Effects of bilateral and unilateral plyometric training on physical performance in male post-pubertal basketball players

Journal:	*International Journal of Sports Physiology and Performance*
Manuscript ID	IJSPP.2024-0208.R2
Manuscript Type:	Original Investigation
Date Submitted by the Author:	n/a
Complete List of Authors:	Aztarain-Cardiel, Kike; University of Zaragoza, Garatachea, Nuria; University of Zaragoza, Physioteraphy and Nursing Pareja-Blanco, Fernando; Universidad Pablo de Olavide,
Keywords:	team sports, stretch-shortening cycle, young athletes, jump training, single-leg exercises, double-leg exercises

Title of the article: Effects of bilateral and unilateral plyometric training on physical performance in male post-pubertal basketball players

Submission type: Original Investigation

Authors: Kike Aztarain-Cardiel[1], Nuria Garatachea[1,2,3,4] & Fernando Pareja-Blanco[5]

[1]Faculty of Health and Sport Sciences, University of Zaragoza, Huesca, Spain.

[2]Growth, Exercise, Nutrition and Development (GENUD) Research Group, University of Zaragoza, Zaragoza, Spain.

[3]Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBER- Obn), Madrid, Spain.

[4]Instituto Agroalimentario de Aragon-IA2-CITA, University of Zaragoza, Zaragoza, Spain.

[5]Physical Performance & Sports Research Center, University of Pablo de Olavide, Sevilla, Spain.

Contact author: Kike Aztarain Cardiel

Faculty of Health and Sport Sciences, University of Zaragoza, Pza. Universidad 3, 22002-Huesca, Spain. +34 974 239 393. E-mail: aztarain7@gmail.com

Preferred running head: bilateral vs unilateral plyometric training

Abstract word count: 249 words.

Text-only word count: 40573377 words

Figures: 10

Tables: 4

ABSTRACT

Purpose: The aim of this study was to analyze the effects of bilateral and unilateral plyometric training (PT) programs on jumping, sprinting, and change of direction ability in male post-pubertal basketball players.

Methods: Forty-three young male basketball players (14.2 ± 1.2 years), from four squads belonging to an elite basketball club, were randomly assigned to 1 of 3 groups: (1) bilateral PT group (BG), (2) unilateral PT group (UG), and (3) control group (CG). The experimental groups followed a PT program twice a weekly for 6 weeks, with BG and UG performing two- and one-legged jumps, respectively. Both groups completed the same number of vertical, horizontal, cyclic, and acyclic jumps. Pre- and Post-training measurements included: 1) countermovement jump (CMJ); 2) unilateral CMJ (CMJ_L and CMJ_R) 3) horizontal jump (HJ); 4) unilateral HJ (HJ_L and HJ_R) 5) straight-line sprint in 20-m (T20); and 6) V-Cut change of direction test (V-Cut).

Results: CMJ, CMJ_L, and CMJ_R were significantly improved by BG and UG ($P<0.001$) meanwhile CG did not change. Both BG and UG improved their performance significantly ($P<0.01$) in HJ_L and HJ_R but only BG significantly increased ($P<0.05$) HJ and showed significantly greater improvements than CG. Furthermore, only BG improved V-Cut performance ($P=0.03$). Neither group increased T20. CG did not improve in any tests.

Conclusions: Bilateral PTBG enhances single and double-leg jump performance in vertical and horizontal directions, as well as change of direction ability. In contrast, an equivalent volume of unilateral PT only improves vertical jumps and unilateral horizontal jumps.

Keywords: team sports, stretch-shortening cycle, young athletes, jump training, single-leg exercises, double-leg exercises

INTRODUCTION

Plyometric training (PT) is characterized by performing different jumps, using the stretch-shortening cycle in which a stretching or eccentric phase is quickly followed by a shortening or concentric phase [1]. The purpose of the stretch-shortening cycle is to enhance the performance compared to isolated concentric actions [1]. Plyometric exercises are widely used in different training routines since they can be easily performed without requiring specific equipment and it is not time-consuming [2,3]. Likewise, it has been shown that PT improves most parameters related to physical fitness and sports performance in healthy individuals and athletes [4–6]. Accordingly, PT is a training methodology commonly used to improve jumping, speed, agility, and lower-body power, among other physical variables, in athletes [5], among them elite basketball players [7].

Plyometric exercises can be executed unilaterally or bilaterally. A unilateral exercise is performed with only one leg, whereas a bilateral exercise is a simultaneous movement by both limbs [8]. Bilateral lower body exercises allow the use of higher external training loads [9], mitigate the bilateral deficit [10](i.e. the inability to generate as much force bilaterally as the sum of the forces generated unilaterally) but lack a stability challenge [11]. Unilateral lower body exercises may improve the bilateral deficit [9] and increase the coordination and activation requirements of the stabilizer muscles [11]. However, this instability limits strength development and the magnitude of the external load that needs to be applied to improve athletic performance [11]. Therefore, the relative benefits of each kind of these exercises represent the relative weaknesses of the others [9].

Following the specificity training principle, many coaches prescribe unilateral PT as they consider it more specific to the sport's physical demands than bilateral PT [9,12]. Furthermore, the differentiation between unilateral and bilateral jumps also varies the intensity of the training, with one-legged jumps being the most intense [13]. Based on this, it is tempting to speculate that unilateral PT may allow greater loads for each leg, potentially leading to greater adaptations than bilateral PT. However, a recent meta-analysis about resistance training [9] concludes that unilateral exercises are no more effective than bilateral exercises in improving sports-specific patterns such as movement speed.

Few studies have analyzed the effects of bilateral or unilateral PT on physical performance [14–18]. Ramírez-Campillo et al.[14] examined the effects of bilateral or unilateral PT in pre-adolescent soccer players (age 11.4 ± 2.2 years) during 6 weeks, 2 sessions per week, and 120-240 jumps/session. Likewise, Drouzas et al.[18] compared bilateral and unilateral PT programs in pre-adolescent soccer players (age ~10 years) during 10 weeks, 2 sessions/week, and 60-120 jumps/session. However, maturation could influence the efficacy of PT, particularly showcasing enhanced benefits in boys during or post-age at peak height velocity (APHV) [19,20]. Other two studies were carried out with physically active, but untrained, students [16,17]. Makaruk et al.[16] examined the effects of bilateral or unilateral PT in untrained female students during 12 weeks, 2 sessions/week, 210-244 jumps/session. Bogdanis et al.[17] compared the effect of single- and double-leg PT in physical education students (men and women) during 6 weeks, 2 sessions/week, and 120-180 jumps/session. ~~It has been shown that the initial strength level may affect the magnitude of adaptation to PT [21].~~ Despite its potential to yield enhancements in explosive performance, it remains to be examined the effects of bilateral and unilateral PT on explosive performance in athletes. To the authors' knowledge, only one study has been conducted on basketball players [15]. However, in that study, the bilateral group only performed vertical jumps, and the unilateral group only horizontal jumps. Following the principle of specificity and transfer of training, if jumps are made in only one direction, improvements will occur mainly in the actions performed in the direction of the training force application[2~~3~~1,22]. Hence, manipulating these two independent variables may have influenced their results.

