5 yd/4.57 m (left) of C). A FITLIGHT unit was positioned at each cone (B, C, and D). Upon the auditory signal, participants sprinted to Cone B, turned a light off with the right hand, laterally shuffled to Cone C (left hand) and Cone D (right hand), and then reversed along the required route. Trials were invalidated if a participant crossed his feet during the shuffle, missed by turning off a light, or went off course. Of the three valid attempts each participant performed, there was 2 minutes rest period between attempts, and the time of analysis was based on the fastest time (to 0.01 s) of the experiment. Reactive stimuli enhance the discriminative validity of the test for court sports, and the reliability coefficients of $ICC = 0.89-0.93$ have been recently reported (Hassan et al., 2022).

Free throw shooting Accuracy (FTSA)

The standardized 10-shot protocol was the test protocol for free throw shooting; the test was conducted at the official NBA-rule foul line (15 ft / 4.57 m in front of the backboard). The shots were taken under controlled conditions with a brief familiarization period. Every shot (ball went into the basket without hitting the rim or the backboard) was counted. The shooting accuracy was calculated as a percentage based on this success rate (e.g., $8/10 = 80\%$). All shots were made within 2 min, and no defensive pressure or external distraction was used to ensure consistency. This protocol corresponds to the protocols employed in elite basketball research and shows high intra-session reliability ($ICC = 0.85-0.91$) and the ability to detect training-related changes in shooting mechanics (Zhang et al., 2023; Li et al., 2024; Sun et al., 2025).

Experimental Procedures

The eight weeks experimental intervention was extended to enhance basketball specific physical adaptations, muscular strength, power, and technical skills through the application of a high intensity functional training (HIFT) program modeled after CrossFit. The experimental group was left to train four times in a week (Saturday, Monday, Wednesday and Thursday) and 32 sessions were supervised. The sessions were 90 to 120 minutes in length and had a standard format which consisted of four successive activities that were Warm-up (15 min), Functional Strength and Conditioning (30-50 min), Basketball-Specific Skill Development (20-45 min) and Cool-down and Recovery (10 min).

1. Functional Strength and Conditioning Phase.

This stage combined multi-joint, compound exercises based on the CrossFit framework but adapted to the biomechanical and metabolic requirements of basketball. Exercises focused on the large muscle areas to work on explosive strength, endurance of the muscles and anaerobic power at the same time. The training block consisted of: Olympic-style weightlifting: Power cleans, overhead presses (7590 percent of 1RM); Plyometrics: Box jumps, lateral bounds; Suspension training: TRX rows, TRX lunges; Kettlebell exercises: Swings, goblet squats; Metabolic conditioning: Battle rope circuits.

The participants did 3-5 sets of 6-10 repetitions each of the exercises, separated by 30 80 seconds of rest between sets and 40 55 seconds of rest between exercises. The intensity was monitored in a systematic study that involved one complementary measurement using percentage of 1RM (relative load) in resistance

exercise, two and a half complementary measurements using percentage of 7590 percent of heart rate (HRmax) during metabolic periods and the Borg Rating of Perceived Exertion (RPE) scale (79 out of 10). This multimodality approach provided a high level of accuracy in the training load, progressive overload, and reduced the risk of injury as the training was individually adjusted (Gianzina & Kassotaki, 2019).

2. Basketball-Specific S.K.D. Phase.

This stage aimed at converting physical benefits into sport-specific performance, where the primary attention was paid to rebounding mechanics and footwork agility, which are the major factors of defensive and offensive performance in basketball. There were drills aimed at improving body control, spatial awareness, speed of direction change and timing during fatigue. Activities involved: Ladder agility exercises to develop foot speed and coordination; Cone-based change of direction patterns to simulate situations in a game; Reactive decision-making exercises on the FITLIGHT™ Trainer System where the subjects were requested to take a response by touching targets that were randomly lit and the test involved maintaining appropriate movement mechanics.

The intensity of all the drills gradually increased through the eight weeks with an increasing complexity and cognitive load to avoid plateaus of adaptation and in order to force neuromuscular transfer. Technical fidelity and safety were achieved by having sessions conducted by certified coaches.

