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Effects of Plyometric Training on Lower Limb Strength and Power in Young Postpubertal High Level Basketball Players

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Abstract

Background: Currently, the scientific evidence available on plyometric training in young basketball players is limited.
Objectives: The aim of this study was to analyze the effects produced by plyometric training over a period of 8 weeks, with a frequency of two weekly training sessions, combining vertical and horizontal force vectors.
Methods: The study involved 28 young men (14.54 ± 0.6 years, a height of 182.76 ± 7.1 cm and a body weight of 68.05 ± 9.8 kg) high-level basketball players and aimed to investigate the effects of this training program on athletes at different maturational states, specifically based on their peak height velocity (PHV) and post-pubertal (post-PHV) stages.
Results: Substantial improvements were achieved in the subjects who have carried out this type of plyometric training in all the parameters evaluated related to the improvement of the jump, linear speed and change of direction.
Conclusions: Therefore, it is crucial to provide valuable information to trainers and physical trainers, enabling them to improve and individualize the conditioning work for optimal performance of their athletes.

Keywords: Plyometric Training, Peak Height Velocity, Adolescent, Basketball, Performance

1. Background

Basketball is characterized by being a collective sport with a great psycho-motor involvement, in which there are a large number of actions of collaboration and opposition with teammates and opponents of the opposing team during the course of their game (1). This sport has evolved in terms of the physical demands of the athletes, directly influenced by the evolution of the rules that constitute the game (2). One of the main peculiarities of modern basketball is the large number of actions during the game that requires high demands at a high and intermittent intensity, caused by the constant transitions of defensive and offensive game (3). At the same time, situations in which the game is stopped between the various actions that occur during the course of the game are produced (a free throw or a technical foul for example). During the course of the game, it is worth noting the great influence of actions such as jumps, accelerations and decelerations and changes of direction (4). Up until now, there are several researches that state a temporal average frequency of 2 seconds for each change in movement pattern originated during the game situations in a game (5).

Given the great physical demands and the high variability of situations that arise during the course of the game, the ability to generate strength in a limited period of time (i.e., power) and to repeat efforts at high intensity are key factors determining sports performance, especially when team sports are considered (6, 7). Therefore, strength and power training are essential to improve performance in each of the actions that happen during the game of basketball as sprints or jumps in different force application vectors, regardless of when there is a peak height of the subjects (8, 9).

A study with 22 elite basketball players concluded with the importance of incorporating exercises unilaterally, since they favor the reduction of asymmetries between the extremities and provide strength improvements in those actions that require a unilateral application of force (10). An asymmetry between 10% and 15% in the single leg countermovement jump indicates a predisposition to future injuries. Studying unilateral jumps gives us an advantage when it comes to reproducing movements that are more similar to competition (11).

The process of evolution or change that occurs in adolescents does not follow a linear trend with their chronological age (12). One of the best known theories was that proposed by Mirwald et al., who defined peak height velocity (PHV) as the maximum height velocity (13). Once the maximum peak of maturation is reached, adaptations generated by factors such as the increase in muscle fibers, an increase in passive body structures, and an increase in creatine phosphate levels, among others, are also obtained (14). As we have previously said, working on strength and power is essential for improving the conditional abilities of a basketball player, for this reason, its individualization according to the time at which the athlete's peak height was found to be particularly relevant to significantly optimize his or her athletic performance (15). The onset of puberty is directly related to the change in the growth of young people, since neuronal and morphological changes occur in the body produced by the development of hormones as important as thyroxine, growth hormone (GH) or insulin, among many others. These changes will directly influence the adaptations generated by the training, obtaining benefits in performance and reduce risk of injury (14).

The current scientific evidence demonstrated that carrying out a varied plyometric training, without the use of external loads (16) in young basketball players, using the lower limbs in a unilateral and bilateral exercises (17), turns out to be a very interesting work proposal when it comes to producing benefits in terms of force-power in actions of maximum linear speed, maximum speed in changing direction, as well as their height levels both in the vertical (height reached in a jump) and horizontal (the distance travelled) planes (16, 18, 19).