Existing studies on bilateral and unilateral PT have focused on non-athletes or pre-adolescent athletes, with limited research on trained athletes, especially basketball players. Given the importance of PT for basketball and the limited research on its effectiveness in athletes, ~~Therefore, given the importance of PT in basketball and the lack of scientific literature regarding the use of bilateral and PT in athletes,~~ the aim of this study was to analyze the effects of bilateral and unilateral PT on physical performance in male post-pubertal basketball players. We hypothesized that following the principle of specificity[22] the bilateral group would obtain greater improvements in performance in two-legged tasks and the unilateral group in one-legged tasks.

METHODS

Experimental design

A randomized controlled trial design was used to compare the effect of bilateral and unilateral PT on jump, sprint, and change of direction (COD) performance in post-pubertal basketball players. Participants were randomly assigned into three different groups as follows: all participants were ordered according to their performance in the countermovement jump (CMJ) test and from this classification, a sequenced distribution (ABCCBA) was used. The PT program lasted 6 weeks during the competitive period (April-May) with 2 sessions per week. Both training groups performed the same number of vertical and horizontal jumps as well as cyclic and acyclic jumps. The difference was that these jumps were performed bilaterally or unilaterally. CG did not conduct any PT. Immediately before and after either intervention the participants performed the following performance tests, in the same order (as described) and on the same day: CMJ, left leg CMJ (CMJ_L), right leg CMJ (CMJ_R) horizontal jump (HJ), left leg HJ (HJ_L), right leg HJ (HJ_R), straight-line sprint in 20-m (T20), and V-Cut test (V-Cut) for assessing COD ability. The players did not engage in any type of intense physical activity 48 hours before the measurements, and they were urged to use the same equipment and footwear at both pre-training and post-training evaluations. Testing sessions were performed in groups of 12 players on a basketball court at the same time of day (5:00-8:00 PM), in the same sports facilities for each participant and the correct execution technique was ensured by visual inspection by the main researcher. In addition, participants were encouraged to maintain their eating habits during the intervention, and they were not allowed to undergo specific conditioning training other than their basketball training. Two weeks before the start of the PT program, subjects completed a 30-minute familiarization session with all the exercises involved in training or testing. They performed 2x4 repetitions of each exercise or test. In addition, during this session, the measurement of anthropometric characteristics was carried out. The study was approved by the Research Ethics Committee of Aragón (approval code 1525) and all procedures were in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki, 1975 and further updates).

Subjects

Forty-seven young male basketball players from four squads of different ages (U13, U14, U15, U16) of the same elite basketball club competing in the Spanish First Division League (ACB), participated in the present study. Participants had a mean of 6.4 ± 1.0 years of systematic basketball training and competition. ~~They performed 4 weekly technical and tactical basketball training sessions plus an official match during the study.~~ Basketball practice patterns during the study were similar. They trained on Monday, Tuesday, Thursday, and Friday and played a competitive game on Saturday. Therefore, Wednesdays and Sundays were recovery days. Basketball practices lasted 90 minutes and involved both technical skills drills and competitive tactical exercises. Four subjects were excluded from data analysis: one due to injury not caused by the intervention and the three remaining did not belong to the club at the time of the final evaluations. The final sample was comprised of 43 participants: bilateral PT group (BG, n = 15), unilateral PT group (UG, n = 15), and control group (CG, n = 13). Anthropometric characteristics are shown in Table 1. Parental or guardian written informed consent for all players involved in this investigation was obtained after they were informed of the risks and benefits of the study.

Insert Table 1

Testing procedures

Before the performance tests, a 10-minute warm-up was performed consisting of 5 minutes of jogging, joint mobility, and a specific warm-up for each test. During all measurements, participants were encouraged to give their best performance. Each test performed is described below.

Anthropometric and maturity measurements: Body mass (kg), standing height (cm), and sitting height (cm) were measured, and the athletes' maturity status was determined using predicted APHV offset [23] represented by the formula: Maturity offset (years) = −9.236 + ((0.0002708 × (leg length × sitting height)) + (−0.001663 × (age × leg length)) + (0.007216 × (age × sitting height)) + (0.02292 × (mass by stature ratio×100)).

Vertical jumps: Bilateral (CMJ) and unilateral (CMJ_L and CMJ_R) vertical jumps with countermovement were performed to evaluate jumping ability with two and one leg. For CMJ, they jumped with their feet hip-width apart and landed in plantar flexion bilaterally. For CMJ_L and CMJ_R, they jumped with one leg and landed in plantar flexion with the same leg while balancing for 3 s. In all these tests subjects were instructed to jump as high as possible after a fast countermovement, which was self-selected, and with hands on the hips. Jump height was calculated through the flight time using a contact platform (Chronojump BoscoSystem, Barcelona, Spain), which has previously been validated[24]. Each subject performed three attempts of each test with 30 s rest between them, and if the difference between jumps was less than 2 cm, the average was calculated. If the difference was greater than 2 cm, two more jumps were made, after which the extreme values were removed and the average of the three remaining values was calculated.

Horizontal jumps: This test was performed both bilaterally (HJ) and unilaterally (HJ_L and HJ_R). For HJ, they positioned themselves with their feet hip-width apart and landed steadily with two legs. HJ_L and HJ_R were executed by jumping with one leg and landing steadily for three seconds with the same leg. Arm swings were allowed to seek the maximum horizontal distance. The distance was calculated from the take-off point to the closest contact point; that is, from the tip of the foot at the start to the heel furthest back in the landing, using a tape measure. Three attempts were made, with a 30-s rest period. The best attempt was recorded for further analysis.