Conversely, the control group was put through a traditional basketball conditioning program that was compared in terms of frequency, duration and the amount of volume per week and excluded all CrossFit-inspired situations (e.g. Olympic lifts, metabolic circuits and complex functional movements). They implemented a program focused on conventional aerobic conditioning, simple strength training, and generic skill training and lacked reactive and high-intensity functional units. This design was chosen in order to directly compare the added value of CrossFit-based HIFT on physiological adaptations (e.g., vertical jump height, upper-body power) and basketball-specific skills (Free throw shooting performance, Basketball-Specific Footwork) that were evaluated with the help of validated field tests mentioned in the Methods section (see table 2 and Appendix B)

Table 2. Weekly Structure of the CrossFit-Based Training Program for the Experimental Group

Training Day	Warm-up (15 min)	Functional Conditioning (30–50 min)	Strength & Basketball-Specific Skill Development (20–45 min)	Cool-down / Recovery (10 min)
Saturday	- Dynamic mobility drills - Light jogging (5 min) - Activation exercises (glutes, core)	- Power cleans (4×6 - 80% 1RM) - Box jumps (3×8) - TRX rows + lunges (3×10) - Battle ropes (4×30 sec)	- Ladder footwork drills - Cone-based change-of-direction - FITLIGHT™ reactive agility tasks	- Static stretching - Foam rolling (lower body)
Monday	- Jump rope (3 min) - Hip & ankle mobility - Core activation	- Overhead press (4×5 - 85% 1RM) - Kettlebell swings (3×15) - Goblet squats (3×10) - Metabolic circuit: rowing + burpees (AMRAP 8 min)	- Rebounding technique under fatigue - Spatial awareness drills - Reaction-based defensive slides	- Breathing exercises - Light static stretching
Wednesday	- Dynamic stretching - Sprint mechanics drills - Core stability	- Front squats (4×6 - 75% 1RM) - Lateral bounds (3×6/side) - TRX push-ups + single-leg RDLs (3×10) - EMOM (Every Minute on the Minute): 10 thrusters × 10 min	- FITLIGHT™ T-test variations - Decision-making under movement - Quick-stop-and-shoot scenarios	- Yoga-inspired flexibility routine - Diaphragmatic breathing
Thursday	- Agility ladder warm-up - Shoulder mobility - Pulse-raising jog	- Clean pulls (3×5 - 90% 1RM) - Medicine ball rotational throws (3×8/side) - Complex: KB swing → goblet squat → overhead press (4 rounds) - Shuttle runs with resistance bands	- Game-like footwork sequences - Defensive closeout + recovery drills - Transition offense simulations	- Full-body static stretching - Hydration & mindfulness cues

All strength loads were individually prescribed based on baseline %1RM assessments, and training intensity was systematically monitored using a multimodal approach—including heart rate (maintained at 75–90% of HRmax), the Borg Rating of Perceived Exertion scale (RPE 7–9 out of 10), and real-time coach observation. At the same time, the basketball-specific skill development aspect was periodized gradually, and

its complexity was escalated after every two weeks, by adding cognitive load (e.g., reactive visual stimuli), shortening the time of rest, and adding more game-like decision-making demands to maintain constant neuromuscular adjustment and skill transfer.

Data analysis

All the statistical analysis of the study was done using IBMS SPSS statistics (Version 26.0). The research team computed the measures of descriptive statistics in all the dependent variables in both experimental and control groups at pre- and post-intervention time points by establishing the means and standard deviations (SD) and coefficient of variation (CV%). The Shapiro-Wilk test verified normality of data distribution and Levene's test assessed homogeneity of variance in the study. The study used two-way repeated measures analysis of variance (ANOVA) to assess intervention effects by using Time (Pre vs. Post) as the within-subjects factor and Group (Experimental vs. Control) as the between-subjects factor. The analysis examined three primary effects which included the main effect of Time and the main effect of Group and the Group $\times$ Time interaction effect. The study reported partial eta squared (η^2) as the effect size measurement which showed small (≥ 0.01) and medium (≥ 0.06) and large (≥ 0.14) effect size thresholds. Researchers applied Greenhouse-Geisser corrections when they found sphericity assumption violations. The Bonferroni correction was used to control for Type I error inflation during post hoc pairwise comparisons between groups. The study used independent samples t-tests to establish baseline equivalence between groups and paired samples t-tests to evaluate within-group changes between pre- and post-intervention periods. Researchers calculated Cohen's d to measure effect sizes for post-test between-group comparisons which were interpreted as trivial (< 0.2) small (0.2–0.5) moderate (0.5–0.8) and large (> 0.8). The researchers reported 95% confidence intervals (CI) and exact p-values for every inferential analysis conducted. The researchers established statistical significance at a p-value threshold of less than 0.05.