The evidence about the ideal moment to introduce this type of plyometric sessions depending on the maturation moment in which athletes find them-selves is scarce. For this reason, the idea of carrying out this research appeared in order to obtain an answer and thus know the effects that are produced by carrying out this type of training in young people who have already reached their maximum peak height velocity (i.e. the time when they grow the fastest during their adolescent growth) (9, 19).

2. Objectives

Based on these observations from current practice and literature, the objective of this study was to analyze the effects produced by plyometric training over a period of 8 weeks, with a frequency of two weekly training sessions, combining vertical and horizontal force vectors, as well as the use of the lower limbs in a bilateral and unilateral manner, respectively, in young post-pubertal basketball players belonging to a high-level club.

3. Methods

3.1. Participants

A total of 28 male participants between the ages of 11 and 15 participated voluntarily, belonging to 3 teams from the base categories of a basketball club of the highest level located in the first Spanish basketball division.

All the participating subjects are in the post-PHV maturational stage, that is, between 1 and +3 years above their maximum peak of maturational development (18). The average chronological age of these subjects is 14.54 ± 0.6 years. Their maturational age with respect to their biological age (PHV age) is 13.00 ± 0.4 years, a height of 182.76 ± 7.1 cm and a body weight of 68.05 ± 9.8 kg.

The total frequency of training of these players is 4 weekly sessions, with a total of ± 6 hours of work, of which 2 hours are dedicated specifically to physical conditioning, adding 1 or 2 competitions per week. Due to muscle injury during a league match, one of the subjects had to drop out of the study training program.

3.2. Anthropometric Assessments

To classify the subjects in a non-invasive and feasible way, the equation of Mirwald et al. was used to obtain data based on the current maturational age with an accuracy of (± 0.5 cm) and in turn, estimate the PHV based on their anthropometric data (13).

The equation to determine the maturational age of the subjects was the following: Maturity Offset = -9.236 + (0.0002708 × Leg length × Sitting height) + (0.001663 × Age × Leg length) + (0.007216 × Age × Height sitting) + (0.02292 × weight/height).

In order to correctly calculate this equation, it has been necessary to obtain data on the gender, height (cm), weight (kg), date of the measurements, date of birth and sitting height (cm) of each subject.

Anthropometric assessments of the subjects were performed one week before the first functional assessments of the study, and one week after finishing the last ones during the competitive period.

3.3. Preparation of Subjects for Assessments

The 48 hours prior to the execution of the evaluations, the subjects did not perform any type of high intensity effort that could negatively influence the test records.

To familiarize the subjects with the tests, they performed a specific activation of the basketball game, which aims to perform exercises that simulate actions that occur during the practice of basketball with an order from lower to higher specificity, in which the subjects are already adapted from the beginning of the season. Subsequently, before each test to be tested, they performed a specific activation of each one of them in order to assess them in the most optimal way possible.

3.3.1. Linear Speed Test

Witty wireless photocells (Microgate, Bolzano, Italy) were necessary to perform the linear speed tests (10) (Figure 1). In this test the distances of 5-m, 10-m-20-m and 25-m were evaluated. Each device was separated at a distance of 1.5 meters by which the subject exceeded running with maximum intentionality.

Between the starting point of the test where the test was begun and the first photocell there was a distance of 0.5 meters marked with a line on the ground. Each subject performed a total of 2 exits per distance to be assessed, choosing the best mark of the two performed for the final assessment of the study.

In order for the subjects to be able to perform the test with full recovery and execute it to the maximum intentionality, the recovery time between the first phase of specific activation and the assessments was 3 minutes passively.

3.3.2. Horizontal Jump Test

To evaluate the horizontal jumps a measuring tape was used in the horizontal plane performing unilateral jumps with both the left and right leg (20).

The subjects were visually analyzed during the test with the aim of achieving a small swing with the leg that does not actively intervene in the test if the subject considers it appropriate, ensuring that the subject maintains body stability on the leg tested after the jump and achieve a correct cushioning in the reception phase (21).

To validate the evaluation, the subject had to maintain stability after the fall for 2 seconds and no difference greater than 5 centimeters between the 3 jumps evaluated.

On the other hand, the evaluation of the triple jump (3- HJI and 3- HJD) was also carried out. The test consisted of performing three consecutive jumps at maximum intentionality with the same leg in the horizontal plane. At the end of the last jump, the subject had to maintain balance in a static position for 2 seconds. For the test to be considered valid, there could not be a difference greater than 5 centimeters between the 3 jumps evaluated. In case the difference was greater, the subject would perform the test again (22).