Straight-line sprint: Sprint performance was assessed with 20 m straight-line sprints using a photoelectric cell system (Chronojump BoscoSystem, Barcelona, Spain). Participants started 0.5 m behind the first photocell and then ran at maximal speed until they reached the second photocell gate located at a 20 m distance from the first one. Two attempts were made, with a 3-minute rest, and the best time was chosen (T20).

Change of direction ability: Subjects performed the V-Cut test, which consists of a 25 m sprint with four 45º CODs, located 5 m apart[25]. For the trial to be valid, participants had to pass the line, drawing on the floor, with one foot completely at every turn. A pair of photocells

(Chronojump BoscoSystem, Barcelona, Spain) were placed at the start and finish. Participants started 0.5 m before the first pair of photocells and ran at maximal speed until they crossed the finish line. Two attempts were carried out, with a 3-minute rest between them. The best attempt was recorded for further analysis (V-Cut).

Training program

Sessions of the PT program were carried out before technical-tactical basketball training, after a 10-minute warm-up (jogging, joint mobility, and specific warm-up). A detailed description of the PT program conducted by each experimental group is provided in Table 2. The experimental groups differed in whether they jumped with one or two legs (i.e., unilateral or bilateral jumps). Both experimental groups performed the same number of vertical, horizontal, acyclic, and cyclic jumps in the same order as described, with an average total volume of 49.3 jumps which has been proved to be sufficient for performance improvement compared to twice the volume of plyometric training in youth basketball players [26~~5~~]. Acyclic jumps refer to those in which there is a short rest (~5 s) between jump repetitions. In contrast, the cyclic jumps were executed with no intra-set rests. In the unilateral-cyclic jumps the athletes jumped alternating both legs. A progressive increase in training volume was scheduled over the weeks, with a 2-week tapering period before the post-training tests. A 2-minute rest was implemented after each set and participants landed with one or two legs in unilateral and bilateral jumps, respectively. The main researcher, who was present at all sessions, asked the subjects to give maximal effort in every jump.

Insert Table 2

Statistical analysis

Values are expressed as mean ± standard deviation (SD). Relative~~The~~ reliability of the measures was calculated via the intraclass coefficient correlation (ICC) with 95% confidence intervals (CI), using the 1-factor random model. Absolute reliability was assessed using the standard error of measurement (SEM), calculated from the root mean square of the intra-subject total mean square term in the repeated-measures analysis of variance (ANOVA) to determine the amount of variability caused by measurement error.[27] Results are presented in both absolute ($m \cdot s^{-1}$) and relative terms, with the latter expressed as the intra-individual ~~, and the~~ coefficient of variation (CV) calculated as CV = 100·SEM/mean. Before starting the intervention, a comparison of the means was performed using a 1-way analysis of variance test to ensure that, once the groups were randomly distributed, there were no significant differences in any of the variables analyzed. In addition, Shapiro- Wilk and Levene's tests were performed to verify the normality of distribution and the homogeneity of variance in each of the examined variables. The sample size was calculated using GPower (Version 3.1.9.4; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany)~~version 3.1.9.4~~, introducing the following parameters: a 3 (groups) x 2 (Pre vs. Post) repeated measures ~~analysis of variance (~~ANOVA~~)~~, expected effect size (ES) (0.5 based on Moran et al., 2021[9]), ~~),~~ error probability (0.05) and power (0.90), which resulted in a total sample size of 42 subjects. For that, we decided to recruit 47 subjects assuming potential drop out throughout the study. To determine the changes produced in performance between pre-training and post-training, a repeated measures analysis of covariance (ANCOVA), 3 (groups) x 2 (times), was carried out, taking the baseline measures of each variable as covariates. Bonferroni's post-hoc adjustments were applied. Significance was accepted at $P < 0.05$. Likewise, the intra-group ES ~~with a 95% CI~~ was calculated using Hedge`s g[27~~6~~], represented by the formula: g = Mpost-Mpre/SDpooled, where Mpost is the mean in post-training, Mpre is the mean in pre-training in each group, and SDpooled is the weighted SD of the pre-training and post-training measurements. Whereas the inter-groups ES was calculated as follows: (mean post-pre differences of one condition) - (mean-post-pre differences of another condition) / pooled SD. The ESs were interpreted based on Rhea´s classification[28] for moderately trained individuals: trivial (<0.35), small (0.35–0.80), moderate (0.80–1.50), or large (>1.50). Statistical analysis was carried out using SPSS version 25 for Windows (IBM Corp., Armonk, NY, USA), in addition to Microsoft Office Excel 2007 for calculating ES and CV.

RESULTS

The reliability values of different tests conducted are shown in Table 3. The ICC values for all variables tested were >0.90 and CVs <10%.

Table 3 about here

Table 4 shows the changes in jump, sprint, and COD performance in all groups. There were significant "time" effects and significant "group x time" interactions for all vertical jumps (CMJ, CMJ$_L$, and CMJ$_R$). Significant increases (P<0.001) were found in both experimental groups (BG and UG) for CMJ (ES; BG: 0.92, UG: 1.01, CG: -0.05), CMJ$_L$, (ES; BG: 1.21, UG: 1.32, CG: 0.02) and CMJ$_R$ (ES; BG: 1.17, UG: 0.96, CG: -0.04), while no significant changes were observed for CG. Moreover, both training groups showed significantly higher enhancements in CMJ, CMJ$_L$, and CMJ$_R$ than CG. Concerning the horizontal jumps, a significant "time" effect (P = 0.01) was observed for HJ$_L$, and significant "group x time" interactions (P<0.001-0.05) were found for HJ (ES; BG: 0.30, UG: 0.02, CG: -0.12), HJ$_L$ (ES; BG: 0.81, UG: 0.74, CG: -0.07), and HJ$_R$ (ES; BG: 0.35, UG: 0.31, CG: -0.08). Only BG significantly increased (P<0.05) HJ performance. Likewise, BG showed significantly greater improvements in HJ than CG (P = 0.02). Both BG and UG improved their performance significantly (P<0.01-0.001) in HJ$_L$ and HJ$_R$. Furthermore, significantly greater improvements were found in HJ$_L$ by BG and UG compared to CG (P<0.01-0.001). Regarding T20 (ES; BG: -0.03, UG: 0.04, CG: 0.08) and V-Cut (ES; BG: -0.30, UG: 0.02, CG: 0.08), no significant "time" effect or significant "group x time" interactions were observed. BG was the only group that increased significantly (P = 0.03) its V-Cut performance. Delta change, and intra- and inter-group ES are reported in Table 4 and the individual changes are in ~~the~~ Figure 1.