Results

Table 2. shows the descriptive statistics for both the experimental group and control group before and after the intervention while showing changes in the primary outcome measurement. The study assessed body composition through three indices which include BMI and fat mass and fat-free mass and the researchers measured muscular power through two methods which included vertical jump height and medicine ball javelin quadrathlon distance and the study measured VO_{2max} as a physiological adaptation and basketball-specific skills through footwork test time and free throw shooting accuracy. Figure 1 provides a visual representation of the magnitude of change in these variables from baseline to post-intervention, which demonstrates that the EG group experienced more significant progress after completing their 8-week CrossFit-based training program. The researchers applied a two-way repeated measures ANOVA to test whether the observed changes reached statistical significance through their results which the authors documented in Table 3 showing F-values and p-values and partial eta squared (η^2) values for Time (Measurement) and Group and their Group $\times$ Time interaction. Figure 2 complements this analysis by showing effect sizes (η^2) for each effect which demonstrates that the groups exhibited different responses through their strong interaction effects. The researchers used Table 4 and Figure 3 to compare the EG and CG through their post-intervention measurement which showed mean values and standard deviations and percentage improvement differences (D. Imp.) and effect sizes (Cohen's d) and 95% confidence intervals and statistical significance levels. The CrossFit-based intervention produced better physical and physiological and skill-related results in female basketball players than the results from the control condition.

Table 2. Descriptive statistics of experimental and control groups

Group	Outcome measures	Pre Mean	Std.	CV %	Post Mean	Std.	CV %	ES	Sig.	Imp. %
EG	BMI (kg/m ²)	22.14	1.32	5.96	20.86	0.94	4.51	0.41	<0.01	5.78
	FM (kg)	18.23	1.85	10.15	16.05	1.42	8.85	0.59	<0.01	11.96
	FFM (kg)	49.82	2.10	4.21	51.94	1.87	3.60	0.62	<0.01	4.26
	VJ (cm)	42.35	2.68	6.33	48.72	2.41	4.95	0.87	<0.01	15.04
	MBJQ (m)	4.82	0.24	4.98	5.64	0.21	3.72	0.91	<0.01	17.01
	VO_{2max} (ml/kg/min)	46.32	2.15	4.64	51.87	1.93	3.72	0.89	<0.01	11.98
	FWT (sec)	14.83	0.42	2.83	12.95	0.36	2.78	0.93	<0.01	12.68
	FTSA (%)	6.40	1.20	18.75	7.80	1.05	13.46	0.76	<0.01	21.88
CG	BMI (kg/m ²)	22.08	1.28	5.79	21.75	1.21	5.56	0.09	0.03	1.50
	FM (kg)	18.15	1.78	9.81	17.82	1.70	9.54	0.11	0.04	1.82
	FFM (kg)	49.76	2.05	4.12	50.12	1.98	3.95	0.18	0.02	0.72
	VJ (cm)	42.28	2.65	6.27	44.15	2.52	5.71	0.35	<0.01	4.42
	MBJQ (m)	4.80	0.23	4.79	5.02	0.22	4.38	0.42	<0.01	4.58
	VO_{2max} (ml/kg/min)	46.25	2.10	4.54	47.68	1.95	4.09	0.34	<0.01	3.09
	FWT (s)	14.80	0.41	2.77	14.32	0.39	2.72	0.38	<0.01	3.24
	FTSA (%)	6.35	1.18	18.58	6.65	1.12	16.84	0.15	0.08	4.72

Key: EG—Experimental Group; CG—Control Group; Min—Minimum; Max—Maximum; BMI— Body fat index; FM—Fat mass; FFM—Fat-free mass; MBJQ—Medicine Ball Javelin Quadrathlon; VO2Max —maximal aerobic capacity; FW—footwork; FTSA— Free throw shooting Accuracy; CV—coefficient of variation; ES— Effect size; Imp. % — improvement percent.

