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SPORTS PERFORMANCE

# Effects of a 4-week weightlifting or plyometric training mesocycle on physical performance in highly trained adolescent basketball players

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**ABSTRACT**

This study examined the effects of weightlifting (WTG) and plyometric (PTG) training on ankle mobility, strength, power, and running performance in highly trained adolescent basketball players. Participants (male, $n = 23$; female, $n = 35$) were randomly assigned to WTG or PTG, training three times weekly for four weeks. Assessments included ankle dorsiflexion, hip strength (ABD-ADD ratio and asymmetry), handgrip strength, lower limb power (Counter Movement Jump -CMJ- and Broad Jump), and running performance. Both interventions significantly improved ankle dorsiflexion (left: $p < .001$, d = 1.10; right: $p < .001$, d = 1.50) and hip strength (left adduction: $p = .001$, d = 0.93; right abduction: $F[1,54] = 6.65$, $p = .013$, d = 0.71). The WTG improved right handgrip strength (m.d. 1.76 kg, $p = .028$, d = 0.23) and CMJ (m.d. 1.81 cm, $p = .004$, d = 0.30). Both groups improved Broad Jump performance (WTG: m.d. 0.13 m, $p = .002$, d = 0.46; PTG: m.d. 0.13 m, $p = .007$, d = 0.47). The PTG showed significant improvement in the Compass Drill ($p = .003$, d = 0.42). Both interventions have the potential to enhance physical performance, with no clear superiority for one type of training over the other.

**HIGHLIGHTS**

- Both plyometric and weightlifting training methods can be effective for enhancing some physical qualities relevant to youth basketball performance.
- Coaches training with young basketball players should consider incorporating these training approaches within their 4-week mesocycle programming.
- Future research should investigate whether a sequenced combination of plyometric and weightlifting training produces additive or synergistic effects on the physical development of adolescent basketball players.

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## Introduction

Physical conditioning is a fundamental component in basketball, essential for developing the physical capacity needed to meet the sport's high physiological and muscular demands (Petway et al., 2020). This becomes particularly critical for adolescent athletes in developmental stages, as it not only promotes physical maturity but also helps to reduce the risk of injuries (Malina et al., 2015). Among the most effective strategies in sport conditioning, weightlifting, and plyometric exercises stand out for their proven benefits (Berton et al., 2018; Morris et al., 2022).

Weightlifting is characterized by performing high-load resisted movements (80–95% of 1 repetition maximum [RM]) with rapid and skilled execution, typically involving a reduced number of repetitions per set. Its capacity to improve muscle strengthening and enhance sports-performance outcomes has been well documented (American College of Sports Medicine, 2009; Comfort et al., 2023). Similarly, research has highlighted positive outcomes from plyometric training programs, which involve quick, powerful exercises requiring rapid transitions between muscle lengthening and shortening phases (e.g. squat jumps, drop jumps, or depth jumps) (Ramirez-Campillo et al., 2022).

Both weightlifting and plyometric training induce comparable physiological adaptations, particularly in improving the rate of force development and peak force production during the concentric phase of movements such as jumps and changes of direction (Cormie et al., 2011). However, weightlifting is an effective strategy for maximizing power output in the countermovement jump (Lamas et al., 2012), whereas plyometric training promotes enhanced improvements in the stretch-shortening cycle and neuromuscular coordination (Arabatzi et al., 2010).

When examining the impact on sports performance, comparative analyses between weightlifting and plyometric training have revealed overall similar effects, with non-significant or negligent differences between them (Berton et al., 2018; Morris et al., 2022). Nevertheless, slight trends

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suggest plyometric training is more suitable for untrained athletes (Berton et al., 2022; Tricoli et al., 2005), while weightlifting could provide a greater extent in strength outcomes among trained athletes (Arabatzi et al., 2010). Notably, despite significant research on these training modalities in adult populations, evidence remains limited for adolescent athletes. Given the clear physiological and musculoskeletal differences between adolescents and adults, findings from adult populations cannot be directly applied to younger athletes. It underscores the need for specific evidence on the effectiveness of weightlifting and plyometric training in adolescent athletic populations. It is especially relevant for weightlifting, where concerns and uncertainties have persisted for decades. In contrast, current evidence indicates its potential benefits for enhancing physical maturation during adolescence (Lloyd & Oliver, 2012) and reducing the risk of injuries (Maffulli et al., 2010).

Among the existing literature, Sammoud et al., (2024). evaluated a corpus of male soccer players (mean age: 12.8 years), observing weightlifting providing similar effects to plyometric training in terms of sprint and agility, with greater benefits on acceleration. Similarly, Kaabi et al., (2022). reported improved neuromuscular performance after an 8-week weightlifting program compared to the same period of plyometric training in elite junior table tennis players. However, Chaouachi et al., (2014). found no significant differences between Olympic weightlifting, moderate-resistance training, and plyometric training in healthy children aged 10–12 years, suggesting that all three modalities can be effective in improving physical performance.

Although these studies provide a basis of knowledge, the limited number of studies, the heterogeneity in intervention characteristics, and the diverse age and training levels of the participants highlight the need for further research to clarify the comparative effectiveness of these training methods. Additionally, existing evidence primarily focuses on explosive performance outcomes (i.e. vertical jump and sprint), with limited data on lower-limb mobility and relative lower-limb strength. Moreover, evaluating the impact of these training programs on hip strength is essential, given the critical role of the hip in basketball movements, as well as its association with injury risk (Thorborg et al., 2010). Hip muscle strength is usually analyzed as inter-limb asymmetry (Belhaj et al., 2016) and force ratio (Rodriguez, 2020), with values close to 1 reducing the risk of injury (Magalhães et al., 2013).

Consequently, the purpose of this study was to compare the effects of 4-week weightlifting and plyometric training on ankle mobility, hip isometric (ratio ABD-ADD and asymmetries) and handgrip strength, lower limb power and jumping and running performance in adolescent highly-trained basketball players from both sexes. It was hypothesized that both training programs would enhance physical and performance outcomes during the intervention period. However, due to the nature of the interventions, weightlifting was expected to provide greater improvements in strength and ankle mobility, while plyometric training was anticipated to be more effective in enhancing power and running performance.

## Methods

This research adopted a randomized controlled trial design, following the CONSORT statement checklist (Cuschieri, 2019), with outcome assessors blinded to group allocation. The study design received ethical approval from the *Human Research Ethics Committee of the University of Valencia*. A prospective research protocol was registered on ClinicalTrials.gov (Registration Number NCT05824780), and no substantial modifications were made subsequently.

Participants were randomized using a computerized random allocation process, conducted by an independent investigator not involved in the study's implementation. The randomly generated sequence assigned a unique number to each participant, which corresponded to one of the two groups: weightlifting training group (WTG), and plyometric training group (PTG). The independent investigator placed the group assignment numbers for each participant's identification in a sealed opaque envelope. This envelope was then provided to the member of the research team responsible for conducting the interventions.

### *Subjects*

According to the aim of the study, healthy highly trained basketball players, both male and female, aged between 12 and 16 years, all belonging to the academic squad of Valencia Basket were invited to participate in the study. These potential athletes compete at the highest formative national levels and undergo intensive training in both physical and technical skills, including 5 sessions per week. Athletes were invited if (I) attended to a frequency of at least 80% training sessions, (II) had at least, one year of experience in the academy squad. However, they were excluded in the presence of any of the following exclusion criteria that alter the athletes' physical capacity or biased the interpretation of the results: (I) current injury or complaint limiting sports activity, self-reportedly(II) history of injury requiring non-operative treatment in the last 3 months, (III) history of injury requiring operative treatment in the last 9 months, (IV) subjects who had previously performed weightlifting training for at least 4 weeks, (V) subjects who were physically unable to perform a strength training program. For those who met the inclusion criteria, both participants and their parents/legal guardians were informed verbally and in writing about the nature, rationale, and implications of the study. Those who agreed to participate, both athletes and parents/legal guardians, signed the informed consent document, which was prepared in accordance with the ethical guidelines of the Declaration of Helsinki and its subsequent updates.

Considering that the participants were recruited from an elite basketball club, the sample size was conditioned by the availability of players depending on the team's needs. A *post-hoc* power analysis (F-tests, within-between interactions, 2 measurements, 2 groups) performed with G*Power version 3.1.9.6 (Faul, 2007) showed statistical power (1-ß) of .85, computing the 58 participants and average effect sizes of the significant effects ($\eta p^2 = .18$).