Table 4 about here

Figure 1 about here

DISCUSSION

To the best of our knowledge, this is the first study that analyzes the effect of isolated bilateral and unilateral PT programs on jump, sprint, and COD performance in basketball players. The main findings were: a) 6 weeks of bilateral and unilateral PT program resulted in similar increases in jump performance; b) UG improved vertical jump performance bilaterally and unilaterally but only its unilateral horizontal jump performance; c) BG increased its vertical and horizontal jump performance with one and two legs; and d) only BG increased its COD performance. Consequently, these findings do not support the coaches' belief that unilateral training is more effective in increasing specific athletic performance than bilateral training [9].

Jumping ability is key for basketball performance because it is one of the team sports with the highest number of jumps in competition (41-56 jumps) and they are crucial for scoring ability and rebounding[29].Regarding vertical jumps, height attained in bilateral (CMJ) and unilateral (CMJ$_L$ and CMJ$_R$) jumps were similarly improved by both BG and UG. In accordance with our findings, Makaruk et al. [16] found that two- and one-legged PT resulted in increases in bilateral and unilateral CMJ heights. In this regard, the fact that such study [16] was conducted with untrained physically active women should be highlighted, since initial strength values and training levels may affect the adaptative response to PT [30~~21~~]. Ramírez-Campillo et al.[14], who designed a PT program similar to the present study, reported significant improvements by bilateral and unilateral PT in Abalakov jumps with one and two legs (i.e., CMJ with arms). Nevertheless, these authors reported a specificity training effect due to bilateral and unilateral PT had a significantly greater increase in two-legged and one-legged jump performance, respectively. Drouzas et al. [18] reported that single- and double-leg squat jumps were equally improved in both unilateral and bilateral PT, but one-legged CMJ was only improved after the unilateral PT. However, the study conducted by Drouzas et al. [18] was carried out in pre-pubertal soccer players (age: 10 years, maturity offset: -3 years). Basketball players participating in the present study were more mature (age: 14.2 years, maturity offset: +1.8 years). It has been shown that older youths (during- or post-APHV) obtain greater adaptive responses to PT compared with younger youths (pre-APHV) [19,20]. Accordingly, several factors as training level or maturation status should be considered when designing PT programs. Specifically, these factors may influence the adaptive responses to bilateral or unilateral PT. In the population under study (post-APHV basketball players), bilateral and unilateral PT programs improve performance in both bilateral and unilateral vertical jumps.

In relation to horizontally oriented jumps, both PT groups improved unilateral performance (i.e., HJ_L and HJ_R). Interestingly, both experimental groups obtained greater improvements in HJ_L than in HJ_R. This could be due to interference with sport-specific training and/or to the players' leg dominance. In a lay-up, a specific basketball movement, if the player is right-handed, they typically execute a first long step with the left leg and brake with the right leg. Therefore, the basketball player ~~is used to braking~~typically brakes with the right leg after the first step in a lay-up, which probably indicates that this leg has ~~more~~ higher eccentric strength [31~~27~~,32~~28~~], so the left leg could have a greater capacity for improvement in this test. Regarding bilateral performance, a noteworthy finding of this study was that only BG increased HJ performance. These findings could be attributed to training specificity. Also following the training principle of specificity, Ramírez-Campillo et al. [14] showed that UG induced greater increases in unilateral horizontal jumps (i.e., HJ_L and HJ_R), whereas BG resulted in higher improvements in the bilateral horizontal jump (i.e., HJ). Likewise, Makaruk et al. [16] found that UG obtained greater increases in five alternate leg bounds than BG. This is supported because unilateral vertical jumps result in 10-25% greater electromyographic activity in the vastus medialis and gastrocnemius muscles than bilateral vertical jumps [33~~29~~]. However, this effect may be exercise-specific as greater quadriceps activation has also been observed in bilateral knee extensions when compared to unilateral knee extensions [34~~0~~]. Therefore, previous literature suggests that the effects of PT are more pronounced in jumps for which athletes have undergone specific training [14,16]. The amplified training effect observed in HJ for BG lends credence to this assertion. Nevertheless, in the current cohort of young basketball players, both bilateral and unilateral PT improved unilateral horizontal jump performance, but only bilateral PT produces an increase in bilateral horizontal jump performance.

Sprinting ability is also relevant for physical performance, as basketball players perform between 18 and 105 sprints, which represents between 2% and 6% of the total game time[29]. Straight-line sprint performance remained unaffected by any of the training interventions, contrasting with findings from Ramírez-Campillo et al. [14], who reported significant reductions in 15 m and 30 m sprint times, and Drouzas et al. [18], who observed significant improvements solely in 5 m sprint times for UG. Our results align with previous interventions carried out by our research group [21,26~~5,31~~], which underscore that isolated PT fails to increase straight-line sprint performance. In terms of changes of direction, which occur in 20.6% of sprints in competitive basketball[29], significant improvements in COD ability were only observed in the BG group~~Concerning COD ability, significant improvements were observed only in BG.~~. Nevertheless, Ramírez-Campillo et al. [14] found significant increases in COD performance by BG and UG, with UG showing superior gains. However, Drouzas et al. [18] reported no significant changes in COD performance for either UG or BG. In accordance with our findings, a recent systematic review and meta-analysis [9] concluded that unilateral resistance training (RT) is no more effective than bilateral RT in improving running speed, including sprinting and COD performance. Furthermore, Appleby et al. [12] reported superior improvements in COD performance with bilateral lower-body RT compared to unilateral lower-body RT, consistent with our results from a PT program. This may be attributed to the greater stability in jumping associated with bilateral PT, enabling a greater force application [11]. Likewise, unilateral jumps are distinguished by slower muscle contractions, facilitating the generation of substantially higher forces in comparison to bilateral jumps [35~~2~~]. Based on the force-velocity curve, bilateral jumps would allow muscles to produce force at higher velocities [36~~3~~], which could benefit performance in high-velocity tasks, such as COD. Furthermore, although the volume of contacts per session was equal for both intervention groups, BG performed twice as many jumps per leg as UG. Therefore, bilateral PT enables lower but more frequent stressors compared to unilateral PT, which may be better tolerated by athletes who need to integrate PT with specific sports training sessions.

