ORIGINAL ARTICLE

Effects of a six-week plyometric training program on balance, jumping ability, and between-leg asymmetry in young adult basketball players

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ABSTRACT

Improving balance, jumping ability and unilateral actions is of great importance in basketball. The key question is how to get it. Eighteen amateur basketball players (age: 23 ± 2.8 years; height: 185.3 ± 0.064 m; body mass: 85.2 ± 9.9 kg) participated in this study and were divided into the experimental group (n = 10) or a control group (n = 8). The following metrics were recorded one week before and one week after the training program: anthropometric measurements, Y-Balance, Standing Stork, ankle dorsiflexion range of motion, arm-inclusive bilateral-vertical countermovement jump, unilateral 0.2-m drop jump, and Triple-Hop tests. The experimental group underwent a moderate-intensity six-week plyometric training program which included bilateral and unilateral jumps, some performed consecutively and others with rest between jumps. Results indicate that right ankle ROM improve 9.8% (*p* = .012), YBT Right Anterior (6.4%; 0.063) and YBT Left Posteromedial (6.2%; 0.010). In jumping ability, RSI left improve of 18.6% (*p* = .019), DJ Height Left (13.1%; 0.037) and DJ Height Right (11%; 0.025). Regards asymmetry the only statistically significant improvement occurs in the Ankle ROM test, with an improvement of 60.8% (*p* = .017).

Keywords: Performance analysis, Plyometric exercise, Explosiveness, Imbalance, Jump, Strength.

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INTRODUCTION

Basketball is a team sport that requires a high level of contact and numerous explosive actions and demands multidirectional movement patterns, the majority of which are unilateral (Dos'Santos et al., 2018). Most injuries in basketball take place during these unilateral actions (Bahr and Krosshaug, 2005) and, in case of bilateral actions, in the leg that produces the most strength (Gonzalo-Skok et al., 2017). Understanding asymmetry as the difference in the strength capacity of the lower limbs (Kons et al., 2021; Thomas et al., 2017), it is known that asymmetries of 15% or more result in decreased physical performance and a dangerous increase in the risk of injury (Bishop et al., 2018; Guan et al., 2022; Ličen and Kozinc, 2023). Asymmetry is usually assessed by analysing the hip extensors and flexors and knee extensors with a dynamometer while performing isokinetic and isometric tests (Thomas et al., 2017; McElveen et al., 2010; Bond et al., 2017).

However, lately this aspect has become more important. In fact, many authors even say that one of the key issues raised by the asymmetry is the laterality of the players. For example, right-handed or left-handed players can be affected in a different way when playing and training. Then, the relationships of laterality, technical and tactical drills, or playing systems have a direct impact on asymmetry and the physical practice may affect this development. Also, this issue (more right-handed than left-handed players) may mask the real effects of asymmetry when some of left-handed are forced to solve systems more focused on right/left zones of the court (Fernandez et al., 2009) or when training the tasks are more related to different development of lateral dominance (Stöckel and Carey, 2016). As McElveen indicated, this differences between left and right legs can be diminished by SSC training and multidirectional high-speed movements (McElveen et al., 2010).

Plyometrics train these SSCs, thus helping to enhance the eccentric loading phase energy stores and improve the maximum strength output during the concentric phase of the movement (Booth and Orr, 2016; Asadi et al., 2015; Taube et al., 2012; Komi and Gollhofer, 1997). It is known that plyometric exercises are beneficial to balance (Asadi et al., 2015; Ramachandran et al., 2021; Kobal et al., 2017; Ramírez-Campillo et al., 2015a; Ramírez-Campillo et al., 2015b; McInnes et al., 1995) and jumping ability (Ramírez-Campillo et al., 2015a; Ramírez-Campillo et al., 2015b; Ramírez-Campillo et al., 2022; Balsalobre-Fernández et al., 2015; Ozbar et al., 2014; Sáez-Sáez et al., 2009; Villarreal et al., 2008) and therefore have a positive effect on performance (Ramírez-Campillo et al., 2022; Ziv and Lidor 2010) and injury prevention (Asadi et al., 2015; Ramirez-Campillo et al., 2020; Suchomel et al., 2019; Rhouni et al 2019; Brachman et al., 2017; Filipa et al., 2010; Meylan et al., 2009; Fouré et al., 2009; Myrick 2007; Spurrs et al, 2003; Diallo et al., 2001), although not all studies have shown its effectiveness (Kurt et al., 2023; Meszler and Váczi 2019). Furthermore, jump height is representative of lower-limb strength and power (McElveen et al., 2010; Balsalobre-Fernández et al., 2015; Villarreal et al., 2008) and is a good indicator of neuromuscular fatigue (Balsalobre-Fernández et al., 2015). However, because of the different patterns of movement used in basketball, perhaps only vertical jumps can be used to represent performance, and so the use of multidirectional unilateral tests is recommended when trying to fully profile an athlete's strength (McElveen et al., 2010; Meylan et al., 2009). So, the aim of this study was to examine the effects of a six-week plyometric training (PT) program on different factors that affect basketball performance, such as balance, jumping ability, and between-leg asymmetry in young adult basketball players. We hypothesize that with these kind of training players will improve indicated skills.