### *Procedures*

The intervention took place in the Alqueria del Basket, Valencia (Spain), in the period between November and December 2022. Participants were assigned to either a weightlifting training group or a plyometric training group. Both training programs consisted of 12 sessions of 45 minutes, conducted on three alternate days per week, spanning a total duration of 4 weeks. These sessions were consistently held at the same time of the day and were supervised by a research team member with more than 5 years of experience in athletic training. To ensure that interventions were conducted at a high intensity, the perception of efforts was assessed through the rating of perceived exertion (RPE), which should be at an 8–9 out of 10. To maintain this high intensity throughout the programs, training parameters were progressively increased each week. However, progression was not performed for the participants who reported a 10/10 RPE, in this case, maintaining the same parameters as in the previous week. The RPE was assessed from the first repetition, being this method reliable to capture the subjective perception of effort (Colado et al., 2023, 2024; Pind & Mäestu, 2017). To familiarize individuals with this method, an explanation was provided with various reference examples, and the initial values obtained were agreed upon collectively. This evaluation was consistently conducted immediately after the session ended. No food supplementation or ergogenic substances were allowed during the training period.

The participants in the WTG additionally underwent a 4-week familiarization period before starting the training program. During this familiarization program, athletes received technical guidance on executing the Olympic movements comprising the program, which were: hang power clean, overhead squat, hang power snatch, clean, split Jerk, and snatch. During each of the three weekly sessions of the training program, two of these specific movements were targeted, being this structure consistent over the weeks. The workout plans were designed for progressing systematically, escalating the sets, repetitions, and loads over the 4 weeks. The intervention began with 4 sets of 10 repetitions at 70% of the one-repetition maximum (1RM) in the first week and the workload progressed in 3 sets of 5 repetitions at 85% (RM) in the fourth week, when possible. Detailed information on the intervention program is presented in Figure 1.

The participants in the PTG adhered to the same weekly framework as those in the WTG, working on two specific exercises each day, with this order remaining constant throughout the program. These exercises included in the plyometric program were as follows: maximum countermovement jump (CMJ), double-leg side jump, maximum squat jump, drop jump (20 cm), single-leg hurdle jump, and double-leg multi-hop. In our designed intervention, the number of contacts was progressively reduced from 240 contacts in week-1 to 90 contacts by week-4, while concurrently increasing the intensity. Intensity progression was achieved

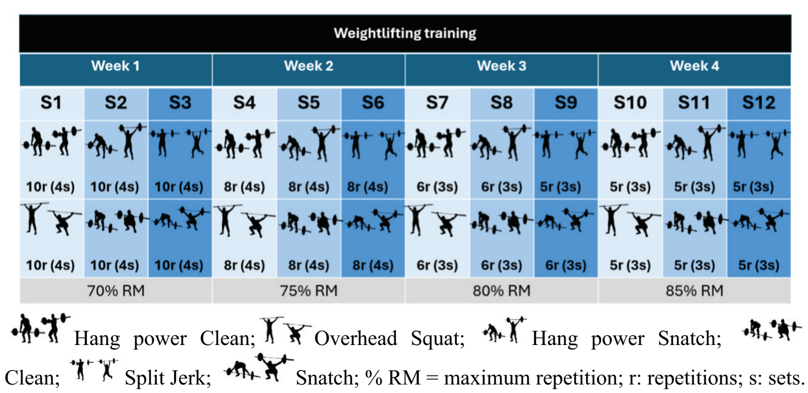


Figure 1. Weightlifting protocol.

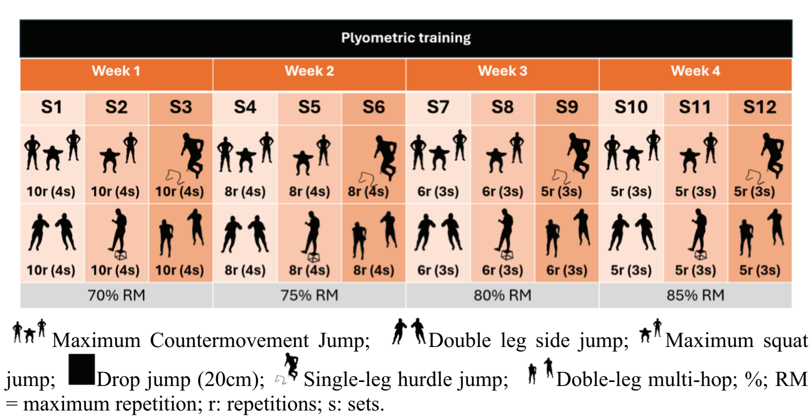


Figure 2. Plyometric protocol.

by incorporating external weights (medicine balls) for the execution of exercises, increasing from 3 to 5, and 9 kg, when possible. This plyometric program was adapted from Kaabi et al., (2022). Detailed information is provided in Figure 2.

## Outcomes

All outcomes assessment was conducted at the ******************** facilities by the same member of the research team, who remained blinded to group allocation. The outcomes assessment encompassed various aspects, including anthropometric measurement, mobility, hip muscle strength, and performance measures, being this order consistent for all evaluations. Measurements were performed at two time points (except anthropometric measurement): two days before starting the training programs (baseline), and one week after the training program (5 weeks after baseline). Before testing, participants performed a standardized warm-up consisting of 5 minutes of light aerobic cycling, followed by 5 minutes of low-intensity strength training (approximately 40% 1RM) for the lower and upper body, aimed at increasing neuromuscular activation. No familiarization period was needed as the entire sample had prior experience with all included tests, which were frequently conducted throughout the competitive season. Three attempts were performed for each test or tested leg (with a 30–45-s rest period allowed) (Cormie et al., 2011) with the best score recorded for further analysis. For agility and sprint test, they were carried out only twice, due to potential fatigue bias.

### Mobility: Weight-bearing ankle dorsiflexion

Ankle dorsiflexion was assessed using the weight-bearing lunge test, employing LegMotion® equipment (LegMotion ®, Check your Motion, Albacete, Spain) and following Cejudo et al., (2014). methodological principles, which demonstrated very high levels of test-retest reliability (ICC values ranged from .96 to .98) (Cormie et al., 2011; Ramirez-Campillo et al., 2022). Participants were instructed to put the assigned foot in the marked spot of the LegMotion® platform and the other foot outside, with toes at the platform's edge (Calatayud, 2015). Then, participants advanced their front knee toward a vertical stick, with the tested foot maintaining contact with the platform. The test was repeated with the stick moved 1 cm farther each time until participants couldn't maintain heel and knee contact for at least 3 seconds. Distance (centimetres) from the big toe to the vertical stick was recorded. Participants were barefoot with hands placed on hips.

### Strength: Hip muscle strength, ratio ABD-ADD, and lower limb asymmetry

The isometric strength of hip abductors (ABD) and adductors (ADD) was collected using the Force-Frame Strength Testing System device (Vald Performance, Albion, Australia). The measurement protocol followed the principles of previous related research (Dominguez-Navarro et al., 2023). Participants were instructed to assume a supine position with their hips and knees bent at a 60º angle. The height of the bar was individually adjusted for each player to ensure that they maintained this angle. To register the values, it was requested, firstly, an isometric hip ADD contraction for 5 seconds (s), and then, after a 5-s rest, a 5-s isometric contraction of the hip ABD muscles. The maximum force values were recorded in Newtons (N). From the results obtained, two more parameters were calculated: interlimb strength, and ADD-ABD ratio. Interlimb values were derived by dividing the right leg to left leg values for ABD and ADD values, expressed as a percentage by the following formula: [(right leg muscle strength – left leg muscle strength)/ right leg muscle strength] × 100. Additionally, the ABD-ADD ratio was computed for each leg (with a range of 0 to 2).

### Strength: Handgrip test

The isometric handgrip test was conducted using the Camry digital hand dynamometer (Camry, CA, USA). Players sat on a chair with their dominant arm close to their body and elbow fully extended. They grasped the dynamometer and gradually applied maximum strength for at least 2 seconds. Three trials were completed, interspersed by a 30-second passive rest between them. The best measurement was used for analysis. They were not allowed to make any extra body movements during the test. The maximum force values were recorded in kilograms.