Some study limitations should be considered when interpreting our results. First, only males were included in the study, so additional research should be done with women. Second, the study duration was 6 weeks (12 sessions), which may limit extrapolations to long-term adaptations related to a PT program. Furthermore, the lack of specific basketball load monitoring could have influenced the results. This could have affected the results at the individual and group level as those with greater participation in training and competitions would have accumulated more fatigue that could influence physical performance. Finally, more research including a group combining bilateral and unilateral jumps should be done, as to our knowledge, it has only been done in youth soccer players [14].

PRACTICAL APPLICATIONS

Strength and conditioning coaches who implement bilateral PT programs may obtain improvements in vertical and horizontal jump performance, both unilaterally and bilaterally, as well as in the COD of their athletes. Nevertheless, if only unilateral PT is prescribed, it will only improve performance in some jumping variables. Future research studies should examine the effects of the combination of bilateral and unilateral jumps in basketball players, as well as including women and other ages and sports.

CONCLUSIONS

A bilateral PT was effective at improving both single and double-leg vertically- and horizontally-oriented jump performance as well as COD ability in male post-pubertal basketball players, whereas an equal volume of unilateral PT only improved performance in vertical jump and unilateral horizontal jumps.

Acknowledgments

The authors thank the club and the players of the club evaluated for their participation in this research work. In addition, we thank Marcos Echevarría for his assistance with the graphics. No sources of funding were used in the preparation of this article. The authors declare no conflict of interest.

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Table 1. Anthropometric characteristics of the three groups.

Group	Age (years)	Maturity offset (years)	APHV (years)	Height (cm)	Sitting height (cm)	Body mass (kg)
BG (n = 15)	14.2 ± 1.1	1.8 ± 0.9	12.8 ± 0.5	182.3 ± 9.1	94.0 ± 5.1	68.3 ± 11.6
UG (n = 15)	14.1 ± 1.3	1.5 ± 0.9	12.9 ± 0.6	181.1 ± 8.0	93.6 ± 4.4	69.1 ± 9.3
CG (n = 13)	14.2 ± 1.3	2.2 ± 1.3	12.8 ± 0.7	183.7 ± 9.0	96.4 ± 4.9	68.6 ± 13.5
Total (n = 43)	14.2 ± 1.2	1.8 ± 1.0	12.8 ± 0.6	182.2 ± 8.6	94.5 ± 4.7	68.7 ± 11.2

Abbreviations: BG: Bilateral jumps group; UG: Unilateral jumps group; CG: Control group; APHV: age at peak height velocity.
Note: Data are expressed as mean ± standard deviation.

Table 2. Descriptive characteristics of the 6-week plyometric training program conducted by the two experimental groups.

Group	Exercises	Set x repetitions					
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
BG (n=15)	Vertical acyclic (bilateral)	2x5	2x6	2x7	2x8	2x6	2x5
	Horizontal acyclic (bilateral)	2x5	2x6	2x7	2x8	2x6	2x5
	Vertical cyclic (bilateral)	2x5	2x6	2x7	2x8	2x6	2x5
	Horizontal cyclic (bilateral)	2x5	2x6	2x7	2x8	2x6	2x5
	Total volume (contacts/session)	40	48	56	64	48	40
UG (n=15)	Vertical acyclic (left leg)	1x5	1x6	1x7	1x8	1x6	1x5
	Vertical acyclic (right leg)	1x5	1x6	1x7	1x8	1x6	1x5
	Horizontal acyclic (left leg)	1x5	1x6	1x7	1x8	1x6	1x5
	Horizontal acyclic (right leg)	1x5	1x6	1x7	1x8	1x6	1x5
	Vertical cyclic (unilateral)	2x5	2x6	2x7	2x8	2x6	2x5
	Horizontal cyclic (unilateral)	2x5	2x6	2x7	2x8	2x6	2x5
	Total volume (contacts/session)	40	48	56	64	48	40

Abbreviations: BG: Bilateral jumps group; UG: Unilateral jumps group.

Table 3. Reliability values of different tests conducted in the present study.

Test	ICC (95% CI)	SEM	CV %
CMJ	0.960 (0.935-0.977)	1.95	6.6
CMJ_L	0.929 (0.898-0.965)	1.69	9.7
CMJ_R	0.939 (0.884-0.958)	1.59	7.6
HJ	0.976 (0.960-0.986)	5.21	2.4
HJ_L	0.953 (0.922-0.973)	6.64	3.6
HJ_R	0.965 (0.941-0.980)	6.07	3.3
T20	0.944 (0.894-0.970)	0.06	1.9
V-Cut	0.951 (0.906-0.974)	0.12	1.7

Abbreviations: ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement; CV: coefficient of variation; CMJ: countermovement jump; CMJL: left leg CMJ; CMJR: right leg CMJ; HJ: horizontal jump; HJL: left leg HJ; HJR: right leg HJ; T20: 20 meters straight-line running sprint test; V-Cut: V-Cut change of direction test.

Table 4. Changes in jumping and running performance after 6 weeks of plyometric training experienced by the three groups.