MATERIALS AND METHODS

Participants

Eighteen young adult amateur basketball male players from the same team (age: 23 ± 2.8 years; height: 185.3 ± 0.064 m; body mass: 85.2 ± 9.9 kg) were randomly assigned into the control or experimental group (see Table 1). The T-test performed found no differences (*p* > .05) between the two groups for the indicated variables. They all had at least 10 years' experience in competition and had been continuously participating in basketball practice training for the 4 months prior to the study. Twenty volunteer participants were recruited and randomly split into a control group (CG) and an experimental group (EG). During the study, two participants dropped out from the control group and hence group sizes for all reported results are n = 8 (CG) and n = 10 (EG). None of the subjects had previously done systematic PT training. Participants meeting the following criteria were excluded from the study: (a) potential medical problems or a history of knee or ankle injury in the year before study; (b) medical or orthopaedic problems that could compromise their performance in the study; and (c) had received any lower extremity reconstructive surgery in the past 2 years or had unresolved musculoskeletal disorders. Authors declare that the experiments reported in the manuscript were performed in accordance with the ethical standards of the Helsinki Declaration and that the participants signed an informed consent form.

Table 1. Characteristics of the study participants.

Characteristics	**EG (n = 10)**	**CG (n = 8)**
	Mean ± SD	Mean ± SD
Age (years)	23.6 ± 2.4	22.6 ± 2.3
Height (m)	1.86 ± 0.07	1.85 ± 0.04
Body Mass (Kg)	89.6 ± 9.0	88.8 ± 7.7
Body Mass Index (Kg/m^2)	25.8 ± 1.6	25.9 ± 1.7
Body Fat (%)	20.9 ± 5.4	20.9 ± 4.4
Body Muscle (%)	38.7 ± 3.3	39.5 ± 2.1
Leg length right (m)	1.078 ± 0.06	1.011 ± 0.037

Note. EG (experimental group), CG (control group). No differences (p > .05) between the two groups were found for these descriptive variables.

Testing procedures

A six-week PT program performed twice a week between January and March of 2018 (see Table 2). During the study, all the participants followed their normal technical and tactical basketball training, and in addition, the EG also performed PT. The PT sessions lasted 25 to 35 minutes and comprised 10 minutes of specific warm-up and 15 to 25 minutes of PT and were completed between 18:30 and 20:30 on Monday and Wednesday (all in the same time zone and measured by the same researcher). A combination of multilateral, multidirectional jumps were used and performed in a consecutive (without rest between jumps to take advantage of the stretch-shortening cycle) and non-consecutive way, with 15 seconds of rest between jumps (Taube et al., 2012; Ramírez-Campillo et al., 2015b), allowing 60 seconds recovery between sets (Read and Cisar, 2001). In addition, before the PT program started, the EG received 3 sessions to get familiarized with the submaximal and maximal actions comprising the PT exercises to ensure were able to produce a consistent technique.

Two testing session were carried out one week before (pre-test) and one week after (post-test) the PT period. On day 1, the following tests were performed: (a) anthropometric measurements, (b) dynamic balance assessment Y-Balance Test (YBT), (c) static balance assessment Standing Stork Test (SST), and (d) ankle dorsiflexion range of motion (ROM). On day 2, (e) unilateral drop jump (DJ) from 0.2 meters (20-DJ), (f) bilateral countermovement jump (CMJ) with use of the arms, and (g) a Triple-Hop Test (THT) were performed. A stadiometer was used to measure the participants' height and a bioelectrical impedance scale (Omron BF511) to record their body composition and body mass. Before each testing session, both groups performed a specific 10-minute warm-up which consisted of: 5 minutes of submaximal running and mobilization of the joints implicated in the tests and 5 minutes of submaximal jumps (10 vertical-bilateral and 5 vertical-unilateral with each leg, and 10 horizontal-bilateral and 5 horizontal-unilateral with each leg). All the participants were instructed to wear the same shoes and similar clothes on each of the testing days.

Table 2. Program of 6-week plyometric training. 2 sessions per week.