The Table 2 results indicate that all the measured variables have improved significantly in the experimental group (EG) compared to the CG that has changes that are not so significant. There were significant changes in the body mass index (BMI; -5.78) and fat mass (FM; -11.96) and significant improvements in fat-free mass (FFM; 4.26) which showed adaptations of the body composition are favorable. Significant improvements were also noted in measures of physical performance: vertical jump height (VJ) was also increased by 15.04%, medicine ball javelin throw distance (MBJQ) was also increased by 17.01% and maximal oxygen uptake (VO 2 max) was also increased by 11.98, which can be interpreted as an improvement of lower and upper body power, as well as aerobic capacity. Moreover, the EG also experienced significant changes in basketball-specific skills, footwork test (FWT) reduced by 12.68 percent (faster agility) and free throw shooting accuracy (FTSA) improved by 21.88 percent. Conversely, most of the variables (including a 4.42% increase in VJ and 4.58% in MBJQ) showed minor statistically significant changes in the CG, with insignificant changes in body composition and skill performance (e.g., FTSA increased only by 4.72%). The large effect sizes (ES = 0.76–0.93) for the EG across performance and skill measures, compared to small effect sizes in the CG (ES = 0.09–0.42), further underscore the efficacy of the CrossFit-based intervention in eliciting comprehensive physical and technical adaptations relevant to basketball performance.

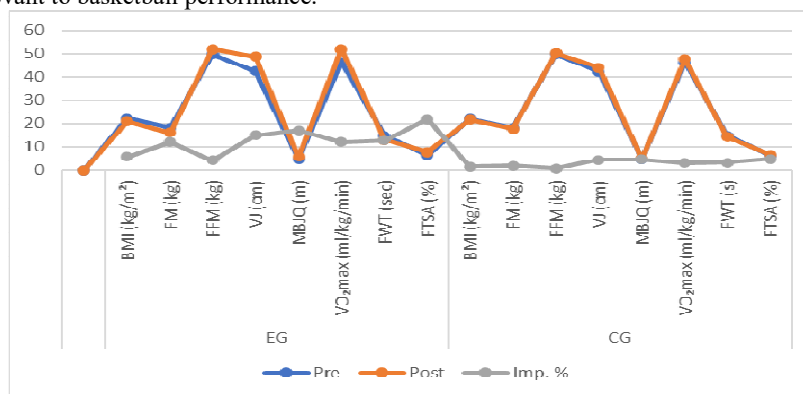


Figure 1. Pre- and Post-Intervention Changes in Anthropometric, Physiological, and Skill Performance Variables for the Experimental Group (EG) and Control Group (CG).

The two-way repeated measures ANOVA results in Table 3 display F-statistic values and p-value outcomes together with η^2 partial eta squared results for both Measurement (Time) and Group main effects plus their Group $\times$ Time interaction effect. The analysis showed no main Group effect at baseline because all variables reached p values above 0.05, which confirmed the experimental and control groups started with equal characteristics. The Measurement main effect showed significant results for all dependent variables because the statistical analysis reached p values below 0.01 for the period between pre- and post-intervention assessment. The Group $\times$ Time interaction demonstrated statistical significance across all outcomes because it showed p values below 0.01 together with effect sizes that ranged from 0.382 to 0.784, which proved that different groups experienced different degrees of change.

Table 3. The post-hoc analyses used analysis of variance (ANOVA) together with partial eta squared (η^2) to assess Measurement and Group and Group $\times$ Time Interaction effects.

