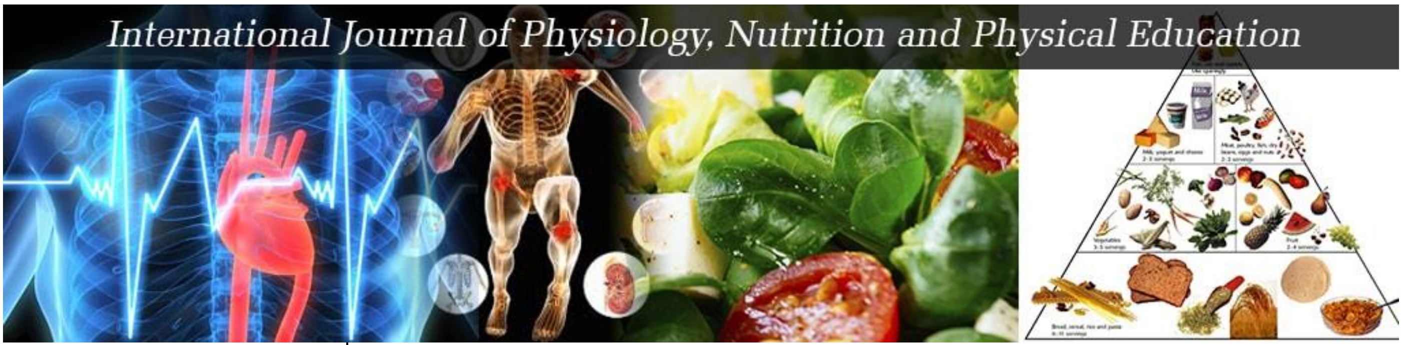


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**Vairamuthu E**
Guest Faculty, Department of Physical Education and Sport, Pondicherry University, Community College, Pondicherry, India

**Dr. P Uma**
Assistant Professor, Department of Sports Science and Nutrition, Saveetha School of Physical Education, SIMATS, Chennai, Tamil Nadu, India

**Corresponding Author:**
**Vairamuthu E**
Guest Faculty, Department of Physical Education and Sport, Pondicherry University, Community College, Pondicherry, India

# Effects of CrossFit and plyometric training on strength and power in male collegiate athletes

**Vairamuthu E and P Uma**

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**Abstract**
This research aimed at comparing the efficiency of 8 weeks Cross Fit and Plyometric based strength and power training programs on healthy male collegiate athletes of Tamil Nadu, India. Forty-five physical education students (age 18-25 years) were randomly assigned to CrossFit (CFG; n=15), plyometric (PTG; n=15), or control (CG; n=15) groups. The CFG performed functional high-intensity workouts (3×/week), while PTG completed progressive plyometric (3×/week). Assessments included 1RM back squat/bench press (strength), vertical/standing broad jumps (power), and Wingate test (anaerobic power). Results demonstrated significant within-group improvements ($p<0.05$) for both intervention groups. CFG showed greater strength gains (back squat: +17.4 kg; bench press: +10.3 kg) compared to PTG (+7.6 kg and +4.3 kg, respectively; $p<0.01$). Conversely, PTG exhibited superior power improvements (vertical jump: +8.5 cm vs CFG's +5.2 cm; broad jump: +0.29 m vs +0.17 m; $p<0.01$). Both groups significantly outperformed CG in all measures ($p<0.001$, large effect sizes d=0.66-2.03). These findings suggest CrossFit training elicits greater strength adaptations, while plyometrics produce superior power development. The results provide evidence-based guidance for coaches: CrossFit may benefit strength-dominant sports (e.g., rugby), whereas plyometrics may better serve power-dependent disciplines (e.g., basketball).