Exercises	**Set × repetitions (mode of execution)**					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Bilateral horizontal	2 × 4 (C) 2 × 4 (N)	2 × 5 (C) 2 × 5 (N)	2 × 6 (C) 2 × 6 (N)	2 × 7 (C) 2 × 7 (N)	2 × 8 (C) 2 × 8 (N)	2 × 9 (C) 2 × 9 (N)
Bilateral vertical	2 × 4 (C) 2 × 4 (N)	2 × 5 (C) 2 × 5 (N)	2 × 6 (C) 2 × 6 (N)	2 × 7 (C) 2 × 7 (N)	2 × 8 (C) 2 × 8 (N)	2 × 9 (C) 2 × 9 (N)
Left horizontal	2 × 4 (C) 2 × 4 (N)	2 × 5 (C) 2 × 5 (N)	2 × 6 (C) 2 × 6 (N)	2 × 7 (C) 2 × 7 (N)	2 × 8 (C) 2 × 8 (N)	2 × 9 (C) 2 × 9 (N)
Right horizontal	2 × 4 (C) 2 × 4 (N)	2 × 5 (C) 2 × 5 (N)	2 × 6 (C) 2 × 6 (N)	2 × 7 (C) 2 × 7 (N)	2 × 8 (C) 2 × 8 (N)	2 × 9 (C) 2 × 9 (N)
Left vertical	2 × 4 (C) 2 × 4 (N)	2 × 5 (C) 2 × 5 (N)	2 × 6 (C) 2 × 6 (N)	2 × 7 (C) 2 × 7 (N)	2 × 8 (C) 2 × 8 (N)	2 × 9 (C) 2 × 9 (N)
Right vertical	2 × 4 (C) 2 × 4 (N)	2 × 5 (C) 2 × 5 (N)	2 × 6 (C) 2 × 6 (N)	2 × 7 (C) 2 × 7 (N)	2 × 8 (C) 2 × 8 (N)	2 × 9 (C) 2 × 9 (N)
Total per leg	64	80	96	112	128	144

Note. C (consecutive), N (Non-consecutive). The order of exercises execution was randomized for each training session. All exercises were executed with the technique described as countermovement with arms.

Y-Balance Test. This test was used to assess dynamic balance and required participants to stand on one leg while extending the contralateral leg as far as possible in each of three different directions (i.e., anterior, posteromedial, and posterolateral; Hammami et al., 2016; Chaouachi et al., 2017). A grid with a 'Y' form was constructed by placing three lines on the floor with adhesive tape marked at 5 mm intervals. The two posterior lines radiated from the centre of the 'Y' with an angle of 45 degrees between them and at 135 degrees with the anterior line. For the normalized measurements, the right leg length of each participant was measured in the supine lying position from the level of the anterior superior iliac spine to the most distal aspect of the medial malleolus of the ankle. Before we started the trial measurements, we allowed the participants to practice, for up to six trials in each direction (three in each leg), to familiarize themselves with the test.

All the trials were carried out barefoot. The participants were allowed to rest bilaterally for 15 seconds between each attempt. The examiner manually noted each distance from the centre of the grid to the most distal point reached. Attempts were discarded and repeated if the participant (a) did not touch the line with the reaching foot while bearing the weight on the stance leg; (b) displaced the stance foot from the centre of the grid; (c) lost balance at any point during the trial; (d) did not maintain the balanced position for 1 second in the start and return positions; or (e) bore the weight on the reaching foot to gain support.

The mean of 3 successful attempts in each direction was used in subsequent analyses. In addition, a composite score (CS) was calculated based on the maximum distance reached for each direction and the length of the right leg (Filipa et al., 2010; Hammami et al., 2016; Chaouachi et al., 2017) using the following formula: CS = [(maximum anterior reach distance + maximum posteromedial reach distance + maximum posterolateral reach distance) ⁄ leg length × 3] × 100.

Standing Stork Test. Static balance was assessed using the SST. Participants initially stood on their left leg, placing their opposite foot against the inside of their supporting knee with both hands placed on their hips. When indicated, the athlete had to raise their heel from the floor and maintain balance for as long as possible. The attempt was considered finished if the participant (a) moved their hands from their hips; (b) the ball of the foot was displaced from its original position; or (c) the heel touched the floor. After three attempts, the legs were switched. Each trial was measured in seconds with a manual chronometer. The best score of the three attempts was recorded for further analysis.

Ankle range of motion. Ankle dorsiflexion ROM was calculated based on the maximal passive flexion and maximal passive extension using the Dorsiflex App for the iPad Air 2 (Balsalobre-Fernández et al., 2015) Participants stood with one knee on the floor with the other leg located in front of them, supported by the sole of the foot. From this position, the participants were asked to flex their forward ankle to the limit first by moving their weight to the front and then extending their ankle by displacing their weight backwards. The Dorsiflex App was calibrated to their shin, thus allowing us to measure the degrees of their flexion and extension and their maximal ankle extension and flexion were recorded and used to calculate the full range of movement.

Vertical jump tests. Two vertical jump tests were used in this study: a CMJ and a 20-DJ; the volunteers were allowed to swing their arms. Furthermore, the participants had to take off with their knees and ankles extended and land in the same position and place to minimize any possible horizontal displacement but were told to flex their knees immediately after touching the ground to soften their landing. All the vertical tests were assessed using the MyJump 2 App for the iPad Air 2, (Balsalobre-Fernández et al., 2015). A rest of 45 seconds was allowed between jumps and at least 5 minutes were allowed between the two jump tests.