Test	Group	Pre-training	Post-training	Intra-group ES	Inter-group ES	%□	*P*-value time effect (η_p^2)	*P*-value group x time (η_p^2)
CMJ (cm)	BG	27.8 ± 5.1	33.5 ± 6.7^{***C}	0.92	BG vs UG: 0.15	20.50	0.04 (0.51)	<0.001 (0.38)
	UG	29.4 ± 5.0	34.3 ± 4.4^{***C}	1.01	BG vs CG: 1.00	16.67		
	CG	31.9 ± 6.3	31.5 ± 6.6	-0.05	UG vs CG: 0.88	-1.25		
CMJ_L (cm)	BG	16.8 ± 3.7	21.5 ± 4.1^{***C}	1.21	BG vs UG: 0.04	27.98	<0.001 (0.71)	<0.001 (0.53)
	UG	17.2 ± 3.5	21.5 ± 3.4^{***C}	1.32	BG vs CG: 1.23	25.00		
	CG	18.6 ± 3.8	18.7 ± 3.3	0.02	UG vs CG: 1.22	0.54		
CMJ_R (cm)	BG	15.2 ± 3.2	19.1 ± 3.3^{***C}	1.17	BG vs UG: 0.06	25.66	<0.001 (0.60)	<0.001 (0.45)
	UG	16.6 ± 4.2	20.3 ± 3.3^{***C}	0.96	BG vs CG: 1.11	22.29		
	CG	17.7 ± 3.9	17.5 ± 4.2	-0.04	UG vs CG: 0.93	-1.13		
HJ (cm)	BG	215.5 ± 18.9	221.9 ± 22.0^{*C}	0.30	BG vs UG: 0.35	2.97	0.12 (0.02)	0.03 (0.16)
	UG	222.6 ± 14.2	222.9 ± 12.6	0.02	BG vs CG: 0.41	0.13		
	CG	214.2 ± 25.0	211.2 ± 22.9	-0.12	UG vs CG: 0.16	-1.40		
HJ_L (cm)	BG	185.9 ± 19.0	201.3 ± 18.0^{***C}	0.81	BG vs UG: 0.30	8.28	0.01 (0.40)	<0.001 (0.33)
	UG	193.3 ± 13.3	203.7 ± 13.9^{***C}	0.74	BG vs CG: 0.80	5.38		
	CG	186.9 ± 22.1	185.3 ± 21.1	-0.07	UG vs CG: 0.63	-0.86		
HJ_R (cm)	BG	187.1 ± 14.7	193.3 ± 19.5**	0.35	BG vs UG: 0.02	3.31	0.77 (0.15)	0.03 (0.17)
	UG	189.1 ± 17.2	195.0 ± 19.2*	0.31	BG vs CG: 0.40	3.12		
	CG	185.2 ± 22.3	183.4 ± 21.0	-0.08	UG vs CG: 0.37	-0.97		
T20 (s)	BG	3.33 ± 0.20	3.33 ± 0.22	-0.03	BG vs UG: -0.06	0.00	0.19 (0.003)	0.86 (0.01)
	UG	3.27 ± 0.14	3.27 ± 0.15	0.04	BG vs CG: -0.10	0.00		
	CG	3.30 ± 0.21	3.32 ± 0.19	0.08	UG vs CG: -0.06	0.61		

V-Cut (s)	BG	7.22 ± 0.35	7.11 ± 0.35*	-0.30	BG vs UG: -0.29	-1.52	0.07 (0.02)	0.11 (0.13)
	UG	7.06 ± 0.42	7.06 ± 0.37	0.02	BG vs CG: -0.36	0.00		
	CG	7.08 ± 0.42	7.11 ± 0.43	0.08	UG vs CG: -0.06	0.42		

Abbreviations: BG: Bilateral plyometric training group (n = 15); UG: Unilateral plyometric training group (n = 15); CG: Control group (n = 13). CMJ: countermovement jump; CMJ_L: left leg CMJ; CMJ_R: right leg CMJ; HJ: horizontal jump; HJ_L: left leg HJ; HJ_R: right leg HJ; T20: time in 20 meters straight-line sprint; V-Cut: V-Cut change of direction test. ES: Effect size. Δ%: intragroup changes from Pre- to Post-training testing. η_p^2: partial eta squared. Significant intragroup differences: *P-value < .05; ** P < .01; *** P < .001. Significant differences with the CG post-training: ^{C}*P*-value < .05. Note: Data are expressed as mean ± standard deviation.

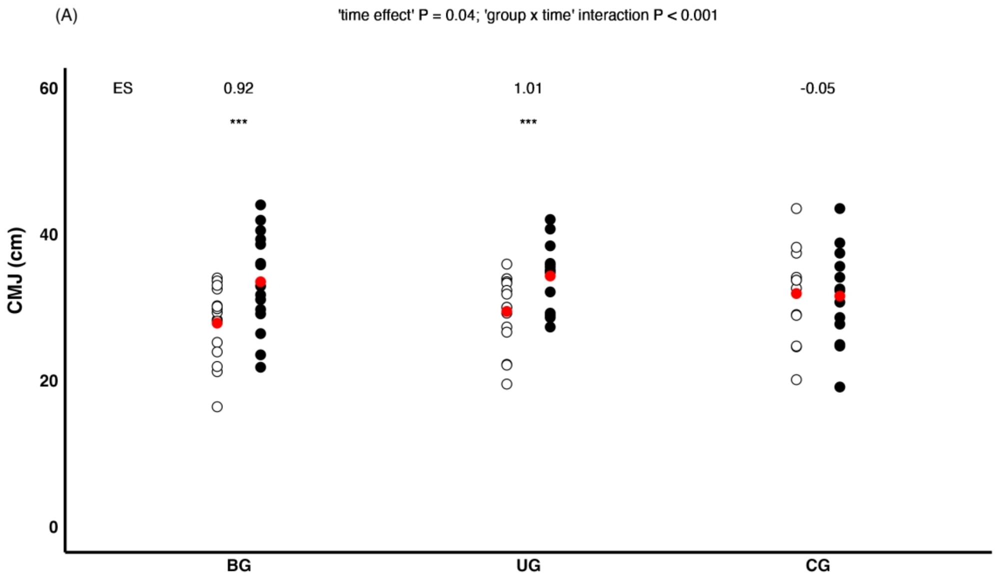

Figure 1A

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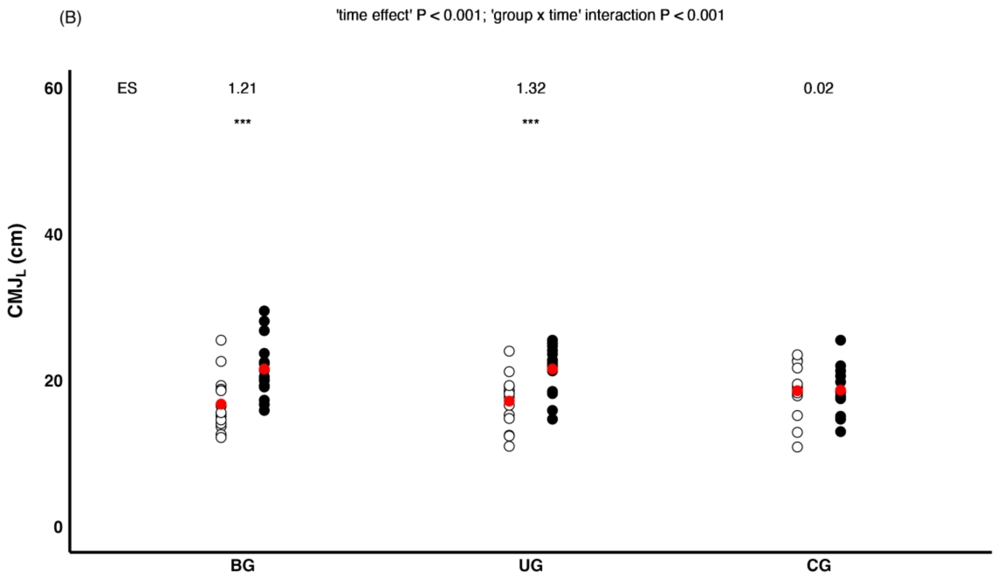