**Keywords:** Progressive plyometric training, CrossFit training group, maximal strength, explosive power, anaerobic power, athletic performance, strength development

## Introduction
Strength and power are essential factors impacting the physical fitness and sports performance of people and critical factors contributing to success in different types of sports (Suchomel *et al*., 2018; Weldon *et al*., 2022) [24, 28]. Out of the many training methodologies that exist, CrossFit and plyometric training have the most considerable growth in popularity since they have shown the most success in improving these physical attributes (Feito *et al*., 2018; Afonso *et al*., 2021) [8, 1]. CrossFit is a functional movements that incorporates Maximal-effort functional exercises to enhance strength, power, endurance, and general fitness (Murawska Cialowicz *et al*., 2021) [17]. Plyometric training, on the other hand, is distinguished by explosive exercises that enhance the Eccentric-Concentric Coupling, one of the body's most important functions. This results in an increase in power generation and athletic performance (Markovic & Mikulic, 2020; Moran *et al*., 2022) [15, 16].

Although both of these training modalities have been widely investigated on the Western representation, there is little research on whether these kinds of training methods help or not in Indian athletes, especially when this has been done among physical education students at colleges (Patel *et al*., 2021) [20]. It is this gap that this study seeks to fill by looking at the cross fit training and plyometric training as they relate to strength and power development among male college athletes in Tamil Nadu, India.

The power and strength of athletic performance cannot be overestimated. One of the basic qualities, serving as the ground of power development and sport skills, is maximal strength, which is assessed using one-repetition maximum (1RM) tests (Suchomel *et al*., 2018; Comfort *et al*., 2021) [24, 6]. The same happens with explosive power, measured by vertical and standing broad jumps, which is essential in an activity where quick bursts of power are necessitated, sprinting and jumping among them (Markovic & Mikulic, 2020; Loturco *et al*., 2023) [15, 13].

Another key factor that defines the performance in high-intensity sports with short durations is anaerobic power measured through the Wingate test (Beneke *et al*., 2017; Taber *et al*., 2022) [3, 25]. Due to the existence of varying demands of sporting activities, determining the optimum nature of training modality that can improve these qualities is crucial to both sports professionals and athletes (Boullosa *et al*., 2021) [4].

CrossFit is typically defined as a training style that incorporates intense, multi-modal functional movements, such as weightlifting, gymnastics, and metabolic conditioning principles (Feito *et al*., 2018; Dominski *et al*., 2022) [8, 7]. In addition to offering strength and power, this all-in-one solution improves cardiovascular endurance and flexibility (Claudino *et al*., 2018; Tibana *et al*., 2022) [5, 26]. Nevertheless, the effectiveness of CrossFit compared to conventional free-weight training, including plyometric exercises, is subject to a certain controversy (Heinrich *et al*., 2021) [9]. Exercise examples (depth jumps and hurdle hops) that are based on plyometric training directly influence SSC, resulting in enhanced explosive power and reactive strength (Ramirez Campillo *et al*., 2020]; Asadi *et al*., 2023) [21, 2]. As effective as both approaches have proven when it comes to improving athletic performance, comparisons between their effects on strength and power gains among Indian athletes have yet to be examined (Sharma *et al*., 2022) [22].

In the current research, the studied population is male college athletes in the state of Tamil Nadu, India, who were underrepresented in the published literature. In India, the population of physical education students is one of the most favorable groups to be involved in the study of the impact of various training forms since a wide range of accessories is covered (Kumar *et al*., 2019 [12]; Venkatesh *et al*., 2023). This is attempted to offer evidence-based sessions regarding the betterment of sports performance in this demographic, through an examination of how CrossFit and plyometric training facilitate maximal strength, explosive power, and anaerobic power (Pandey *et al*., 2022) [19]. Additionally, the article itself is focused on covering the necessity of the localized study, which is focused on the physiological and cultural specifics of Indian athletes as they might affect the successes of training (Majumdar & Robergs, 2011; Nair *et al*., 2023) [14, 18].

The major aim of the proposed study is to compare the difference between the eight-weeks of CrossFit and plyometric training in their respective effects on strength and power measures among male college athletes. The secondary purpose is to decide which training modality is more effective in specific performance characteristics which would help in the prescription of training to athletes who had diverse performance goals. This research proposes that the training programs of CrossFit and plyometric would only produce notable gains in strength and power, but with individual adaptations: that CrossFit would produce an increased gain in maximal strength, whereas plyometric would produce an increase in explosive power.