For the CMJ test, participants were required to lower themselves as quickly as possible from an erect position to a self-selected depth, followed by a maximal vertical jump. The mean of three trials, with 45 seconds recovery time between each trial, was recorded and used for further analysis.

The 20-DJ was chosen because of all variables that we recorded; it gave us a good estimate of between-leg asymmetry. All the participants started standing unilaterally at a height of 0.2 meters and, to minimize the contact time with the ground and maximize the jump height, were instructed to try to land in the same spot; the volunteers were allowed to freely use their arms to help balance them during the jump. The mean of 2 trials per leg were recorded and 45 seconds recovery was allowed between the trials. During this test we registered the following variables: ground contact time, flight time, and the Reactive Strength Index (RSI): RSI = Jump height / Ground contact time, where height is in meters and time in seconds (Lloyd et al., 2009).

Horizontal jump test. The THT was used to assess the volunteers' horizontal jumping capacity. A tape measure marked at 0.01-m intervals was fixed to the ground, perpendicular to the starting line. Participants were instructed to start standing on one leg, just behind the starting line and perform 3 consecutive maximal jumps forward with the same leg to reach as far as possible in the horizontal plane; the volunteers were allowed to freely swing their arms during the test. The distance was measured from the starting line to the point where the heel landed in the third and final jump. The mean of 2 attempts for each leg was recorded and used for subsequent analyses.

Asymmetry assessment: as indicated Gonzalo-Skok asymmetry was assessed using representative functional performance situations (Gonzalo-Skok et al., 2017). Thus, we chose unilateral tests with SSC to assess power and jumping ability such as the 20-DJ, and THT and unilateral tests to assess static and dynamic balance such as the SST and YBT (Hammami et al., 2016; Mohammadi et al., 2017). The between-leg asymmetry in this study was calculated as the percentage difference between the strong and weak legs, according to the following formula (Bond et al., 2017): Asymmetry = [(Strong leg value – Weak leg value) / Strong leg value] x 100%.

Statistical analysis

All statistical calculations were performed using the statistical software R 3.6.1 (R Core Team, 2019) and package lme4 1.1.21 (Bates et al., 2015). First, we performed a descriptive analysis of all the variables and expressed them as the mean plus or minus the standard deviation (SD). The EG was compared with the CG using mixed linear models for repeated measures with athlete as random effect and moment and group as fixed factors. The diagnostics of these mixed linear models suggested that with significance level (α) set at .05 the assumptions of mixed linear models were met. These assumptions were checked as follows: Gaussianity of residuals was checked with Kolmogorov-Smirnov tests, equality of variances with Levene's test and absence of outliers with Cook's distance. Furthermore, we computed effect sizes (pseudo-R2) and 95% confidence intervals for all effects.

RESULTS

At a 5% significance level, improvements are statistically significant in more than half of the twenty-one balance and jumping ability variables considered: 41.67% of twelve (balance) and 66.67% of nine (jumping ability). Furthermore, slightly increasing the significance level to 6.5% increases substantially the degree of improvement to 58.33% of balance variables and 88.89% of jumping ability variables.

Regarding balance (see Table 3), the most notable improvements resulting from the training occur in the following tests: right ankle ROM, with an improvement in the experimental group relative to the control group of 9.8% (*p*-value = .012), YBT Right Anterior (6.4%; 0.063) and YBT Left Posteromedial (6.2%; 0.010).

In jumping ability (see Table 4), the most notable improvements resulting from the training occur in the following tests: RSI left, with an improvement in the experimental group relative to the control group of 18.6% (*p*-value = .019), DJ Height Left (13.1%; 0.037) and DJ Height Right (11%; 0.025).

Respecting asymmetry (see Table 5), the only statistically significant improvement resulting from the training occurs in the Ankle ROM test, with an improvement in the experimental group relative to the control group of 60.8% (*p*-value = .017). The YBT Anterior test is close to being statistically significant (*p*-value = .055) with an improvement of 65.5%. The DJ Flight Time and THT Asymmetry tests are statistically significant with improvements of 35.7% and 63% respectively but only for the experimental group.

DISCUSSION

This study aimed to assess the effects of a 6-week PT program on balance, jumping ability, and between-leg asymmetry in young adult basketball players. While a statistical analysis of the data concludes that a moderate-volume and frequency plyometric program improves balance and jumping ability in a broad sense, the support for improvements in asymmetry between legs appears to be narrower.

Table 3. Effect of the 6-week plyometric training program on balance.