Figure 1B

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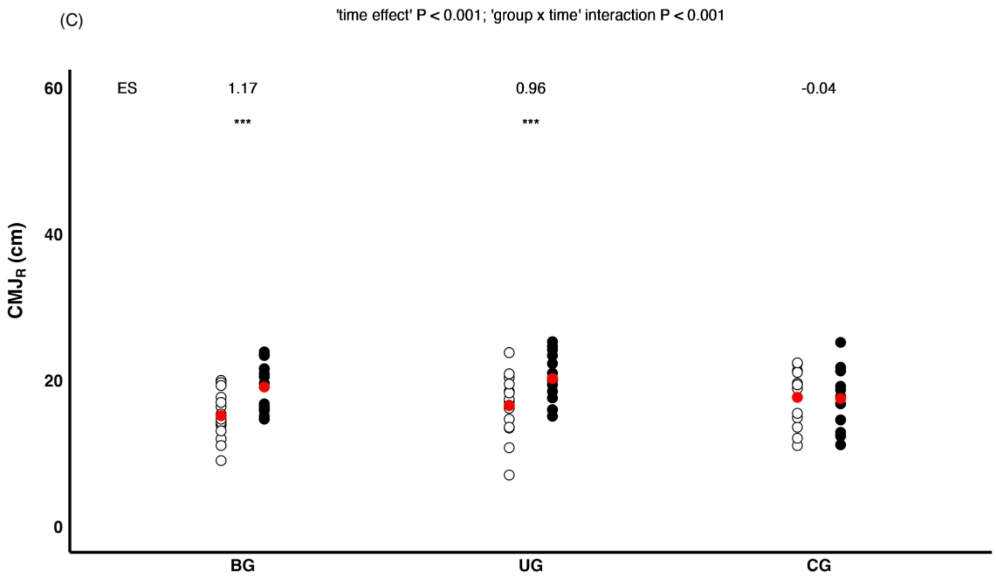

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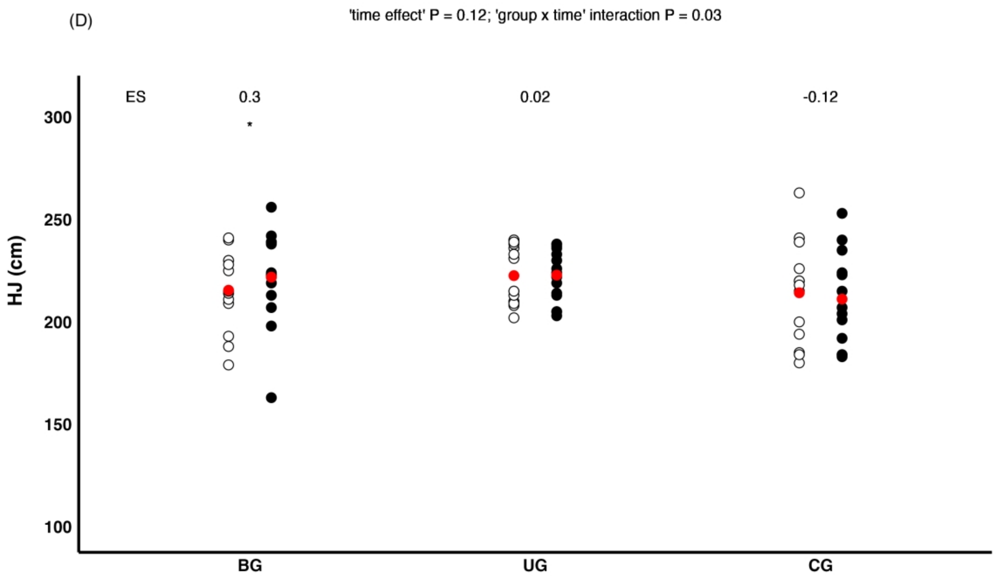

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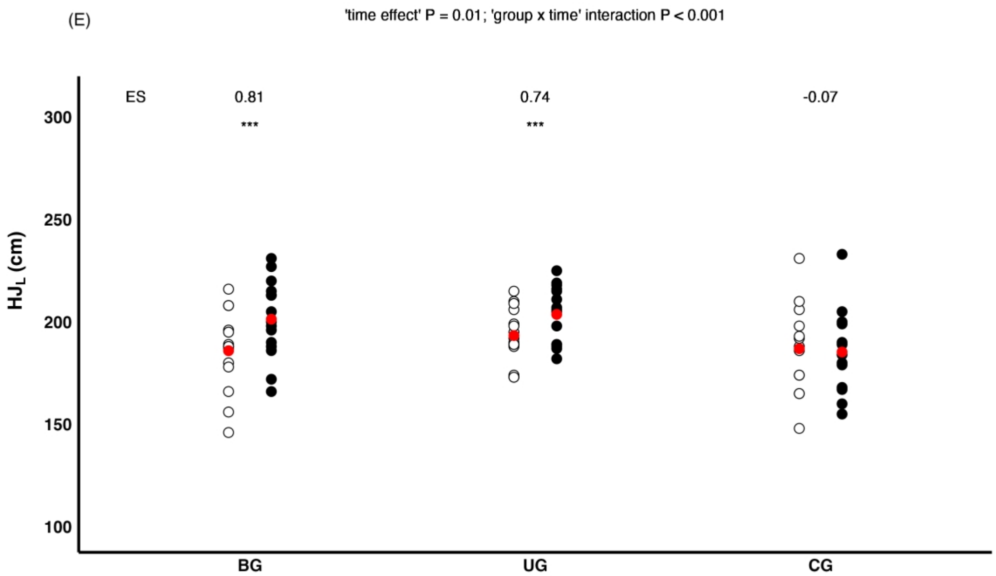