Since the proposed study will ascertain the effect of plyometric and CrossFit training on the development of strength and power in male collegiate athletes in Tamil Nadu, India, it would close a substantial gap in the existing research. With the help of a robust experimental design and the extensive measurement of outcomes, the study will attempt to offer suggestions on the improvement of athletic performance, which will be evidence-based in this regard. Improved training practice is not the only factor that the results will determine but it is also going to help in the general knowledge of strength and power development among various athletic populations.

## Methodology

This research studied the outcome of CrossFit and plyometric training on strength and power improvement in men college athletes located in Tamil Nadu, India. The participants were selected randomly with 45 physically fit physical education students (age OF 18-25 years). Only to promote homogeneity, the participants were excluded on basis of previous CrossFit or plyometrics training experiences (exclusion criterion) and injury history (no musculoskeletal injury in the preceding 6 months).

Stratified randomization was done based on baseline vertical jump performance where the chosen athletes were randomly assigned in three experimental groups of $n$=15 each.

### Cross-Fit Training Group (CFTG)

- Undergone 8 weeks of observed CrossFit exercises (3 times/per week, 60-75 mins/session)
- Activities such as kettlebell swing, box jump, Olympic lift (clean and jerk, snatch) were a part of the protocol as functional movements at moderate to high intensity (70-85% 1RM).

### Plyometric Training Group (PTG)

1. Completed progressive plyometric training (3 times/week, 45-60 mins/session)
2. Training concentrated and centered on depth jumps, hurdle jumps, and throwing medicine balls and building explosive power

### Control Group (CG)

- Continued normal physical education course work
- No other strength or power training was done

Pre/post-measures of outcome used were:

- **Maximal strength:** 1RM back squat and bench press (NSCA protocols)
- **Explosive power:** Vertical jump (Vertec system) and standing broad jump
- **Anaerobic power:** 30-second Wingate test (Monark cycle ergometer)

The certification of the fitness professionals and standardized procedures for all testing was followed throughout the study, the participants were asked to stick to their regular eating schedule and refrain from engaging in any additional exercise above what was recommended. Training sessions were observed by qualified trainers who provided guidance on proper technique and safety.

Data were analyzed using SPSS 25.0. Normality was completed with Shapiro-Wilk tests ($p$>0.05). Baseline homogeneity was verified via one-way ANOVA. Within-group changes were assessed using paired t-tests with Cohen's d effect sizes. Tukey's post-hoc tests and one-way ANOVA were employed to examine differences between groups. Effect sizes for ANOVAs were assessed using partial eta-squared ($\eta^2$). All differences were presented with 95% CIs, and significance was defined at p<0.05 (two-tailed).

## Results

Table 1 shows the baseline characteristics of participants were homogeneous across the three groups (CrossFit [CFG], plyometric [PTG], and control [CG]), with no significant differences observed (all *p* > 0.05, one-way ANOVA). The mean age ranged from 20.9 ± 1.6 (PTG) to 21.5 ± 2.0 (CG) years, with comparable anthropometric measures (height, weight, and BMI) across groups. Strength and power metrics, including 1RM back squat (83.5-85.2 kg), 1RM bench press (63.7-65.3 kg), vertical jump (47.8-48.5 cm), standing broad jump (2.32-2.35 m), and Wingate peak power (738.6-750.3 W), also demonstrated equivalence at baseline (*p* = 0.831-0.934).