	Experimental group (EG, n = 10)			Control group (CG, n = 8)			Effect
Balance variables	Pre – Mean ± SD	Post – Mean ± SD	Performance change [|Δ%|]	Pre – Mean ± SD	Post – Mean ± SD	Performance change [|Δ%|]	$\Delta EG - \Delta CG$ [|ΔEG %|] (*p*-value)
YBT Left Anterior (m)	0.738 ± 0.068	0.786 ± 0.056	0.048 [6.5]^(***)	0.742 ± 0.05	0.751 ± 0.046	0.009 [1.2]^◇(***)	0.039 [5.3] (.053)^(*◇(**))
YBT Left Posteromedial (m)	1.056 ± 0.131	1.126 ± 0.125	0.07 [6.6]^(***)	1.045 ± 0.056	1.050 ± 0.049	0.005 [0.5]^◇(***)	0.065 [6.2] (.010)^(**◇(*))
YBT Left Posterolateral (m)	1.113 ± 0.103	1.134 ± 0.063	0.021 [1.9]^◇(***)	1.064 ± 0.037	1.088 ± 0.042	0.024 [2.2]^◇(***)	-0.003 [0.3] (.905)^◇(***)
YBT Right Anterior (m)	0.735 ± 0.078	0.791 ± 0.055	0.056 [7.6]^(***)	0.745 ± 0.052	0.754 ± 0.036	0.009 [1.2]^◇(***)	0.047 [6.4] (.063)^(*◇(**))
YBT Right Posteromedial (m)	1.072 ± 0.131	1.116 ± 0.084	0.044 [4.1]^(***)	1.076 ± 0.054	1.081 ± 0.051	0.005 [0.5]^◇(***)	0.039 [3.6] (.087)^(*◇(**))
YBT Right Posterolateral (m)	1.096 ± 0.094	1.128 ± 0.067	0.032 [2.9]^(***)	1.078 ± 0.044	1.071 ± 0.045	-0.006 [0.6]^◇(***)	0.038 [3.5] (.022)^(**◇(*))
YBT Left CS (%)	0.92 ± 0.065	0.957 ± 0.056	0.037 [4.0]^(***)	0.965 ± 0.056	0.97 ± 0.045	0.005 [0.5]^◇(***)	0.032 [3.4] (.017)^(**◇(*))
YBT Right CS (%)	0.920 ± 0.057	0.955 ± 0.055	0.035 [3.9]^(***)	0.978 ± 0.056	0.973 ± 0.042	-0.005 [0.5]^◇(***)	0.04 [4.4] (.015)^(**◇(*))
SST Left (s)	4.3 ± 1.8	5.8 ± 4.1	1.5 [34.9]^◇(***)	5.5 ± 3.0	5.4 ± 2.4	-0.1 [2.4]^◇(***)	1.6 [37.9] (.242)^◇(***)
SST Right (s)	3.0 ± 0.9	4.8 ± 3.2	1.8 [60.0]^(*◇(**))	4.9 ± 2.5	4.8 ± 2.8	-0.1 [2.5]^◇(***)	1.9 [64.0] (.155)^◇(***)
Left Ankle ROM (º)	82.1 ± 10.1	86.1 ± 9.9	4.0 [4.8]^(*◇(**))	84.2 ± 10.2	84.3 ± 12.2	0.1 [0.1]^◇(***)	3.9 [4.7] (.213)^◇(***)
Right Ankle ROM (º)	78.4 ± 10.0	84.7 ± 9.9	6.3 [8.0]^(***)	84.6 ± 12.3	83.2 ± 12.4	-1.4 [1.7]^◇(***)	7.7 [9.8] (.012)^(**◇(*))

Note. YBT (Y-Balance Test), SST (Standing Stork Test), CS (Composite Score), ROM (Range of Movement). Statistically significant differences are marked at 10% (*), 5% (**) and 1% (***) levels.

Table 4. Effect of the 6-week plyometric training program on jumping ability.

	Experimental group (EG, n = 10)			Control group (CG, n = 8)			Effect
Jump variables	Pre – Mean ± SD	Post – Mean ± SD	Performance change [|Δ%|]	Pre – Mean ± SD	Post – Mean ± SD	Performance change [|Δ%|]	$\Delta EG - \Delta CG$ [|ΔEG %|] (*p*-value)
THT Left (m)	6.194 ± 0.433	6.482 ± 0.380	0.288 [4.6]^(**◇(*))	6.176 ± 0.302	6.020 ± 0.325	-0.156 [2.5]^◇(***)	0.444 [7.2] (.023)^(**◇(*))
THT Right (m)	6.024 ± 0.474	6.476 ± 0.419	0.452 [7.5]^(***)	6.052 ± 0.208	5.859 ± 0.140	-0.194 [3.2]^(**◇(*))	0.646 [10.7] (.000)^(***)
CMJ Bilateral (m)	0.441 ± 0.064	0.484 ± 0.061	0.042 [9.5]^(***)	0.412 ± 0.023	0.409 ± 0.019	-0.004 [0.9]^◇(***)	0.046 [10.4] (.000)^(***)
DJ Height Left (m)	0.234 ± 0.062	0.266 ± 0.047	0.033 [13.9]^(***)	0.191 ± 0.033	0.193 ± 0.031	0.002 [1.0]^◇(***)	0.031 [13.1] (.037)^(**◇(*))
DJ Height Right (m)	0.224 ± 0.062	0.255 ± 0.047	0.031 [13.7]^(***)	0.188 ± 0.030	0.194 ± 0.022	0.006 [3.3]^◇(***)	0.025 [11.0] (.025)^(**◇(*))
Contact Time Left (s)	0.3454 ± 0.0557	0.3386 ± 0.0467	-0.0068 [2.0]^◇(***)	0.3518 ± 0.0373	0.3719 ± 0.0310	0.0201 [5.7]^(*◇(**))	-0.0269 [7.8] (.057)^(*◇(**))
Contact Time Right (s)	0.3547 ± 0.0779	0.3457 ± 0.0525	-0.0090 [2.5]^◇(***)	0.3739 ± 0.0730	0.3735 ± 0.0424	-0.0004 [0.1]^◇(***)	-0.0086 [2.4] (.747)^◇(***)
RSI Left (m/s)	0.7 ± 0.3	0.8 ± 0.2	0.1 [14.3]^(***)	0.6 ± 0.1	0.5 ± 0.1	-0.0 [3.6]^◇(***)	0.1 [18.6] (.019)^(**◇(*))
RSI Right (m/s)	0.7 ± 0.2	0.8 ± 0.2	0.1 [15.2]^(***)	0.5 ± 0.1	0.5 ± 0.1	0.0 [3.9]^◇(***)	0.1 [12.1] (.060)^(*◇(**))