### Lower limb power: Counter movement jump (CMJ) and broad jump test

These tests are commonly used in basketball players as a performance-related outcome due to their ability to measure explosive strength and transfer it to specific basketball manoeuvres (Heishman et al., 2019).

To perform the CMJ test, participants stood on a platform, in the marked area. Then, they were instructed to perform a vertical jump, after receiving a verbal order, as high as possible with both hands resting on the hips to avoid swing movement. Jump height was measured using the validated Optojump jump platform (Microgate, Bolzano, Italy) (Glatthorn et al., 2011). Three consecutive jumps were performed, and the best record in centimeters was recorded for subsequent analysis.

To perform the Broad Jump Test, the player stands with feet shoulder-width apart behind a starting line. Upon the signal, they bend at the hips, knees, and ankles while swinging their arms backward to prepare for a countermovement. The player then explosively extends their lower limbs to propel forward, with arms swinging forward to aid the jump. During flight, the body and legs are fully extended, with arms forward. Upon landing, the player absorbs impact by flexing the hips, knees, and ankles, stabilizing their body. The jump distance, measured from the starting line to the heel's landing point, is recorded in centimeters

### Running performance: Cone drill test

This test is used to measure agility, providing quantifiable parameters for changing directions in sprinting, which is related to sports performance (Mann et al., 2016). For its measurement, participants had to navigate a circuit characterized by various changes in direction, where they had to touch four cones as quickly as possible (Gál-Pottyondy et al., 2021). The time taken to complete the circuit was recorded in seconds.

This test has demonstrated very high reliability (ICC: .962) (Mann et al., 2016).

### Running performance: 20-meters sprint

Sprint capacity was measured for 20 meters. Participants began in a standardized 3-point stance behind a marked starting line and performed a 20 m sprint at maximal speed. The test commenced following an acoustic signal from the evaluator, with timing initiated as soon as the participant moved from the starting position, thereby breaking the photocell beam. Two photocells (Microgate® Polifemo Radio Light, Bolzano, Italy) were placed to record the athlete's time in seconds when passing the 20-meter mark.

### Statistical analyses

All the statistical analyses were conducted with IBM SPSS Statistics for Macintosh version 28.0.1.1 (IBM Corp.©, Armonk, NY, United States). After a basic data curation, we conducted descriptive analyses. A participant presenting non-recoverable missing outcome data was removed from the study. No more outcome data were missing or excluded. Data are reported as mean ± standard deviation and 95% confidence interval (CI) in brackets. A cut-off criterion of $p < .05$ was uniformly established as statically significant.

The normality of data distribution was assessed through the Kolmogorov-Smirnov test. Most of the variables showed a normal Gaussian distribution with homogeneous variances between both study groups. The variables that violated the assumption of normality were transformed through the so-called 'Two Step Approach' (Templeton, 2011). Step 1 consists of converting the non-normal variable into a percentile rank with uniformly distributed probabilities. Afterward, Step 2 consists of calculating the inverse-normal to the result of Step 1 to form a variable consisting of normally distributed z-scores.

At this point, a two-way mixed analysis of variance (ANOVA) was conducted with the time (preintervention and postintervention) and training group (weightlifting and plyometrics) as the within- and between-participants factors, respectively. The effect size was calculated through the partial eta squared ($\eta p^2$), where $.01 < \eta p^2 < .06$ constitutes a small effect, $.06 \leq \eta p^2 \leq .14$ medium, and $\eta p^2 > .14$ a large effect. Afterward, we transformed $\eta p^2$ to Cohen's d (https://www.psychometrica.de/effect_size.html; Section 6: Computation of d from the F-Value of Analysis of Variance). Pairwise *post-hoc* comparisons were conducted with the Bonferroni correction. The effect size for the post-hoc comparisons was calculated through Cohen's d, with $d < 0.50$ constituting a small effect, $0.50 \leq d \leq 0.79$ moderate, and $d \geq 0.80$ a large effect (Cohen, 1988).

## Results

A total of 58 participants (male, $n = 23$; female, $n = 35$) were enrolled in the study. Participants were divided into WTG (male, $n = 12$; female, $n = 19$) and PTG (male, $n = 11$; female, $n = 16$). However, two participants (2 males from PTG) dropped out of the study due to not complying with all the procedures, as presented in Figure 3. The baseline characteristics of the participants included in each group can be found in Table 1.

### Ankle range of motion

Table 2 presents the range of motion outcomes.

Both training interventions (factor time) significantly influenced both ankles dorsiflexion (left: F[1,54] = 15.99, $p < .001$, $\eta p^2 = .23$, d = 1.10; right: F[1,54] (Núñez et al., 2022; Petway et al., 2020) = 29.83, $p < .001$, $\eta p^2 = .36$, d = 1.50). All the rest of the factors and interactions did not show a significant effect ($p \geq .729$).

Both training programs improved left (WTG: mean difference [m.d.] 1.15 cm, 95%CI [0.30–2.00], $p = .008$, d = 0.33; PTG: m.d. 1.37 cm, 95%CI [0.43–2.31], $p = .005$, d = 0.48) and right ankle dorsiflexion (WTG: m.d. 1.31 cm, 95%CI [0.63–1.98], $p < .001$, d = 0.42; PTG: m.d. 1.44 cm, 95%CI [0.69–2.19], $p < .001$, d = 0.48). Nonsignificant between-group differences existed in ankle range of motion (all $p > .481$).

### Hip isometric strength, ratio ABD-ADD, and lower limb 14 asymmetry

Table 3 presents the isometric strength outcomes.

Both training interventions (factor time) influenced hip adduction (left: F[1,54] = 11.63, $p = .001$, $\eta p^2 = .18$, d = 0.93; right: F[1,54] = 4.77, $p = .033$, $\eta p^2 = .08$, d = 0.60), right-hip abduction (F[1,54] = 6.65, $p = .013$, $\eta p^2 = .11$, d = 0.71), and adduction interlimb asymmetry (F[1,54] = 7.08, $p = .010$, $\eta p^2 = .12$, d = 0.73). All the rest of the factors and interactions did not show a significant effect ($p \geq .267$).

Both training groups improved left hip adduction strength (WTG: m.d. 14.12 N, 95%CI [1.07–27.16], $p = .034$, d = 0.27; PTG: m.d. 19.09 N, 95%CI [4.56–33.62], $p = .011$, d = 0.38) and the PTG improved adduction strength interlimb asymmetry (m. d. 2.58%, 95%CI [0.55–4.61], $p = .014$, d = 0.55). The PTG showed significantly more left and right hip abduction strength both pre- and post-intervention ($p = .003$–$.006$). No other significant between-group *post-hoc* differences were encountered in isometric strength ($p \geq .079$).

### Strength: Handgrip and lower limb power

Table 4 presents the muscle strength and power results.

Both training interventions (factor time) influenced right handgrip strength (F[1,54] = 8.69, $p = .005$, $\eta p^2 = .14$, d = 0.81), CMJ (F[1,54] = 11.99, $p = .001$, $\eta p^2 = .18$, d = 0.95), and Broad Jump Test (F[1,54] = 17.95, $p < .001$, $\eta p^2 = .25$, d = 1.16). No influence of time*group was found for the handgrip strength or lower-limb power ($p \geq .185$).

Only the WTG improved right-hand handgrip (m.d. 1.76 kg, 95%CI [0.20–3.32], $p = .028$, d = 0.23) and CMJ (m.d. 1.81 cm, 95%CI [0.61–3.01], $p = .004$, d = 0.30); both training groups improved the performance in the Broad Jump Test (WTG: m.d. 0.13 m, 95%CI [0.05–0.21], $p = .002$, d = 0.46; PTG: m.d. 0.13 m, 95%CI [0.04–0.22], $p = .007$, d = 0.47). There were no between-group *post-hoc* differences (all $p > .093$).

### Change of direction and 20-meter sprint

Table 5 presents the change-of-direction and sprint results.