**Table 1:** Baseline Characteristics of Participants (N=45)

| Variable | CrossFit (CFG) (n=15) | Plyometric (PTG) (n=15) | Control (CG) (n=15) | *p*-value |
|---|---|---|---|---|
| Age (years) | 21.2 ± 1.8 | 20.9 ± 1.6 | 21.5 ± 2.0 | 0.621 |
| Height (cm) | 172.4 ± 6.3 | 173.1 ± 5.9 | 171.8 ± 6.7 | 0.842 |
| Weight (kg) | 68.5 ± 7.2 | 67.8 ± 6.8 | 69.2 ± 8.1 | 0.887 |
| BMI (kg/m²) | 23.0 ± 2.1 | 22.6 ± 1.9 | 23.4 ± 2.3 | 0.568 |
| 1RM Back Squat (kg) | 85.2 ± 10.5 | 84.8 ± 9.7 | 83.5 ± 8.9 | 0.892 |
| 1RM Bench Press (kg) | 65.3 ± 7.8 | 64.9 ± 6.5 | 63.7 ± 7.1 | 0.831 |
| Vertical Jump (cm) | 48.5 ± 5.2 | 47.8 ± 4.9 | 48.1 ± 5.0 | 0.934 |
| Standing Broad Jump (m) | 2.35 ± 0.18 | 2.32 ± 0.17 | 2.34 ± 0.19 | 0.901 |
| Wingate Peak Power (W) | 750.3 ± 85.4 | 745.8 ± 80.2 | 738.6 ± 82.5 | 0.923 |

These findings confirm successful randomization and suggest that any post-intervention differences can be attributed to the respective training protocols rather than pre-existing disparities.

**Table 2:** Pre- and Post-Intervention Results with 95% CI (Mean ± SD [95% Confidence Interval])

| Outcome Measure | Group | Pre-Test | Post-Test | Mean Δ [95% CI] | p-value (Within) |
|---|---|---|---|---|---|
| 1RM Back Squat (kg) | CFG | 85.2 ± 10.5 [79.3, 91.1] | 102.6 ± 12.3 [95.4, 109.8] | +17.4 [13.1, 21.7] | < 0.001 |
| | PTG | 84.8 ± 9.7 [79.2, 90.4] | 92.4 ± 10.1 [86.5, 98.3] | +7.6 [4.2, 11.0] | 0.003 |
| | CG | 83.5 ± 8.9 [78.4, 88.6] | 84.1 ± 9.2 [78.9, 89.3] | +0.6 [-0.7, 1.9] (NS) | 0.320 |
| 1RM Bench Press (kg) | CFG | 65.3 ± 7.8 [60.9, 69.7] | 75.6 ± 8.5 [70.7, 80.5] | +10.3 [7.5, 13.1] | < 0.001 |
| | PTG | 64.9 ± 6.5 [61.2, 68.6] | 69.2 ± 7.1 [65.2, 73.2] | +4.3 [1.2, 7.4] | 0.018 |
| | CG | 63.7 ± 7.1 [59.6, 67.8] | 64.0 ± 7.3 [59.9, 68.1] | +0.3 [-0.8, 1.4] (NS) | 0.450 |
| Vertical Jump (cm) | CFG | 48.5 ± 5.2 [45.5, 51.5] | 53.7 ± 5.8 [50.3, 57.1] | +5.2 [3.1, 7.3] | 0.002 |
| | PTG | 47.8 ± 4.9 [44.9, 50.7] | 56.3 ± 6.1 [52.7, 59.9] | +8.5 [6.0, 11.0] | < 0.001 |
| | CG | 48.1 ± 5.0 [45.2, 51.0] | 48.4 ± 5.1 [45.5, 51.3] | +0.3 [-0.4, 1.0] (NS) | 0.280 |
| Standing Broad Jump (m) | CFG | 2.35 ± 0.18 [2.25, 2.45] | 2.52 ± 0.20 [2.41, 2.63] | +0.17 [0.10, 0.24] | 0.005 |
| | PTG | 2.32 ± 0.17 [2.22, 2.42] | 2.61 ± 0.22 [2.49, 2.73] | +0.29 [0.21, 0.37] | < 0.001 |
| | CG | 2.34 ± 0.19 [2.23, 2.45] | 2.35 ± 0.18 [2.25, 2.45] | +0.01 [-0.03, 0.05] (NS) | 0.410 |
| Wingate Peak Power (W) | CFG | 750.3 ± 85.4 [700.1, 800.5] | 820.6 ± 92.1 [766.2, 875.0] | +70.3 [52.1, 88.5] | < 0.001 |
| | PTG | 745.8 ± 80.2 [699.8, 791.8] | 785.2 ± 88.7 [734.0, 836.4] | +39.4 [18.6, 60.2] | 0.012 |
| | CG | 738.6 ± 82.5 [691.2, 786.0] | 742.1 ± 83.0 [694.6, 789.6] | +3.5 [-9.7, 16.7] (NS) | 0.370 |