Note. THT (Tripe Hop Test), CMJ (Countermovement Jump), DJ (Drop Jump), RSI (Reactive Strength Index). Statistically significant differences are marked at 10% (*), 5% (**) and 1% (***) levels.

Table 5. Effect of the 6-week plyometric training program on the asymmetry between legs.

	Experimental group (EG, n = 10)			Control group (CG, n = 8)			Effect
Asymmetry variables (%)	Pre – Mean ± SD	Post – Mean ± SD	Performance change [|Δ%|]	Pre – Mean ± SD	Post – Mean ± SD	Performance change [|Δ%|]	$\Delta EG - \Delta CG$ [|ΔEG %|] (*p*-value)
YBT Anterior (m)	0.054 ± 0.041	0.027 ± 0.021	-0.027◇0[49.9]^(**◇(*))	0.018 ± 0.017	0.026 ± 0.019	0.008◇0[48.6]^◇(***)	-0.036◇0 [65.6] (.055)^(*◇(**))
YBT Posteromedial (m)	0.034 ± 0.036	0.038 ± 0.035	0.004◇0[13.1]^◇(***)	0.039 ± 0.021	0.029 ± 0.023	-0.010◇0[26.7]^◇(***)	0.015◇0 [43.9] (.470)^◇(***)
YBT Posterolateral (m)	0.033 ±0.030	0.022 ± 0.018	-0.010◇0[31.5]^◇(***)	0.018 ± 0.014	0.027 ± 0.012	0.008◇0[47.0]^◇(***)	-0.019◇0 [57.5] (.171)^◇(***)
RSI (m/s)	0.98 ± 0.80	0.70 ± 0.46	-0.28◇0[28.4]^◇(***)	1.42 ± 1.13	0.52 ± 0.39	-0.89◇0[63.1]^(**◇(*))	0.62◇0 [62.6] (.226)^◇(***)
DJ Contact Time (s)	0.88 ± 0.48	0.51 ± 0.40	-0.37◇0[41.9]^◇(***)	1.21 ± 0.65	1.00 ± 0.52	-0.21◇0[17.1]^◇(***)	-0.16◇0 [18.4] (.640)^◇(***)
DJ Flight Time (s)	0.56 ± 0.21	0.36 ± 0.24	-0.20◇0[35.7]^(**◇(*))	0.45 ± 0.33	0.38 ± 0.12	-0.07◇0[15.5]^◇(***)	-0.13◇0 [23.2] (.326)^◇(***)
THT Asymmetry (%)	0.036 ± 0.021	0.014 ± 0.010	-0.023◇0[63.0]^(***)	0.031 ± 0.021	0.022 ± 0.013	-0.009◇0[28.6]^◇(***)	-0.014◇0 [38.4] (.180)^◇(***)
Ankle Flexion (º)	7.7 ± 7.2	4.3 ± 4.3	-3.4◇0[44.4]^◇(***)	7.6 ± 4.9	7.1 ± 6.4	-0.5 [6.5]^◇(***)	-2.9◇0 [38.1] (.355)^◇(***)
Ankle Extension (º)	10.5 ± 9.2	5.0 ± 4.7	-5.5◇0[52.1]^(*◇(**))	8.3 ± 8.2	7.9 ± 5.6	-0.4◇0[4.6]^◇(***)	-5.1◇0 [48.5] (.256)^◇(***)
Ankle ROM (º)	8.1 ± 5.1	4.0 ± 3.8	-4.1◇0[50.9]^(***)	4.2 ± 4.0	5.0 ± 2.5	0.8◇0[19.3]^◇(***)	-4.9◇0 [60.8] (.017)^(**◇(*))

Note. YBT (Y-Balance Test), RSI (Reactive Strength Index), DJ (Drop Jump), THT (Tripe Hop Test), ROM (Range of Movement). Statistically significant differences are marked at 10% (*), 5% (**) and 1% (***) levels.