Both training interventions (factor time) influenced the change of direction (Compass Drill: F[1,54] = 11.42, $p = .001$,

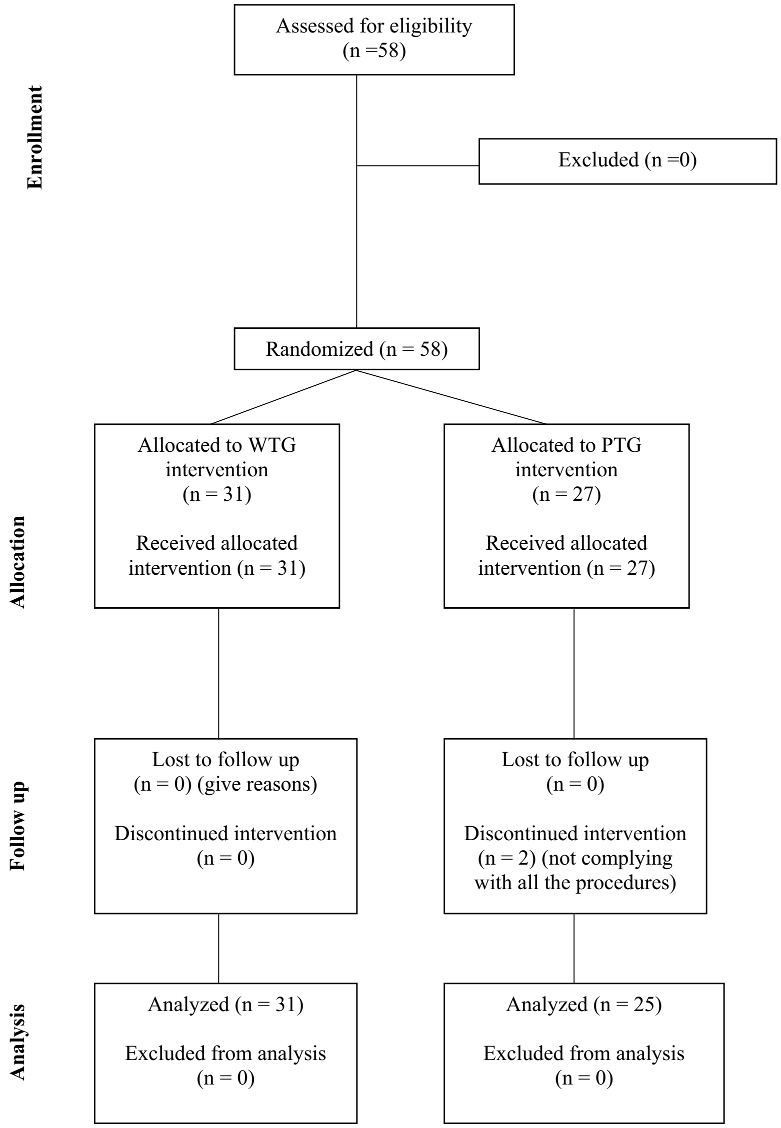


Figure 3. Flow chart of the participants. WTG: Weightlifting Training Group; PTG: Plyometric Training Group.

Table 1. Baseline characteristics of the participants.

| Variable | Group | n | Mean | Std. Dev. | Sig. | ES |
|---|---|---|---|---|---|---|
| Age | Weightlifting | 31 | 14.77 | 1.18 | .862 | 0.05 |
| (years) | Plyometrics | 25 | 14.72 | 1.14 | | |
| Height (centimetres) | Weightlifting | 31 | 178.60 | 9.70 | .360 | 0.25 |
| | Plyometrics | 25 | 180.96 | 9.28 | | |
| Mass (kilograms) | Weightlifting | 31 | 67.04 | 10.50 | **.049*** | **0.54** |
| | Plyometrics | 25 | 72.87 | 11.07 | | |
| Body Mass Index (kg/m$^2$) | Weightlifting | 31 | 20.92 | 1.79 | **.025*** | **0.61** |
| | Plyometrics | 25 | 22.17 | 2.30 | | |

The results of the descriptive and inferential analyses (between-participant comparisons) are presented.; Sig.: p-value of significance; ES: effect size measured through Cohen's d. * indicates significant differences (p<0.05)

$\eta p^2 = .18$, d = 0.93). The sprint was not affected by the factor time and the time*group interaction did not affect the change of direction or sprint ($p \geq .187$).

Only the PTG significantly improved from pre- to post-intervention in the Compass Drill (m.d. 0.22 seconds, 95%CI [0.09–0.36], $p = .003$, d = 0.42). There were no between-group *post-hoc* differences (all $p > .118$).

## Discussion

The present study aimed to compare the potential of two training programs, one based on plyometrics and the other on weightlifting, to improve upper and lower limb strength, ankle mobility, lower limb power, and running performance in adolescent elite basketball players of both sexes. The findings indicate that both training methodologies can similarly

Table 2. Ankle range of motion results.

| Variable | Group | Time | Mean | Std. Dev. | 95% CI Lower | 95% CI Upper | Pre-post Difference |
|---|---|---|---|---|---|---|---|
| Left ankle dorsiflexion (centimetres) | Weightlifting | Pre | 13.13$^{(.860)}$ | 3.40 | 12.02 | 14.24 | **.008*** |
| | | Post | 14.28$^{(.689)}$ | 3.65 | 13.06 | 15.50 | |
| | Plyometrics | Pre | 13.27 | 2.63 | 12.04 | 14.51 | **.005*** |
| | | Post | 14.64 | 3.02 | 13.29 | 16.00 | |
| Right ankle dorsiflexion (centimetres) | Weightlifting | Pre | 12.48$^{(.579)}$ | 3.03 | 11.39 | 13.58 | **<.001*** |
| | | Post | 13.79$^{(.481)}$ | 3.19 | 12.68 | 14.90 | |
| | Plyometrics | Pre | 12.94 | 3.05 | 11.72 | 14.16 | **<.001*** |
| | | Post | 14.38 | 2.95 | 13.14 | 15.62 | |

The results of the descriptive and inferential analyses (within-and-between-participant post-hoc analyses) are presented. The level of significance of the between-group differences is shown as a superscript next to the mean. Significant *p* values (<0.05) are highlighted in bold font and with '*'. Std. Dev: standard deviation. CI: confidence interval.

Table 3. Hip isometric strength and asymmetries results.

| Variable | Group | | M | Std. Dev | 95% CI Lower | 95% CI Upper | Pre-post Difference |
|---|---|---|---|---|---|---|---|
| Left hip adduction strength (N) | Weightlifting | Pre | 262.36$^{(.272)}$ | 49.03 | 244.37 | 280.35 | **.034*** |
| | | Post | 276.48$^{(.163)}$ | 54.93 | 257.64 | 295.31 | |
| | Plyometrics | Pre | 277.27 | 51.08 | 257.24 | 297.30 | **.011*** |
| | | Post | 296.36 | 48.81 | 275.39 | 317.33 | |
| Right hip adduction strength (N) | Weightlifting | Pre | 280.61$^{(.152)}$ | 50.42 | 262.08 | 299.13 | .081 |
| | | Post | 291.58$^{(.215)}$ | 57.67 | 272.08 | 311.09 | |
| | Plyometrics | Pre | 300.68 | 52.70 | 280.05 | 321.31 | .186 |
| | | Post | 309.87 | 49.43 | 288.15 | 331.59 | |
| Left hip abduction strength (N) | Weightlifting | Pre | 274.69$^{\mathbf{(.005)*}}$ | 43.29 | 259.40 | 289.98 | .436 |
| | | Post | 278.40$^{\mathbf{(.006)*}}$ | 39.03 | 263.48 | 293.33 | |
| | Plyometrics | Pre | 308.09 | 41.29 | 291.06 | 325.12 | .722 |
| | | Post | 309.98 | 44.28 | 293.36 | 326.59 | |
| Right hip abduction strength (N) | Weightlifting | Pre | 266.42$^{\mathbf{(.003)*}}$ | 45.34 | 249.47 | 283.36 | .055 |
| | | Post | 277.13$^{\mathbf{(.003)*}}$ | 42.47 | 260.09 | 294.16 | |
| | Plyometrics | Pre | 306.11 | 49.12 | 287.25 | 324.98 | .095 |
| | | Post | 316.44 | 52.72 | 297.47 | 335.40 | |
| Adduction strength interlimb asymmetry (%) | Weightlifting | Pre | 6.72$^{(.079)}$ | 4.36 | 4.99 | 8.45 | .254 |
| | | Post | 5.67$^{(.450)}$ | 3.79 | 4.30 | 7.04 | |
| | Plyometrics | Pre | 9.03 | 5.28 | 7.10 | 10.95 | **.014*** |
| | | Post | 6.45 | 3.82 | 4.92 | 7.98 | |
| Abduction strength interlimb asymmetry (%) | Weightlifting | Pre | 6.05$^{(.719)}$ | 4.43 | 4.58 | 7.53 | .588 |
| | | Post | 6.58$^{(.639)}$ | 4.34 | 5.13 | 8.02 | |
| | Plyometrics | Pre | 5.65 | 3.64 | 4.01 | 7.30 | .701 |
| | | Post | 6.07 | 3.57 | 4.46 | 7.68 | |
| Left hip adduction-abduction strength ratio (range 0–2) | Weightlifting | Pre | 0.98$^{(.100)}$ | 0.19 | 0.92 | 1.04 | .577 |
| | | Post | 1.00$^{(.321)}$ | 0.15 | 0.94 | 1.05 | |
| | Plyometrics | Pre | 0.90 | 0.14 | 0.84 | 0.97 | .078 |
| | | Post | 0.96 | 0.13 | 0.90 | 1.01 | |
| Right hip adduction-abduction strength ratio (range 0–2) | Weightlifting | Pre | 1.06$^{(.199)}$ | 0.18 | 1.00 | 1.12 | .642 |
| | | Post | 1.07$^{(.107)}$ | 0.16 | 1.01 | 1.12 | |
| | Plyometrics | Pre | 1.00 | 0.14 | 0.93 | 1.07 | .897 |
| | | Post | 1.00 | 0.15 | 0.93 | 1.06 | |