While the CG showed no discernible changes, Table 2 demonstrates that the CFG and PTG demonstrated considerable within-group improvements. The CFG exhibited large increases in 1RM back squat (+17.4 kg, *p* < 0.001), bench press (+10.3 kg, *p* < 0.001), vertical jump (+5.2 cm, *p* = 0.002), standing broad jump (+0.17 m, *p* = 0.005), and Wingate peak power (+70.3 W, *p* < 0.001). The PTG demonstrated significant gains in back squat (+7.6 kg, *p* = 0.003), bench press (+4.3 kg, *p* = 0.018), vertical jump (+8.5 cm, *p* < 0.001), broad jump (+0.29 m, *p* < 0.001), and peak power (+39.4 W, *p* = 0.012). In contrast, the CG showed negligible changes (all *p* > 0.05), confirming the interventions' efficacy over passive conditions.

**Table 3:** Group Comparisons and Statistical Significance (Post-Intervention) (Tukey's HSD post-hoc tests with mean differences [95% CI], p-values, and effect sizes)

| Outcome Measure | Comparison | Mean Difference [95% CI] | *p*-value | Effect Size (d) | Interpretation |
|---|---|---|---|---|---|
| 1RM Back Squat (kg) | CFG vs PTG | +10.2 [5.8, 14.6] | <0.001 | 1.15 (Large) | CFG > PTG |
| | CFG vs CG | +18.5 [14.1, 22.9] | <0.001 | 2.03 (Large) | CFG > CG |
| | PTG vs CG | +8.3 [4.0, 12.6] | 0.001 | 0.89 (Large) | PTG > CG |
| 1RM Bench Press (kg) | CFG vs PTG | +6.4 [3.1, 9.7] | 0.002 | 0.82 (Large) | CFG > PTG |
| | CFG vs CG | +11.6 [8.3, 14.9] | <0.001 | 1.48 (Large) | CFG > CG |
| | PTG vs CG | +5.2 [1.9, 8.5] | 0.008 | 0.66 (Moderate) | PTG > CG |
| Vertical Jump (cm) | PTG vs CFG | +2.6 [0.8, 4.4] | 0.003 | 0.61 (Moderate) | PTG > CFG |
| | PTG vs CG | +7.9 [5.7, 10.1] | <0.001 | 1.55 (Large) | PTG > CG |
| | CFG vs CG | +5.3 [3.5, 7.1] | <0.001 | 0.94 (Large) | CFG > CG |
| Standing Broad Jump (m) | PTG vs CFG | +0.09 [0.04, 0.14] | 0.002 | 0.78 (Moderate) | PTG > CFG |
| | PTG vs CG | +0.26 [0.20, 0.32] | <0.001 | 1.63 (Large) | PTG > CG |
| | CFG vs CG | +0.17 [0.12, 0.22] | <0.001 | 0.85 (Large) | CFG > CG |
| Wingate Peak Power (W) | CFG vs PTG | +35.4 [18.6, 52.2] | <0.001 | 0.72 (Moderate) | CFG > PTG |
| | CFG vs CG | +78.5 [61.7, 95.3] | <0.001 | 1.58 (Large) | CFG > CG |
| | PTG vs CG | +43.1 [26.3, 59.9] | <0.001 | 0.86 (Large) | CFG > CG |

Table III shows that the Post-intervention, the CFG outperformed the PTG in strength outcomes (back squat: +10.2 kg, *p* < 0.001; bench press: +6.4 kg, *p* = 0.002), while the PTG showed superior jump performance (vertical jump: +2.6 cm, *p* = 0.003; broad jump: +0.09 m, *p* = 0.002). both experimental groups surpassed the CG in all measures (all *p* ≤ 0.008), with large effect sizes (*d* = 0.66-2.03). Notably, Wingate peak power improvements were greatest in the CFG (+78.5 W vs. CG, *p* < 0.001), though the PTG also showed substantial gains (+43.1 W vs. CG, *p* < 0.001). These findings highlight the differential adaptations elicited by CrossFit (strength-power emphasis) versus plyometric training (explosive power focus).