The test ended once a total of 3 jumps had been made with the left leg and another 3 with the right leg.

3.3.3. 5 + 5 with 180 Degrees Change of Direction Test

The 180° change of direction was evaluated with the 5 + 5 meters test using Witty wireless photocells (Microgate, Bolzano, Italy) (Figure 2). For a correct evaluation, the subjects began the test at a distance of 0.5 meters from the first photocell and had to cross the 5-metre mark with the leg that made the change of direction and return to maximum intentionality until the first photocell. In the event that the subjects did not exceed the mark of the last photocell, the evaluation was repeated again. Prior to the evaluation, an activation was performed simulating the test on two occasions. The test consists of two evaluations for each leg that makes the change of direction with a 2-minute rest passively between each of the series. Only the best attempt with each of the legs was recorded (23).

3.3.4. V-Cut Test

To evaluate motor actions of change of direction similar to the actions that are carried out during the game of basketball, the V-cut test is performed, which consists of making 45° direction changes every 5 meters, with a total of 25 meters in 4 changes of direction (Figure 3) (24). The distance between the cones was 0.7 meters. For the V-cut test to be considered valid, subjects had to completely overshoot the foot making the change of direction. The test was performed a total of 2 times with a recovery period of 3 minutes between each attempt (24). The time was recorded by the Witty wireless photocells (Microgate, Bolzano, Italy), selecting the best time of the two attempts.

3.4. Research Procedure

The training program carried out for this intervention lasts a period of 8 weeks, with a working frequency of 2 days per week with approximate time of 1 hour per work session. The first training of the week consists of work on the vertical force vector and in a bilateral way. In the second weekly training a work on the horizontal force vector is performed in a unilateral way. The resting period necessary for overcompensation to occur is 48 hours between training sessions (25).

Each work session consisted of a total of 5 jumping exercises. Per series, an active recovery was performed in which complementary core exercises and central stabilization of the trunk were carried out in order to prevent imbalances. Said core work was performed in all the exercises except for the “Hurdle Jump” exercise of the

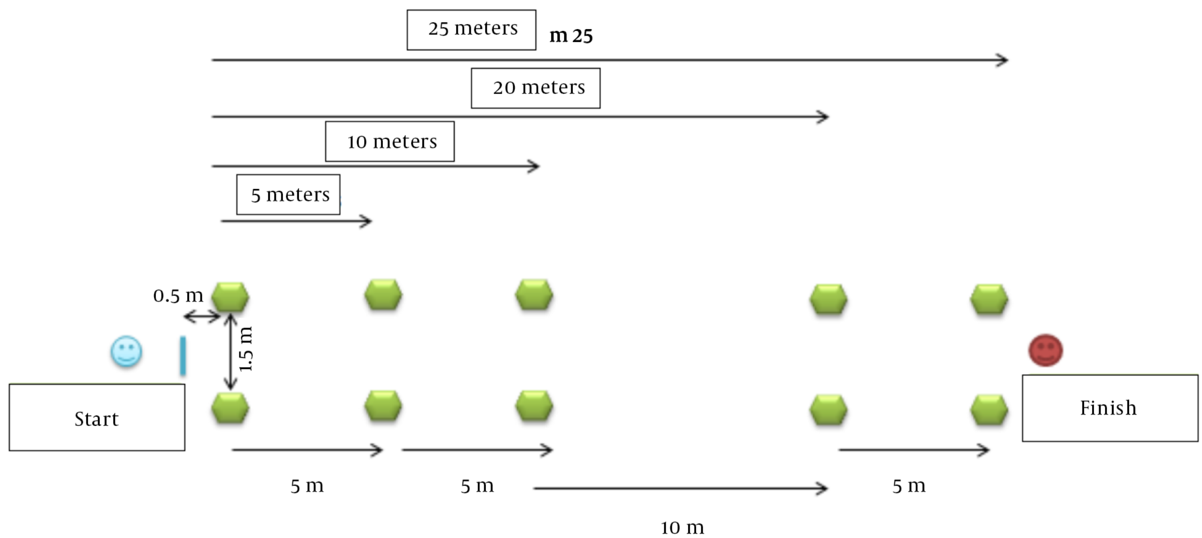

Figure 1. Outline of the line sprint test 5-m, 10-m, 20-m, 25-m.