The results of the descriptive and inferential analyses (within-and-between-participant post-hoc analyses) are presented. The level of significance of the between-group differences is shown as a superscript next to the mean. Significant *p* values (<0.05) are highlighted in bold font and '*'. Std. Dev: standard deviation. CI: confidence interval.

enhance most of the physical performance markers, over 4 weeks. No clear superiority was evident for one type of training over the other, as there were no significant differences between the two training programs for most of the outcomes evaluated. However, weightlifting training appears to provide greater benefits for handgrip strength and jump, while plyometric training seems to improve the Compass Drill to a bigger extent.

The observed results partially confirm the study hypothesis that both methodologies would similarly improve the analyzed outcomes, with weightlifting further enhancing strength outcomes and plyometric training change of direction outcomes. Consistent with our initial hypothesis, most of the analyzed variables responded similarly regardless of the training methodology. Contrary to our initial hypothesis, ankle mobility did not improve more in the weightlifting training group compared to the plyometric group; this outcome may be attributed to the short duration of the intervention. On the other hand, our initial hypothesis that plyometric training would improve power and running performance was also partially confirmed, with plyometrics improving agility more than weightlifting but not sprint or jump performance.

These findings align with those obtained in various meta-analyses, confirming weightlifting as an effective training

Table 4. Muscle strength and power results.

| Variable | Group | Time | M | Std. Dev. | 95% CI Lower | 95% CI Upper | Pre-post Difference |
|---|---|---|---|---|---|---|---|
| Left hand handgrip (kilograms) | Weightlifting | Pre | 30.48$^{(.398)}$ | 7.21 | 27.83 | 33.13 | .840 |
| | | Post | 30.34$^{(.093)}$ | 6.74 | 27.89 | 32.79 | |
| | Plyometrics | Pre | 32.17 | 7.52 | 29.22 | 35.12 | .111 |
| | | Post | 33.46 | 6.89 | 30.73 | 36.19 | |
| Right hand handgrip (kilograms) | Weightlifting | Pre | 31.10$^{(.118)}$ | 7.73 | 28.42 | 33.78 | **.028*** |
| | | Post | 32.86$^{(.148)}$ | 7.75 | 30.04 | 35.67 | |
| | Plyometrics | Pre | 34.27 | 7.06 | 31.29 | 37.26 | .059 |
| | | Post | 35.94 | 7.90 | 32.81 | 39.08 | |
| CMJ (centimeters) | Weightlifting | Pre | 30.25$^{(.329)}$ | 5.35 | 28.18 | 32.32 | **.004*** |
| | | Post | 32.06$^{(.568)}$ | 6.51 | 29.72 | 34.40 | |
| | Plyometrics | Pre | 31.77 | 6.22 | 29.47 | 34.08 | .058 |
| | | Post | 33.06 | 6.47 | 30.46 | 35.67 | |
| Broad Jump Test (meters) | Weightlifting | Pre | 1.97$^{(.717)}$ | 0.28 | 1.87 | 2.08 | **.002*** |
| | | Post | 2.10$^{(.740)}$ | 0.29 | 2.01 | 2.20 | |
| | Plyometrics | Pre | 2.00 | 0.30 | 1.89 | 2.12 | **.007*** |
| | | Post | 2.13 | 0.24 | 2.02 | 2.23 | |

The results of the descriptive and inferential analyses (within-and-between-participant post-hoc analyses) are presented. The level of significance of the between-group differences is shown as a superscript next to the mean. Significant *p* values (<0.05) are highlighted in bold font and with '*'. Std. Dev: standard deviation. CI: confidence interval.

Table 5. Running performance results.

| Variable | Group | Time | M | Std. Dev. | 95% CI Lower | 95% CI Upper | Pre-post Difference |
|---|---|---|---|---|---|---|---|
| Compass Drill (seconds) | Weightlifting | Pre | 6.21$^{(.757)}$ | 0.45 | 6.03 | 6.38 | .132 |
| | | Post | 6.11$^{(.478)}$ | 0.37 | 5.95 | 6.27 | |
| | Plyometrics | Pre | 6.25 | 0.53 | 6.05 | 6.44 | **.003*** |
| | | Post | 6.03 | 0.52 | 5.85 | 6.20 | |
| 20-meter sprint (seconds) | Weightlifting | Pre | 3.47$^{(.731)}$ | 0.19 | 3.40 | 3.54 | .688 |
| | | Post | 3.48$^{(.601)}$ | 0.26 | 3.38 | 3.58 | |
| | Plyometrics | Pre | 3.45 | 0.21 | 3.37 | 3.53 | .840 |
| | | Post | 3.44 | 0.30 | 3.33 | 3.55 | |

The results of the descriptive and inferential analyses (within-and-between-participant post-hoc analyses) are presented. The level of significance of the between-group differences is shown as a superscript next to the mean. Significant *p* values (<0.05) are highlighted in bold font and with '*'. Std. Dev: standard deviation. CI: confidence interval.

method to enhance sports performance parameters related to explosive strength (American College of Sports Medicine, 2009; García-Valverde et al., 2022; Hoffman et al., 2004). Notably, weightlifting demonstrated higher effect sizes particularly in terms of Broad jump (d = 0.46), and hip adductor strength (d = 0.38). The optimization of the stretch-shortening cycle, improvement in muscle coactivation, and increased recruitment of muscle units have been identified as key neuromuscular responses contributing to these enhanced outcomes (Berton et al., 2018). Additionally, this training program also led to time-group improvements in less-studied outcomes, such as ankle mobility, with small-to-moderate effect sizes (left ankle dorsiflexion: d = 0.33; right ankle dorsiflexion: d = 0.42), and handgrip strength, which showed a small effect size (d = 0.23). These improvements may be linked to an enhanced capacity for selective muscle activation and improved motor control (Adami et al., 2022; Arabatzi & Kellis, 2012). The positive effects resulting from weightlifting programs among basketball players are comparable to those observed in other sports populations, such as soccer (Rodríguez-Rosell et al., 2017), table tennis (Kaabi et al., 2022), volleyball (İnce, 2019), or active individuals not participating in any specific sport (Channell & Barfield, 2008). These effects can be understood as the physiological implications of weightlifting being potentially beneficial regardless of the participants' sports specialization. Also irrespective of the age of the participants, weightlifting has been observed to be effective not only in young adults (García-Valverde et al., 2022) but also in adolescents (Chaouachi et al., 2014), as shown in our findings. Therefore, these findings support previous empirical evidence (Chaouachi et al., 2014; Johnson et al., 2011), which suggests that incorporating the faster and more complex movements produced by weightlifting or plyometrics can be beneficial for this population. This challenges misconceptions about the suitability of these training methods for younger individuals. Additionally, this research indicates that the benefits of weightlifting can be observed even with a four-week training period. This duration is shorter than those used in other studies (Arabatzi & Kellis, 2012; Hawkins et al., 2009; Hoffman et al., 2004), and it may open the possibility of incorporating weightlifting programs in shorter periods during competition.