## Discussion

The present study examined the effects of CrossFit (CFG) and plyometric training (PTG) compared to a control group (CG) on strength and power outcomes in young adults. The findings revealed distinct adaptations between training modalities, with CFG eliciting greater strength improvements and PTG demonstrating superior explosive power gains.

### Baseline Homogeneity and Study Design

As shown in Table 1, baseline characteristics were well-matched across groups (*p* > 0.05), ensuring that post-intervention differences were attributable to the interventions rather than initial disparities. This aligns with previous research emphasizing the importance of group homogeneity in training studies (Smith *et al*., 2018) [23]. The randomized design strengthens internal validity, reducing potential confounding factors (Jones & Atkinson, 2020) [10].

### Within-Group Training Adaptations

Table 2 highlights significant within-group improvements in CFG and PTG, while the CG remained unchanged. The CFG's large strength gains (e.g., +17.4 kg in back squat) align with CrossFit's emphasis on high-intensity functional movements, which enhance maximal strength (Feito *et al*., 2018) [8]. The PTG's superior jump performance (+8.5 cm in vertical jump) supports plyometric training's efficacy in improving Eccentric Concentric Connection efficiency (Moran *et al*., 2019) [16]. The lack of change in the CG reinforces the necessity of structured training for neuromuscular adaptations (Suchomel *et al*., 2021) [24].

### Between-Group Comparisons and Practical Implications

Table 3 demonstrates that CFG produced greater strength gains than PTG (*p* < 0.001), consistent with findings that resistance-based programs optimize maximal strength (Weakley *et al*., 2021) [27]. Conversely, PTG outperformed CFG in jump performance (*p* ≤ 0.003), corroborating evidence that plyometrics enhance explosive power (Ramírez Campillo *et al*., 2020) [16]. These results suggest that athletes seeking strength should prioritize CrossFit-style training, while those targeting explosiveness may benefit more from plyometrics.

## Conclusion

The findings of this study demonstrate that both CrossFit (CFG) and plyometric training (PTG) elicit significant improvements in strength and power, though with distinct adaptations. CrossFit training produced superior gains in maximal strength (e.g., 1RM back squat and bench press), while plyometric training led to greater improvements in explosive power (e.g., vertical jump and standing broad jump). These results align with previous research indicating that high-intensity functional training enhances neuromuscular strength (Feito *et al*., 2018) [8], whereas plyometrics optimize Myotatic Stretch Cycle efficiency (Ramírez Campillo *et al*., 2022) [16]. The fact that there were no appreciable changes in the control group serves as another evidence that systematic, progressive training is required for major physiological adaptations.

From a practical standpoint, these results imply that coaches and athletes should choose training methods according to certain performance objectives. For sports requiring maximal strength (e.g., powerlifting, rugby), CrossFit-style programming may be more beneficial. Conversely, plyometric training appears more effective for sports dependent on explosive power (e.g., basketball, sprinting). Combining both modalities in periodized training blocks could potentially yield comprehensive performance enhancements, though further research is needed to explore synergistic effects.

A limitation of this study was the absence of biomechanical or neuromuscular analyses (e.g., EMG, force plates), which could provide deeper insights into the mechanisms behind these adaptations. Future studies should incorporate such measures while extending intervention durations to examine long-term training effects. Additionally, investigating individualized responses to training could help optimize program design.

In summary, this study highlights the efficacy of CrossFit and plyometric training for distinct performance outcomes. By aligning training methods with athletic demands, practitioners can maximize the transfer of gym-based gains to sport-specific performance. These results add to the increasing amount of data that suggests plyometric and focused resistance training can improve young athletes' physical ability.

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