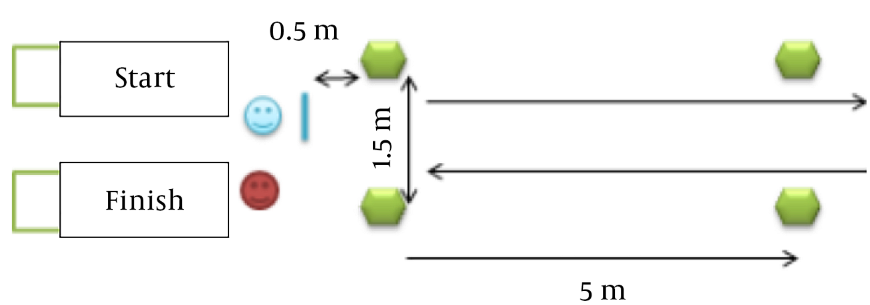

Figure 2. Outline of COD Test 5 + 5 m 180°.

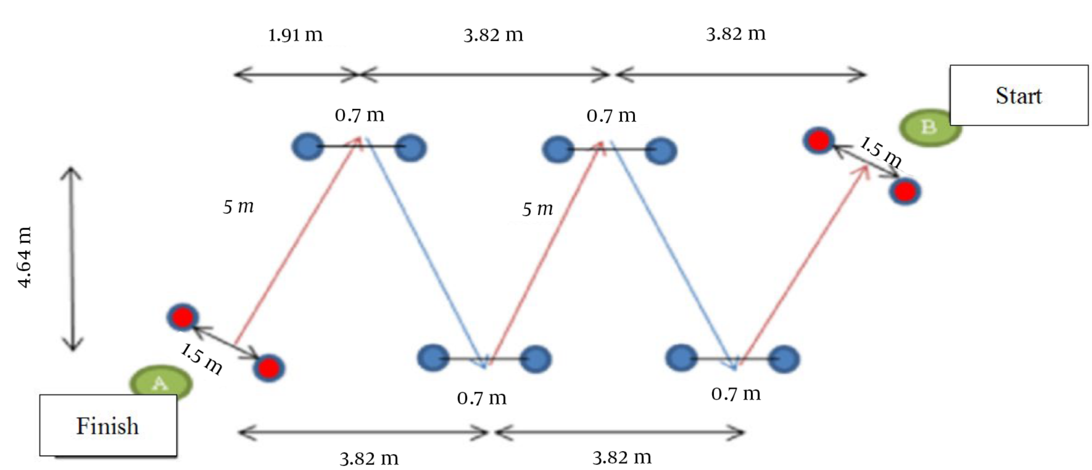

Figure 3. Outline of V-cut test.

first weekly session given its high physical demand. The recovery period between two exercises was 2 minutes.

Next, a graphic representation of the complete training plan used for the preparation of this study will be carried out (Table 1).

3.5. Statistical Analysis

The data shown in the present study are represented as mean standard deviation. All analyses in this study were carried out using IBM SPSS Statistics 21 software.

The Shapiro-Wilk statistical test was used to verify that the data were normally distributed. To observe whether or not there are significant intra-group differences, the t-student test was established for related samples, considering a value as significant when $p < 0.05$. Cohen's d was performed to calculate if the quantitative probability of the performance of the subjects had been small > 0.2, moderate > 0.6 , large > 1.2 (26).

4. Results

After analyzing the first test to assess in post-PHV subjects, substantially better results (ES = -1.56) can be observed in the 25-m test marks. Therefore, significant improvements (P = 0.03) have been observed between the pre-test and post-test evaluations, thus improving the linear speed of the subjects at a distance of 25-m.

Secondly, the 180° CODL test was analyzed in which the subjects improved their results, but without obtaining substantial improvements (ES = -0.26) as, for example, in the 25-m linear speed test (ES = -1.56). Therefore, no significant improvements were established with respect to the pre-test.