Plyometric training enhanced strength and sports performance outcomes in a similar manner, with greater effect sizes in the Compass Drill (d = 0.42) and the reduction of adduction strength asymmetry (d = 0.55). Most of the existing literature also suggests non-significant differences between plyometric and weightlifting training (Berton et al., 2018; Morris et al., 2022), both proving more effective than moderate-load strength training in improving performance-related parameters or strength values (Johnson et al., 2011; Sáez de Villarreal et al., 2012). Furthermore, the study by Arabatzi et al., (2010). also demonstrated the effectiveness of weightlifting and plyometric training in improving variables related to explosive strength, whether performed separately or in combination.

Only minor differences between weightlifting and plyometric have been reported in the literature, with weightlifting providing greater explosive strength-related outcomes. This is consistent with the higher CMJ and handgrip values observed in the weightlifting group in our study. Concretely, Kaabi et al., (2022) found that weightlifting led to greater improvements in jumping outcomes compared to plyometrics among table tennis players. Similarly, Chaouachi et al., (2014) reported that weightlifting training resulted in more pronounced benefits in vertical jump compared to plyometric training. However, it is important to note that the participants in this study were 10–12 years old, which does not allow for direct comparisons with our study, as the differing maturation ages of the subjects may have been an influential factor in obtaining the results (Hammami et al., 2022). Additionally, greater handgrip strength appears to be another benefit of weightlifting, as suggested by Adami et al., (2022), who indicating that individuals who regularly perform high-load strength exercises exhibit better handgrip strength, compared to those who engage in endurance training. In contrast, plyometrics induced greater improvements in agility, which differs from the findings of some authors (Kaabi et al., 2022), but are in line with others (Negra et al., 2020). Likewise, these isolated improvements in agility may be attributed to the relatively short duration of the interventions.

Furthermore, the mechanism underlying these improvements may be different, and therefore, the timing of the season during which each program is implemented appears to be relevant (Newton et al., 2002). Specifically, it was suggested that weightlifting is more appropriate in the preseason and plyometric in the competition period, and both programs combined may be used in the transition from pre-competition to the competition period (Arabatzi et al., 2010). Nevertheless, these recommendations were based on healthy, active subjects and may not be specific to young elite-level basketball players, especially considering the increase, and its impact, of season-congested schedules (Moran et al., 2019).

Our results indicate a significant reduction in lower limb asymmetry for adductor strength for both groups, but more pronounced in the plyometric intervention. These findings align with those of Sammoud et al., (2024), who reported small to moderate reductions following an 8-week plyometric training intervention in pre-adolescent soccer players. While their intervention shared similarities with ours – incorporating various jump types (e.g. horizontal, vertical) – it followed a different progression strategy. Specifically, their protocol increased the number of contacts from 50 to 120 without adding external loads, whereas our approach intensified the training by incorporating external loads. Despite increasing interest in optimizing plyometric training parameters, there is still no consensus on whether the number of contacts, external load, or a combination of both is most beneficial for improving physical capacity (de Villarreal et al., 2009; Ramirez-Campillo et al., 2023).

Regarding the ABD-ADD ratio, no significant changes were observed, as the baseline values in our sample were already close to the desired ratio, as reported by Magalhães et al., (2013), suggesting a minimal potential for further improvement. While the neurophysiological basis for managing asymmetries remains unclear, it is plausible that the improved motor patterns observed could enhance bilateral actions. Such changes may be driven by neural adaptations resulting from both training methods, which place substantial demands on the nervous system (Santos et al., 2023).

The combination of maximal lifting velocity resistance training has been suggested to induce specific improvements in performance outcomes (Jones et al., 2001). In a more specific manner, and aligned with the findings of the present study, the systematic review by Mateluna-Nuñez et al (Núñez et al., 2022). also advocates for the use of stretch-shortening cycles. This review found that the second pull in certain weightlifting derivatives, as well as maneuvers incorporating the stretch-shortening cycle in their hanging variants, can lead to significant enhancements in jumping, sprinting, and agility for athletes across various team sports.

A latent question in interpreting the enhanced outcomes achieved by both interventions, may account for understanding the underlying physiological mechanism. The absence of a control group not performing any conditioning could raise concerns about the influence of biological maturation on improved physical capacity. However, considering that the routine of five training sessions per week may be sufficient to stimulate musculoskeletal maturation, the specific effects of highly transferable explosive manoeuvres (such as plyometrics) or intensive muscle training (like weightlifting) might better explain the observed improvements in physical capacity over a relatively short period of 4 weeks.

Likewise, a deeper understanding of the physiological adaptations could be valuable for better periodizing the programs and even exploring the possibility of combining them for progressive and effective adaptations. Analysing the viability of a combined approach will help maximize benefits while minimizing physical costs, especially during congested seasons, which is a common concern in elite sports.

Additionally, the method of implementing these methodologies is crucial for their effectiveness. Factors such as the athlete's skill level, stage of the season, and execution intent must be carefully considered to maximize their benefits (Busso et al., 1992). In this context, adolescent basketball players are generally more familiar with plyometric training than with weightlifting, as plyometrics is more commonly integrated into their season schedule. Consequently, a 4-week familiarization period preceded the weightlifting intervention. This formative program focused more on acquiring technical skills than on performing high-load weightlifting (Berton et al., 2018). Therefore, the benefits of this familiarization process seem to provide a skilled status sufficient to achieve outcomes comparable to those from plyometric training. However, it remains uncertain whether a longer familiarization period would have led to greater expertise in weightlifting, potentially resulting in more significant physiological and performance improvements compared to plyometrics.

This research presents some limitations. First, the results are limited to a short period of 4 weeks. Therefore, it is unknown whether the enhanced outcomes would be maintained differently depending on the training performed. Additionally, 4 weeks could be considered a short intervention, especially for weightlifting programs, which require time to correctly acquire execution techniques. Furthermore, while athletes followed the same physical and technical training schedule, the amount of physical activity performed outside the study is unknown. Muscular physiological adaptations can be influenced by various factors, such as motivation and other psychological aspects, sleep quality, food intake, and hormonal response, which cannot be addressed in the current study. Future research should consider these factors for a more comprehensive understanding of muscular response.

## Practical applications

This study demonstrates that both plyometric and weightlifting training methods effectively enhance physical capacities important for youth basketball performance. Coaches can integrate these approaches into 4-week mesocycles, consisting of 45-minute sessions, three times per week, while maintaining high intensity.

Weightlifting training should focus on Olympic lifts, such as hang power cleans, snatches, and overhead squats. Starting with moderate loads (~70% of 1RM) and progressing to heavier loads (~85% of 1RM) ensures safe and effective strength development. Plyometric training, including counter-movement jumps, squat jumps, and drop jumps, should progressively reduce ground contacts (from 240 to 90) while increasing intensity using external weights like medicine balls. Monitoring intensity through the RPE scale, targeting levels of 8–9 out of 10, is a practical strategy to maintain effectiveness and prevent overtraining.

Future research should investigate whether combining these methods in a single program could produce additive effects, providing further insights into athletic development in young basketball players.

## Conclusion

Both weightlifting and plyometric training interventions have the potential to enhance athletic performance after a short mesocycle of 4 weeks. As previously reported, the two methods are similar in terms of effective adaptations, and no clear superiority of one intervention over the other has been evidenced during this time. Consequently, either plyometric or weightlifting can be integrated into adolescent basketball training programs depending on the phase of the season or the individual needs of the player. Further research is required to elucidate the combined effects of these two training modalities on adolescent basketball players' performance.

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## Clinical trial registration

A prospective research protocol was registered on ClinicalTrials.gov (Registration Number NCT05824780)

## Data availability statement

Complete data will be available under reasonable request to the corresponding author.

## Ethics approval

The study design received ethical approval from the Human Research Ethics Committee of the Universitat de Valencia (UV-INV_ETICA-3264539)

## Patient consent

Both participants and parents/legal guardians gave their written informed consent to participate in the study, in accordance with the ethical guidelines of the Declaration of Helsinki and subsequent updates.