Outcome measures	Measurement			Group			Intercept			Group $\times$ Time Interaction		
	F	P	η^2	F	P	η^2	F	P	η^2	F	P	η^2
BMI (kg/m ²)	48.62	<0.01	0.621	0.94	0.341	0.031	9245.18	<0.01	0.997	18.35	<0.01	0.382
FM (kg)	198.74	<0.01	0.872	0.12	0.732	0.004	19205.63	<0.01	0.998	32.16	<0.01	0.521
FFM (kg)	215.38	<0.01	0.880	0.03	0.862	0.001	35120.47	<0.01	0.999	28.94	<0.01	0.492
VJ (cm)	320.56	<0.01	0.915	0.08	0.781	0.003	118742.31	<0.01	0.999	102.73	<0.01	0.776
MBJQ (m)	285.41	<0.01	0.904	0.15	0.702	0.005	61280.92	<0.01	0.999	94.82	<0.01	0.761
VO2max (ml/kg/min)	245.89	<0.01	0.892	0.06	0.808	0.002	78450.16	<0.01	0.999	87.34	<0.01	0.745
FWT (s)	298.72	<0.01	0.908	0.11	0.745	0.004	74320.58	<0.01	0.999	108.45	<0.01	0.784
FTSA (%)	112.36	<0.01	0.790	0.04	0.842	0.001	18650.24	<0.01	0.998	42.67	<0.01	0.588

Notes: BMI = Body Mass Index, FM = Fat Mass, FFM = Fat-Free Mass, VJ = Vertical Jump Height (cm), MBJQ = Medicine Ball Javelin Quadrathlon (meters), VO 2max = Maximal Oxygen Uptake (ml/kg/min), FWT = Footwork Test Time (seconds), FTSA = Free Throw Shooting Accuracy (%), η^2 = Partial Eta Squared, p = 0.01 is considered to be statistically significant.

In the two-way repeated measures ANOVA, Measurement (Time) produced statistically significant main effects in all dependent variables ($p < 0.01$), which suggests that there are significant differences between pre- and post-intervention conditions no matter the group assignment. The Group variable did not show any significant main effect for any of the outcome measures which demonstrate that the experimental group and control group started at the same baseline level before the intervention. The Group $\times$ Time Interaction showed highly significant results for all variables ($p < 0.01$) which produced large effect sizes (η^2 ranging from 0.382 for BMI to 0.784 for FWT). The two groups exhibited different patterns of change over time because the experimental group experienced greater improvements after completing the CrossFit-based training program. The values of Intercept F and η^2 which exceeded 0.997 demonstrated that individual baseline performance levels remained exceptionally stable thus confirming the internal validity of measurement results. The significant interaction effects together with large partial eta squared values establish strong statistical evidence that body composition improvements (BMI, FM, FFM) and physical performance enhancements (VJ, MBJQ, VO_{2max}) and basketball-specific skill development (FWT, FTSA) occurred because of the CrossFit intervention rather than natural growth and routine training and testing repetition (see figure 2).

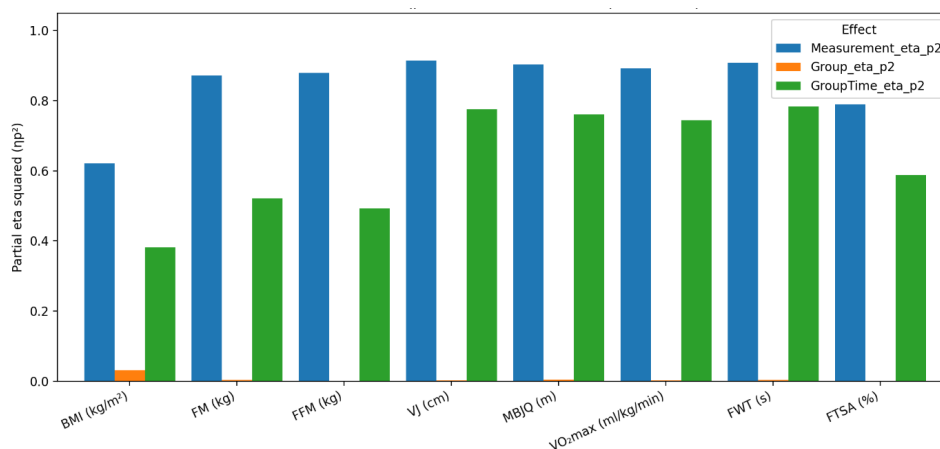


Figure 2. Effect sizes (η^2) for Measurement, Group, and Group $\times$ Time.