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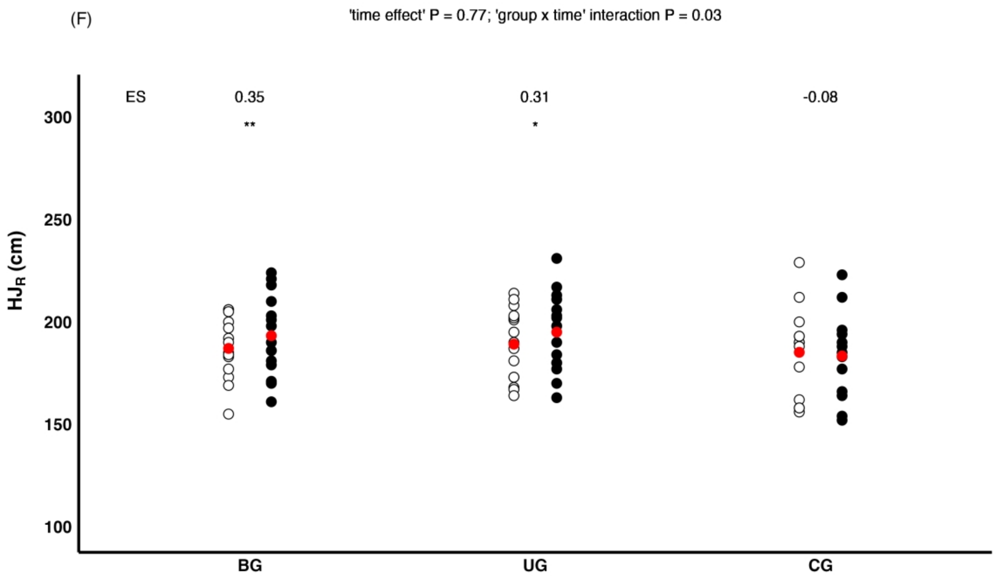

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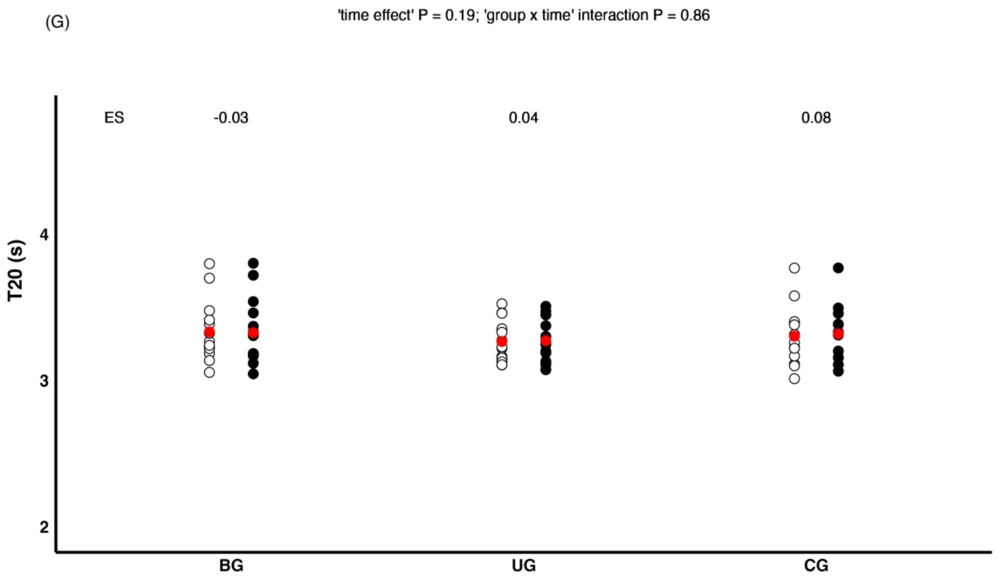

Figure 1G

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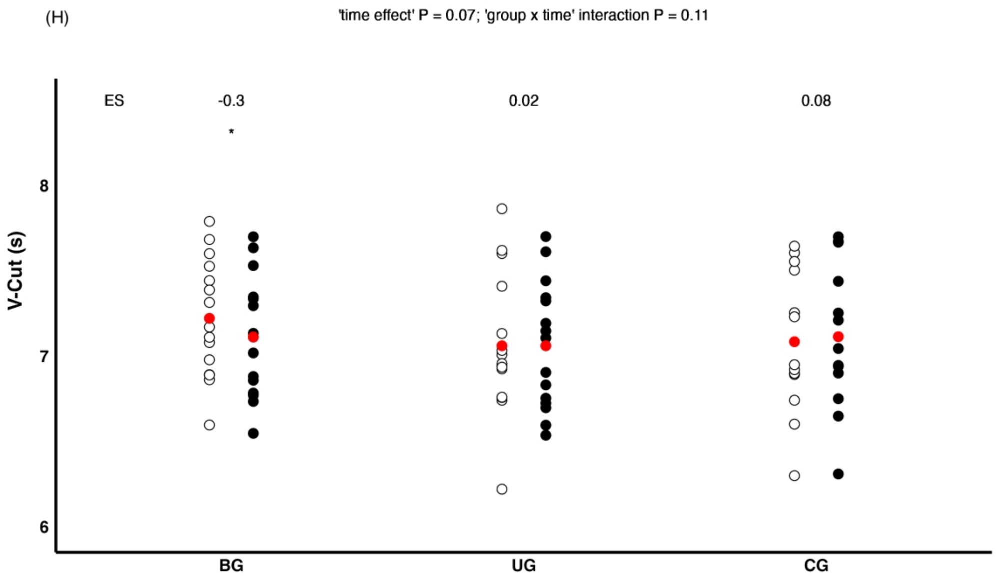

Figure 1H

254x152mm (300 x 300 DPI)

FIGURE CAPTION

Figure 1: A, Changes produced in countermovement jump (CMJ) from Pre- to Post-training for each group. B, Changes produced in left leg countermovement jump (CMJ_L) from Pre- to Post-training for each group. C, Changes produced in right leg countermovement jump (CMJ_R) from Pre- to Post-training for each group. D, Changes produced in horizontal jump (HJ) from Pre- to Post-training for each group. E, Changes produced in left leg horizontal jump (HJ_L) from Pre- to Post-training for each group. F, Changes produced in right leg horizontal jump (HJ_R) from Pre- to Post-training for each group. G, Changes produced in straight-line sprint (T20) from Pre- to Post-training for each group. H, Changes produced in change of direction ability (V-Cut) from Pre- to Post-training for each group. BG, Bilateral plyometric training group (n = 15); UG, Unilateral plyometric training group (n = 15); CG, Control group (n = 13). ES, within-group effect size from Pre- to Post-training. Intragroup significant differences from Pre- to Post-training: * $P \leq .05$, ** $P \leq .01$, *** $P \leq .001$