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## References

Adami, P. E., Rocchi, J. E., Melke, N., De Vito, G., Bernardi, M., & Macaluso, A. (2022). Physiological profile comparison between high intensity functional training, endurance and power athletes. *European Journal of Applied Physiology*, *122*(2), 531–539. https://doi.org/10.1007/s00421-021-04858-3

American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, *41*(3), 687–708. https://doi.org/10.1249/MSS.0b013e3181915670

Arabatzi, F., & Kellis, E. (2012). Olympic weightlifting training causes different knee muscle-coactivation adaptations compared with traditional weight training. *The Journal of Strength & Conditioning Research*, *26*(8), 2192. https://doi.org/10.1519/JSC.0b013e31823b087a

Arabatzi, F., Kellis, E., & Saèz-Saez De Villarreal, E. (2010). Vertical jump biomechanics after plyometric, weight lifting, and combined (Weight lifting + Plyometric) training. *The Journal of Strength & Conditioning Research*, *24*(9), 2440. https://doi.org/10.1519/JSC.0b013e3181e274ab

Belhaj, K., Meftah, S., Mahir, L., Lmidmani, F., & Elfatimi, A. (2016). Isokinetic imbalance of adductor-abductor hip muscles in professional soccer players with chronic adductor-related groin pain. *European Journal of Sport Science*, *16*(8), 1226–1231. https://doi.org/10.1080/17461391.2016.1164248

Berton, R., Lixandrão, M. E., Pinto, E., Silva, C. M., & Tricoli, V. (2018). Effects of weightlifting exercise, traditional resistance and plyometric training on countermovement jump performance: A meta-analysis. *Journal of Sports Sciences*, *36*(18), 2038–2044. https://doi.org/10.1080/02640414.2018.1434746

Berton, R., Silva, D. D., Santos, M. D., Silva, C. E., & Tricoli, V. (2022). Weightlifting derivatives vs. plyometric exercises: Effects on unloaded and loaded vertical jumps and sprint performance. *PLOS ONE*, *17*(9), e0274962. https://doi.org/10.1371/journal.pone.0274962

Busso, T., Häkkinen, K., Pakarinen, A., Kauhanen, H., Komi, P. V., Lacour, J. R. & (1992). Hormonal adaptations and modelled responses in elite weightlifters during 6 weeks of training. *European Journal of Applied Physiology and Occupational Physiology*, *64*(4), 381–386. https://doi.org/10.1007/BF00636228

Calatayud, J., Martin, F., Gargallo, P., García-Redondo, J., Colado, J. C., & Marín, P. J. (2015). The validity and reliability of a new instrumented device for measuring ankle dorsiflexion range of motion. *International Journal of Sports Physical Therapy*, *10*(2), 197–202.

Cejudo, A., Sainz de Baranda, P., Ayala, F., & Santonja, F. (2014). A simplified version of the weight-bearing ankle lunge test: Description and test-retest reliability. *Manual Therapy*, *19*(4), 355–359. https://doi.org/10.1016/j.math.2014.03.008

Channell, B. T., & Barfield, J. P. (2008). Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. *The Journal of Strength & Conditioning Research*, *22*(5), 1522. https://doi.org/10.1519/JSC.0b013e318181a3d0

Chaouachi, A., Hammami, R., Kaabi, S., Chamari, K., Drinkwater, E. J., & Behm, D. G. (2014). Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training. *The Journal of Strength & Conditioning Research*, *28*(6), 1483. https://doi.org/10.1519/JSC.0000000000000305

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). L. Erlbaum Associates.

Colado, J. C., Gené-Morales, J., Jiménez-Martínez, P., Flandez, J., Ferri-Caruana, A. M., & Babiloni-Lopez, C. (2023). Rating of perceived exertion in the first repetition is related to the total repetitions performed in elastic bands training. *Motor Control*, *27*(4), 830–843. https://doi.org/10.1123/mc.2023-0017

Colado, J. C., Gene-Morales, J., Jiménez-Martínez, P., Saez-Berlanga, A., Ferri-Caruana, A. M., Garcia-Ramos, A., Flandez, J., & Babiloni-Lopez, C. (2024). Concurrent validation of the resistance intensity scale for exercise for monitoring velocity-based training with elastic bands. *Heliyon*, *10*(7), e28298. https://doi.org/10.1016/j.heliyon.2024.e28298

Comfort, P., Haff, G. G., Suchomel, T. J., Soriano, M. A., Pierce, K. C., Hornsby, W. G., Haff, E. E., Sommerfield, L. M., Chavda, S., Morris, S. J., Fry, A. C., & Stone, M. H. (2023). National strength and conditioning association position statement on weightlifting for sports performance. *The Journal of Strength & Conditioning Research*, *37*(6), 1163–1190. https://doi.org/10.1519/JSC.0000000000004476

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: Part 2 - training considerations for improving maximal power production. *Sports Medicine (Auckland, NZ)*, *41*(2), 125–146. https://doi.org/10.2165/11538500-000000000-00000

Cuschieri, S. (2019). The CONSORT statement. *Saudi Journal of Anaesthesia*, *13*(Suppl 1), S27–S30. https://doi.org/10.4103/sja.SJA_559_18

de Villarreal, E. S. S., Kellis, E., Kraemer, W. J., & Izquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: A meta-analysis. *The Journal of Strength & Conditioning Research*, *23*(2), 495. https://doi.org/10.1519/JSC.0b013e318196b7c6

Dominguez-Navarro, F., Casaña, J., Perez-Dominguez, B., Ricart-Luna, B., Cotolí-Suárez, P., & Calatayud, J. (2023). Dynamic balance and explosive strength appears to better explain single leg hop test results among young elite female basketball athletes. *Scientific Reports*, *13*(1), 5476. https://doi.org/10.1038/s41598-023-31178-7

Faul, F., Erdfelder, E., Lang, A. G., & Buchel, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Gál-Pottyondy, A., Petró, B., Czétényi, A., Négyesi, J., Nagatomi, R., & Kiss, R. M. (2021). Collection and advice on basketball field tests-a literature review. *Applied Sciences*, *11*(19), 8855. https://doi.org/10.3390/app11198855

García-Valverde, A., Manresa-Rocamora, A., Hernández-Davó, J. L., & Sabido, R. (2022). Effect of weightlifting training on jumping ability, sprinting performance and squat strength: A systematic review and meta-analysis. *International Journal of Sports Science & Coaching*, *17*(4), 917–939. https://doi.org/10.1177/17479541211061695

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M., & Maffiuletti, N. A. (2011). Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *The Journal of Strength & Conditioning Research*, *25*(2), 556–560. https://doi.org/10.1519/JSC.0b013e3181ccb18d

Hammami, R., Gene-Morales, J., Nebigh, A., Rebai, H., & Colado, J. C. (2022). Speed improves with eccentric hamstring training in athletes of different maturity status. *Pediatric Exercise Science*, *34*(2), 99–107. https://doi.org/10.1123/pes.2021-0080

Hawkins, S. B., Doyle, T. L. A., & McGuigan, M. R. (2009). The effect of different training programs on eccentric energy utilization in college-aged males. *The Journal of Strength & Conditioning Research*, *23*(7), 1996. https://doi.org/10.1519/JSC.0b013e3181b3dd57

Heishman, A., Daub, B., Miller, R., Brown, B., Freitas, E., & Bemben, M. (2019). Countermovement jump inter-limb asymmetries in collegiate basketball players. *Sports*, *7*(5), 103. https://doi.org/10.3390/sports7050103

Hoffman, J. R., Cooper, J., Wendell, M., & Kang, J. (2004). Comparison of Olympic vs. traditional power lifting training programs in football players. *The Journal of Strength & Conditioning Research*, *18*(1), 129–135. https://doi.org/10.1519/1533-4287,(2004)018<0129:coovtp>2.0.co;2

İnce, İ. (2019). Effects of split style Olympic weightlifting training on leg stiffness vertical jump change of direction and sprint in collegiate volleyball players. *Universal Journal of Educational Research*, *7*(1), 24–31. https://doi.org/10.13189/ujer.2019.070104