Table 4. The experimental group and control group post-test results showed mean values together with standard deviation measurements and percentage improvement results.

Outcome measures	Experimental		Control		ES	D. Imp.	CI		Sig.
	Mean	Std. Deviation	Mean	Std. Deviation			Lower	Upper	
BMI (kg/m²)	20.86	0.94	21.75	1.21	0.41	3.96%	-1.520	-0.260	<0.01
FM (kg)	16.05	1.42	17.82	1.70	0.59	9.93%	-2.580	-0.960	<0.01
FFM (kg)	51.94	1.87	50.12	1.98	0.62	3.54%	1.020	2.620	<0.01
VJ (cm)	48.72	2.41	44.15	2.52	0.87	8.12%	3.210	5.930	<0.01
MBJQ (m)	5.64	0.21	5.02	0.22	0.91	12.35%	0.490	0.750	<0.01
VO_{2max} (ml/kg/min)	51.87	1.93	47.68	1.95	0.89	8.79%	3.210	5.170	<0.01
FWT (s)	12.95	0.36	14.32	0.39	0.93	9.57%	-1.620	-1.120	<0.01
FTSA (%)	7.80	1.05	6.65	1.12	0.76	17.29%	0.620	1.680	<0.01

Notes: D. Imp. — Differences in improved percent.

The data presented in Table 4 reveal that the experimental group demonstrated significantly greater post-intervention improvements across all measured variables compared to the control group ($p < 0.01$). The experimental group showed significant body fat mass (FM) losses of 9.93 percent and BMI losses of 3.96 percent with a corresponding gain in fat-free mass (FFM) which shows desirable body composition changes. The experiment also reported great physical performance changes involving an 8.12 percent growth in vertical jump height (VJ) and a 12.35 percent growth in medicine ball throw distance (MBJQ) and a 8.79 percent growth in maximal oxygen uptake (VO_{2max}) that reflected stronger lower-body and upper-body strength as well as an enhanced aerobic activity. Basketball-specific skills improved significantly, as the experimental group finished the footwork test (FWT) 9.57% faster and scored 17.29% higher in free throw shooting accuracy (FTSA) compared to the control group. The findings demonstrate their practical importance because of the large effect sizes ($ES = 0.76-0.93$) which establish non-overlapping confidence intervals that demonstrate the CrossFit-based training program helps female basketball players achieve better athletic performance and physiological development (See figure 3).

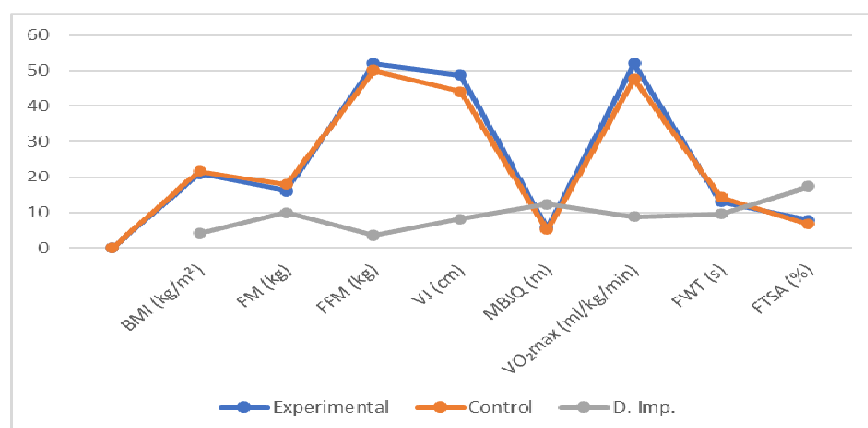


Figure 3. Comparison of mean scores of the experiment and control groups after intervention and improvement rates.