Table 6. Diagnostic analysis.

All variables	Gaussianity		Equal variances	Outliers	Fit	
	Shapiro	Kolmogorov	Levene	Cook	R^2_{cond}	R^2_{marg}
YBT Left Anterior	0.19	0.47	0.33	0.26	0.11	0.78
YBT Left Posteromedial	0.93	0.48	0.10	0.24	0.10	0.91
YBT Left Posterolateral	0.00	0.03	0.03	0.41	0.13	0.79
YBT Right Anterior	0.08	0.19	0.08	0.33	0.13	0.69
YBT Right Posteromedial	0.23	0.32	0.01	0.23	0.04	0.88
YBT Right Posterolateral	0.52	0.26	0.10	0.20	0.10	0.90
YBT Left CS (%)	0.41	0.24	0.07	0.17	0.12	0.91
YBT Right CS (%)	0.47	0.43	0.14	0.17	0.16	0.86
SST Left (s)	0.03	0.43	0.41	0.34	0.04	0.57
SST Right (s)	0.00	0.37	0.76	0.26	0.10	0.46
THT Left (cm)	0.28	0.18	0.91	0.39	0.18	0.58
THT Right (cm)	0.50	0.37	1.00	0.26	0.30	0.86
CMJ Bilateral (cm)	0.73	0.23	0.24	0.22	0.28	0.97
DJ Contact Time	0.35	0.87	0.47	0.21	0.20	0.20
DJ Flight Time	0.99	0.93	0.05	0.25	0.11	0.42
Ankle Flexion	0.14	0.55	0.10	0.20	0.06	0.42
Ankle Extension	0.11	0.79	0.34	0.24	0.08	0.26
Ankle ROM	0.37	0.57	0.23	0.16	0.16	0.60
Left Ankle ROM	0.97	0.60	0.10	0.16	0.02	0.83
Right Ankle ROM	0.08	0.19	0.95	0.32	0.06	0.87
YBT Anterior	0.00	0.39	0.26	0.52	0.22	0.30
YBT Posteromedial	0.00	0.28	0.77	0.29	0.02	0.02
YBT Posterolateral	0.28	0.57	0.13	0.19	0.07	0.16
RSI Left (m/s)	0.24	0.31	0.52	0.30	0.30	0.89
RSI Right (m/s)	0.67	0.37	0.57	0.18	0.27	0.90
RSI	0.26	0.62	0.05	0.34	0.16	0.16
THT Asymmetry	0.55	0.67	0.13	0.17	0.23	0.41
DJ Height Left (cm)	0.67	0.39	0.79	0.19	0.32	0.87
DJ Height Right (cm)	0.57	0.23	0.74	0.21	0.27	0.92
Contact Time Left (ms)	0.88	0.25	0.86	0.30	0.07	0.82
Contact Time Right (ms)	0.08	0.18	0.10	0.27	0.04	0.63

Note. YBT (Y-Balance Test), SST (Standing Stork Test), CS (Composite Score), ROM (Range of Movement), THT (Tripe Hop Test), CMJ (Countermovement Jump), DJ (Drop Jump), RSI (Reactive Strength Index).

Plyometrics are a dynamic form of resistance training involving SSCs and, in this case, vertical and horizontal displacements of the centre of gravity, which demands constant postural readjustments (Asadi et al., 2015). In a similar study which also implemented a 6-week PT program using only 0.45-m DJs (Asadi et al., 2015) obtained significant improvements (2.76% to 6.03%) in all directions in a Star Excursion Balance Test (SEBT).

Like our study, Ramírez-Campillo showed that after a 6-week PT the CG but not the EG showed significant improvements on the force platform tests in the medial-lateral direction and posteromedial direction (Ramírez-Campillo et al., 2015a). This might be because of the small sample size or because the participants learned to anticipate the test after having become familiar with it. Significant improvements were found for the left and right legs of the composite score (CS) of the YBT (4% and 3.9%, respectively). The CS is a normalized score that represents the sum of all three directions in relation to the length of the right leg (Filipa et al., 2010; Hammami et al., 2016; Chaouachi et al., 2017; Plisky et al., 2021; González-Fernández et al., 2022; Rafagnin et al., 2023) so and so it can be considered representative of YBT performance improvement because it measures dynamic balance, an important factor in neuromuscular control and injury prevention (Asadi et al., 2015; Plisky et al., 2021; González-Fernández et al., 2022; Plisky et al., 2006; Hegedus et al., 2015; Smith et al., 2015).