Johnson, B. A., Salzberg, C. L., & Stevenson, D. A. (2011). A systematic review: Plyometric training programs for young children. *The Journal of Strength & Conditioning Research*, *25*(9), 2623. https://doi.org/10.1519/JSC.0b013e318204caa0

Jones, K., Bishop, P., Hunter, G., & Fleisig, G. (2001). The effects of varying resistance-training loads on intermediate– and high–velocity-specific adaptations. *The Journal of Strength & Conditioning Research*, *15*(3), 349. https://doi.org/10.1519/1533-4287(2001)015<0349:TEOVRT>2.0.CO;2

Kaabi, S., Mabrouk, R. H., & Passelergue, P. (2022). Weightlifting is better than plyometric training to improve strength, counter movement jump, and change of direction skills in tunisian elite male junior table tennis players. *The Journal of Strength & Conditioning Research*, *36*(10), 2912–2919. https://doi.org/10.1519/JSC.0000000000003972

Lamas, L., Ugrinowitsch, C., Rodacki, A., Pereira, G., Mattos, E. C. T., Kohn, A. F., & Tricoli, V. (2012). Effects of strength and power training on neuromuscular adaptations and jumping movement pattern and performance. *The Journal of Strength & Conditioning Research*, *26*(12), 3335. https://doi.org/10.1519/JSC.0b013e318248ad16

Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. *Strength & Conditioning Journal*, *34*(3), 61. https://doi.org/10.1519/SSC.0b013e31825760ea

Maffulli, N., Longo, U. G., Gougoulias, N., Loppini, M., & Denaro, V. (2010). Long-term health outcomes of youth sports injuries. *British Journal of Sports Medicine*, *44*(1), 21–25. https://doi.org/10.1136/bjsm.2009.069526

Magalhães, E., Silva, A. P. M. C. C., Sacramento, S. N., Martin, R. L., & Fukuda, T. Y. (2013). Isometric strength ratios of the hip musculature in females with patellofemoral pain: a comparison to pain-free controls. *The Journal of Strength & Conditioning Research*, *27*(8), 2165. https://doi.org/10.1519/JSC.0b013e318279793d

Malina, R. M., Rogol, A. D., Cumming, S. P., Coelho e Silva, M. J., & Figueiredo, A. J. (2015). Biological maturation of youth athletes: Assessment and implications. *British Journal of Sports Medicine*, *49*(13), 852–859. https://doi.org/10.1136/bjsports-2015-094623

Mann, J. B., Ivey, P. A., Mayhew, J. L., Schumacher, R. M., & Brechue, W. F. (2016). Relationship between agility tests and short sprints: reliability and smallest worthwhile difference in National Collegiate Athletic Association Division-I Football players. *The Journal of Strength & Conditioning Research*, *30*(4), 893. https://doi.org/10.1519/JSC.0000000000001329

Moran, L. R., Hegedus, E. J., Bleakley, C. M., & Taylor, J. B. (2019). Jump load: Capturing the next great injury analytic. *British Journal of Sports Medicine*, *53*(1), 8–9. https://doi.org/10.1136/bjsports-2018-099103

Morris, S. J., Oliver, J. L., Pedley, J. S., Haff, G. G., & Lloyd, R. S. (2022). Comparison of weightlifting, traditional resistance training and plyometrics on strength, power and speed: A systematic review with meta-analysis. *Sports Medicine*, *52*(7), 1533–1554. https://doi.org/10.1007/s40279-021-01627-2

Negra, Y., Chaabene, H., Stöggl, T., Hammami, M., Chelly, M. S., & Hachana, Y. (2020). Effectiveness and time-course adaptation of resistance training vs. plyometric training in prepubertal soccer players. *Journal of Sport and Health Science*, *9*(6), 620–627. https://doi.org/10.1016/j.jshs.2016.07.008

Newton, R. U., Hakkinen, K., Hakkinen, A., McCormick, M., Volek, J., & Kraemer, W. J. (2002). Mixed-methods resistance training increases power and strength of young and older men. *Medicine and Science in Sports and Exercise*, *34*(8), 1367–1375. https://doi.org/10.1097/00005768-200208000-00020

Núñez, C. A. M., Zavala-Crichton, J. P., Monsalves-Álvarez, M., Olivares-Arancibia, J., & Yáñez-Sepúlveda, R. (2022). Efectos del entrenamiento con movimientos de halterofilia en el rendimiento de esprint, salto y cambio de dirección en deportistas: Una revisión sistemática (Effects of weightlifting training on sprint, jump and change of direction performance in athlete: Una revisión sistemática. *Retos*, *44*, 464–476. https://doi.org/10.47197/retos.v44i0.88670

Petway, A. J., Freitas, T. T., Calleja-González, J., Leal, D. M., & Alcaraz, P. E. (2020). Training load and match-play demands in basketball based on competition level: A systematic review. *PLOS ONE*, *15*(3), e0229212. https://doi.org/10.1371/journal.pone.0229212

Pind, R., & Mäestu, J. (2017). Monitoring training load: Necessity, methods and applications. *Acta Kinesiologiae Universitatis Tartuensis*, *23*, 7–18. https://doi.org/10.12697/akut.2017.23.01

Ramirez-Campillo, R., García-Hermoso, A., Moran, J., Chaabene, H., Negra, Y., & Scanlan, A. T. (2022). The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis. *Journal of Sport and Health Science*, *11*(6), 656–670. https://doi.org/10.1016/j.jshs.2020.12.005

Ramirez-Campillo, R., Thapa, R. K., Afonso, J., Perez-Castilla, A., Bishop, C., Byrne, P. J., & Granacher, U. (2023). Effects of plyometric jump training on the reactive strength index in healthy individuals across the lifespan: A systematic review with meta-analysis. *Sports Medicine*, *53*(5), 1029–1053. https://doi.org/10.1007/s40279-023-01825-0

Rodriguez, R. (2020). Measuring the hip adductor to abductor strength ratio in ice hockey and soccer players: A critically appraised topic. *Journal of Sport Rehabilitation*, *29*(1), 116–121. https://doi.org/10.1123/jsr.2018-0250

Rodríguez-Rosell, D., Torres-Torrelo, J., Franco-Márquez, F., González-Suárez, J. M., & González-Badillo, J. J. (2017). Effects of light-load maximal lifting velocity weight training vs. combined weight training and plyometrics on sprint, vertical jump and strength performance in adult soccer players. *Journal of Science & Medicine in Sport*, *20*(7), 695–699. https://doi.org/10.1016/j.jsams.2016.11.010

Sáez de Villarreal, E., Requena, B., & Cronin, J. B. (2012). The effects of plyometric training on sprint performance: A meta-analysis. *The Journal of Strength & Conditioning Research*, *26*(2), 575. https://doi.org/10.1519/JSC.0b013e318220fd03

Sammoud, S., Negra, Y., Bouguezzi, R., Ramirez-Campillo, R., Moran, J., Bishop, C., & Chaabene, H. (2024). Effects of plyometric jump training on measures of physical fitness and lower-limb asymmetries in prepubertal male soccer players: A randomized controlled trial. *BMC Sports Science, Medicine and Rehabilitation*, *16*(1), 37. https://doi.org/10.1186/s13102-024-00821-9

Santos, P. D. G., Vaz, J. R., Correia, J., Neto, T., & Pezarat-Correia, P. (2023). Long-term neurophysiological adaptations to strength training: A systematic review with cross-sectional studies. *The Journal of Strength & Conditioning Research*, *37*(10), 2091–2105. https://doi.org/10.1519/JSC.0000000000004543

Templeton, G. F. (2011). A two-step approach for transforming continuous variables to normal: Implications and recommendations for is research. *CAIS*, *28*(4), 41–58. https://doi.org/10.17705/1CAIS.02804

Thorborg, K., Petersen, J., Magnusson, S. P., & Hölmich, P. (2010). Clinical assessment of hip strength using a hand-held dynamometer is reliable. *Scandinavian Journal of Medicine & Science in Sports*, *20*(3), 493–501. https://doi.org/10.1111/j.1600-0838.2009.00958.x

Tricoli, V., Lamas, L., Carnevale, R., & Ugrinowitsch, C. (2005). Short-term effects on lower-body functional power development: Weightlifting vs. vertical jump training programs. *The Journal of Strength & Conditioning Research*, *19*(2), 433–437. https://doi.org/10.1519/R-14083.1