Discussion

The study results show that female basketball athletes who did an 8-week CrossFit-based high-intensity functional training (HIFT) program experienced superior body composition results and better muscular power and aerobic capacity and basketball abilities than the control group who used traditional training methods. The results demonstrate that HIFT functions as an effective training method which helps athletes acquire multiple physical skills they need for their team sports competition (Feito et al., 2018; Neto & Kennedy, 2019). The study demonstrates that CrossFit causes major fat loss which results in lower body mass index and higher fat-free mass thus showing its ability to enhance body composition. The research findings by Moscatelli et al., (2023), Brisebois et al., (2018), show that HIFT training programs produce high metabolic stress and hormonal changes which lead to benefits in fat oxidation and muscle mass development. The changes to body composition did not impact athletic performance abilities which female athletes need to maintain for their health and competitive athletic performance (Stanković et al., 2023).

Basketball running movements demand players to execute multiple jumps and sprints which involves high-intensity running because basketball performance requirements of the sport directly impact their basketball power and strength development (Milanović et al., 2020). CrossFit training implements Olympic weightlifting, plyometric exercises, and ballistic movements, which causes neuromuscular adaptations and increases speed of force production, according to established research on strength and power training methods (Samsudin et al., 2025; Lamas et al., 2012). The study by Cao et al., (2025), Barrera-Domínguez et al., (2023), Shamim, (2021), shows that traditional training methods generate smaller results than CrossFit exercises which establish CrossFit exercises as the best method to build sport-specific power. Basketball players need to restore their energy after demanding matches, which requires basketball players to develop their VO₂max by 11.98% because these aerobic improvements serve as essential resources that players require for recovery during their matches. CrossFit provides its users with the same cardiovascular advantages as HIIT according to study findings, whereas HIIT has been proven to deliver cardiovascular benefits (Shamim, 2021; Cao et al., 2025). CrossFit uses a circuit training format which forces participants to keep their heart rates high during metabolic training sessions that develop their aerobic capacity at the same rate as conventional strength training methods (Moscatelli et al., 2023; Feito et al., 2018).

Basketball players demonstrated footwork agility enhancement through their training which resulted in a 12.68% reduction in FWT and a 21.88% increase in FTSA. The study results demonstrate that better reactive footwork performance depends on using cognitive-motor challenges as training materials for agility training (Li et al., 2024; Wang et al., 2024). The skill-development phase utilized the FITLIGHT™ system which improved players' decision-making abilities under fatigue through better perceptual-cognitive processing while they performed defensive and offensive agility tasks in actual game conditions (Hassan, 2025). The study shows improved core stability and postural control along with better body composition and aerobic capacity, which results in improved fine motor control during shooting, according to Zhang et al. (2023) who connected physical and metabolic capacities to dynamic shooting accuracy in elite female players.

The study found results that differ from the earlier research conducted by Cao et al. (2025) and Cao et al. (2024) which demonstrated that HIIT produced different outcomes for skill execution. The study by Cao et al. (2024) and Neto and Kennedy (2019) produced results because we conducted the intervention with HIFT programs and basketball skill training in a single training session. The study results show that functional training should connect with the movement patterns and cognitive requirements that athletes need for their particular

sport. The study shows that all variables demonstrate large effect sizes ($ES = 0.76\text{--}0.93$) which provide evidence for both statistical significance and practical significance that coaches and athletes can use. The study shows that CrossFit programs with proper supervision maintain their safety features because users experience no adverse events or program cancellations while trained female athletes can participate in the program (Gianzina & Kassotaki, 2019; Klimek et al., 2017). The study by Hassan (2025) and Feito et al. (2019) proves that basketball players can enhance their physical and psychological development through CrossFit training which leads to improvements in all areas of their basketball-specific skills. The research results demonstrate that HIFT should be included in athletic development training programs for athletes who compete in their off-season and pre-season periods, but they should avoid using HIFT during competitive phases until they complete their recovery time.