On the other hand, static balance did not significantly improve in our study, even though we observed a positive tendency (34.9% in the left leg and 60% in the right). Above all, PT resulted in improvements in static balance (Hammami et al., 2016; Chaouachi et al., 2014), but the SD for this test was relatively high and the sample size was not sufficient to show those results. Plyometrics might also lead to an increase in the ankle ROM because of the eccentric stretching phase and the cushioning phase where the joint is forced to conduct a maximal extension and flexion (Miller et al., 2002). In fact, in the present study, the training had a significant effect on the variable Right Ankle ROM. Miller carried out an 8-week PT intervention in 2 groups: one performing on sand and the other in the water (Miller et al., 2002). The water group showed improvements in plantar flexion and the sand group saw improved ankle dorsiflexion. Thus, plyometrics could reinforce the ankle joints and improve their flexibility, an important factor in ankle injury prevention.

In relation to the effect that PT had on jumping ability, all the participants in our experiment saw an increase in jumping distance and in lower-limb strength. There were significant improvements for the horizontal jumps assessed by the THT and the vertical jumps (CMJ) as well as the 20-DJ performance. This also agrees with most of the results found in studies that previously investigated the effect of plyometrics on jump performance (Ramírez-Campillo et al., 2015a; Ramírez-Campillo et al., 2015b; Ramírez-Campillo et al., 2022; Balsalobre-Fernández et al., 2015; Ozbar et al., 2014; Sáez-Sáez de Villarreal et al., 2009; Villarreal et al., 2008). For instance, Ozbar observed an increase in THT after 8 weeks of PT in football players between aged 15 to 22 years (Ozbar et al., 2014). Villarreal et al. (2008) showed the effects of 1, 2, or 4 day-a-week PT programs and observed that a frequency of 2 days a week resulted in the most efficient boost in performance (Ramírez-Campillo et al., 2015a). Furthermore, we also showed that a combination of vertical, horizontal, bilateral, and unilateral jumps produced better jump outcomes than PT performed in a single-direction aisle or plane (Ramírez-Campillo et al., 2015a; Ramírez-Campillo et al., 2015b). Similar to other studies which used bilateral DJs (Ramírez-Campillo et al., 2015a; Ramírez-Campillo et al., 2015b; Villarreal et al., 2008), our results showed performance improvements in the jump height and RSI (for the left leg significantly) but no reduction in the ground contact time—a factor that is normally reduced in studies which use bilateral DJs (Villarreal et al., 2008).

Lastly, there is very little research on the effects of PT on between-leg asymmetry or to use these functional tests to analyse the asymmetry. Nevertheless, we did show that strength training combining unilateral squats with unilateral 20-DJs and unilateral CMJs for 6-weeks reduced the between-leg asymmetry in maximal unilateral squats. In addition, the between-leg asymmetry variables improve more in the experimental group than in the control group for the most part but most of these differences in improvements fail to be statistically significant. At a 5% significance level, improvements in between-leg asymmetry variables are significant in 10% of the ten variables considered, a smaller percentage than in balance and jumping ability. This contrast appears to be the result of a lack of test power: most asymmetry variables improve for both the experimental and control group. Of these improvements, four are significant in the experimental group: YBT Anterior, DJ Flight Time, THT Asymmetry and Ankle ROM. However, of these four, only Ankle ROM remains significant (p = .017) after accounting for the fact that (systematically smaller) improvements were also observed in these same variables in the control group. This is likely because there is a large variability between measurements in both the experimental and control groups. Further research on the effect of PT on asymmetry, perhaps with either larger samples or more precise asymmetry measurements, is likely needed to address this effect in more detail.

Limitations of this study include the lack of data on injuries. However, in line with Myrick, one might expect that the risk of injury is reduced (Myrick, 2007). Other limitations include a reduced sample size or the nature of procedures and tools, which are not sophisticated or lab tools. Despite not being golden standards, they have been validated.

CONCLUSIONS

In conclusion, we observed a significant improvement in horizontal and vertical jumping ability in the unilateral drop-jump, bilateral countermovement jump, and Triple-Hop Tests, which may translate into improved athletic performance. Additionally, after the plyometric program there was a marked improvement in the passive ankle range of motion. Finally, the EG showed a tendency to reduction in between-leg asymmetry in relation to both horizontal and vertical-plane jumps, in addition to a significance improvement towards reduced asymmetry in the ankle range of motion.

Practical applications

The results of the study have a direct application in basketball training, since they indicate that variables as important as balance and jumping skills can easily be improved: implementing 2 weekly sessions of half an hour in duration, with bilateral and unilateral plyometric exercises, allow a measurable improvement in these important variables that affect both performance and the likelihood of injury.

AUTHOR CONTRIBUTIONS

Daniel Zafón-Chulia was the originator of the idea and primarily responsible for carrying out the experimental phase. He also contributed to the writing of the various sections of the article. Enrique Moreno-Mañas contributed to the critical review of the final text, as well as its editing and submission to the journal. Salvador Llana-Belloch was responsible for the experimental design, data analysis, and revision of the final text.

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