Sport implications

The research findings prove to be useful to sports institutions that train and condition female basketball players. The findings revealed that basketball-specific CrossFit program attained various fitness effects that qualified it as an effective training solution that saved time. High-intensity functional training (HIFT) protocols can be applied to sports organizations in the pre-season and off-season to ensure maximum physical development and at the same time retain technical skills. T

he results showed that CrossFit training which combines general physical training with basketball drills, produces superior results in both reactive footwork and free throw shooting. The research supports a shift from isolated conditioning approaches toward integrated, context-specific training models that mirror the cognitive and physiological demands of actual gameplay (Hassan, 2025; Neto & Kennedy, 2019). The research results showed safe results because participants achieved high study compliance with the well-supervised CrossFit program designed for trained female athletes. Sports organizations should invest in certified HIFT coaches who will create personalized training plans to help athletes achieve peak performance while learning proper techniques and managing their training load (Gianzina & Kassotaki, 2019; Feito et al., 2018). The results show that academic institutions should update strength and conditioning programs to include evidence-based HIFT components for training academies and clubs and national training centers. The institutions will develop athletes who possess better power and agility and endurance for the modern basketball game which features intermittent high-intensity play (Cao et al., 2024; Milanović et al., 2020).

Study Limitations and Future study

The study demonstrates that an 8-week CrossFit-based training program effectively improves female players body composition and physical performance and basketball-specific skills according to its study results. The study results face interpretation challenges because four study limitations exist which affect their validity for broader application. The small sample size which included 30 participants ($n = 30$) limits statistical analyses power while diminishing the study results external validity.

The research team achieved internal validity through randomization and baseline homogeneity, but upcoming studies need to recruit participants from larger groups who represent different age categories and skill levels and competitive standards. The study focused on female basketball players, but its findings need to be treated as exclusive to that group because the research field has historically excluded women from its studies. The study needs to conduct comparative research which studies both genders to determine whether CrossFit adaptation patterns remain uniform across all gender groups. The research established an eight-week period as the maximum time for its intervention. The study found improvements across all areas, but its results showed uncertain base gains which needed further observation to confirm their future development and long-term maintenance and specific adjustments to training patterns. Future research needs to analyze CrossFit testing effects through both ongoing or scheduled testing which spans multiple training cycles between 12 to 24 weeks to determine its long-term impact on skill retention and overtraining hazards. The study failed to control all extraneous factors which included participants dietary intake and sleep quality and psychological stress and menstrual cycle stage.

Participants followed their normal daily pattern according to researcher's orders but unmeasured lifestyle changes during the study period created variations that affected their recovery and hormonal responses and performance results. The research requires objective monitoring through methods like food diaries and actigraphy and salivary cortisol testing to identify all study confounders. Finally, The study collected its sample from Minya Governorate Egypt which restricts its cultural and environmental variety.

The program's efficiency may experience regional differences which stem from various training cultures and facility access and nutritional patterns. CrossFit-based conditioning requires validation through multi-center trials which test its cross-contextual applicability in female basketball across diverse geographic and socio-cultural participant groups. The study shows that a basketball-tailored CrossFit program effectively improves young female players athletic performance through its time-efficient training method, but future research needs to address its limitations. The research will help establish evidence-based training systems to assist women's basketball development.

Conclusions

The study demonstrates that an 8-week basketball-specific CrossFit high-intensity functional training program serves as an effective method to improve physical and physiological parameters together with basketball skills in female players. The experimental group achieved statistically significant improvements in body composition because their body fat decreased while their fat-free mass increased. They achieved athletic improvements through better vertical jumps and medicine ball throws together with enhanced aerobic capacity ($\text{VO}_{2\text{max}}$) and basketball-specific skills that included better reactive footwork agility and free throw shooting accuracy. The study results demonstrate how CrossFit functions as a multifaceted training method which requires sport-specific adaptations to achieve optimal performance. The implemented HIFT program uses Olympic lifts together with plyometrics and metabolic conditioning and contextualized skill drills to create an integrated structure which links general physical preparation to on-court performance. The combined training methods established through this program improved both basic fitness and technical skills which athletes needed to perform during intense basketball match situations. The results demonstrate that trained female athletes can safely use well-supervised CrossFit protocols because the study found no adverse events while trained female athletes achieved large effect sizes in key variables. The method provides a practical solution for team sports because it enables athletes to enhance their performance through multiple training methods which they can execute within their limited training time while maintaining their skills. Strength and conditioning professionals should implement periodized CrossFit sessions by developing basketball-specific programs which they should use during off-season and pre-season periods for complete athletic development. Researchers should investigate how long-term program participation affects injury resilience and game performance and how these programs can be used in all age groups and competitive levels throughout women's basketball.

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