After carrying out the evaluations of the 180° CODR test, we can observe how the subjects improved their results, obtaining substantial improvements (ES = -1.13), unlike the results obtained with the change of direction executed with the lower left limb (ES = -0.26).

In the evaluations of the V-cut test, improvements in the results were observed, but they were substantially better (ES = -0.21). Therefore, no significant improvements (P = 0.23) were established with respect to the pre-test. Substantial improvements (ES = 0.66 to 1.23) could be observed in horizontal jump with respect to the previous evaluations. Significant improvements have been observed between the pre-test and post-test evaluations when performing a horizontal jump with the lower left limb (P = 0.02) and with the right lower limb (P = 0.04).

In the triple jump test, substantial improvements (ES = 0.83 to 1.23) were observed in the results after carrying out the training program. Therefore, significant improvements (P = 0.011 to 0.02) were established with respect to the pre-test.

5. Discussion

The aim of this study was to investigate the effects produced by a plyometric training program in young high-level basketball players in the post-pubertal maturational stage. To determine these effects, assessments were made of the 25-m linear speed test, SHL, SHR, 3HSL and 3HSR unilateral horizontal jump test, V-cut test and finally the 180° CODL and CODR test.

From a general perspective, it can be said that between the evaluations that were carried out prior to the training program and those that were carried out after it, significant improvements were observed in practically all the variables to be evaluated, with the exception of the V-cut test, as can be seen in the Table 2.

In the post-test evaluations of the 25-m linear speed test, improvements were observed with respect to the pre-test evaluations. These data are confirmed by other studies that also carried out plyometric training and obtained improvements in sprinting over different distances. A study that conducted 16-week bilateral vertical plyometric training results showed improvements in 5m and 10m sprint time by 0.04 seconds (8). Likewise, in another study that was carried out during 8 weeks and where the subjects trained 2 days per week, the group that performed plyometric training offered improvements in the 5 m, 10 m, 15 m, and 20 m data compared to the group that did not perform this type of training (27).

On the other hand, there are several studies in which vertical and horizontal training are compared, as well as if the training is bilateral or unilateral and in which improvements are obtained from different distances. In a first study after 6 weeks in which vertical bilateral and horizontal unilateral plyometric training were compared, the results were that both types of training improved the data of the 5 m, 10 m and 25 m (17). In a second study lasting 6 weeks, the subjects improved in the 15 m and 30 m sprint in both vertical and horizontal bilateral plyometric training and in vertical and horizontal unilateral plyometric training (16). Unilateral exercises favor the reduction of asymmetries between limbs and improve strength in those actions that require a unilateral application of strength (10). A 6-week unilateral eccentric overload training intervention with a frequency of 2 sessions per week showed substantial improvements in almost all functional tests of lower extremity strength and power, as well as reduced asymmetries between lower extremities (28).

Table 2. Changes Produced in Post-adolescent Subjects (post-PHV) Between Pre-test and Post-test Assessments [a, b]

Variables	Pre-test	Post-test	Probabilities	Sig. Differences (P)
Test 25 m	3.92 ± 0.05	3.81 ± 0.09	-1.56 (great)	0.026
180° CODL	2.70 ± 0.13	2.67 ± 0.10	-0.26 (great)	0.013
180° CODR	2.73 ± 0.06	2.64 ± 0.10	-1.13 (great)	0.033
Test V-cut	6.99 ± 0.25	6.94 ± 0.22	-0.21 (small)	0.23
SHL	165.50 ± 18.82	17.8 ± 18.65	0.66 (moderate)	0.020
SHR	161.88 ± 9.51	170.88 ± 13.41	0.78 (moderate)	0.041
3HSL	522.75 ± 25.83	572.73 ± 55.77	1.23 (great)	0.017
3HSR	516.38 ± 41.59	555.38 ± 52.18	0.83 (moderate)	0.011

[a] Data are presented as mean ± SD (standard deviation).
[b] Effect size; Great/moderate/small probability of the effect produced. For linear sprint of 25 metres (test 25-m); For 180° change of direction with left leg (180° CODL); For 180° change of direction with the right leg (180° CORD); time in the direction change test (V-Cut test); For a single unilateral horizontal jump (SHL) AND (SHR); To perform three consecutive horizontal jumps unilaterally (3HSL) AND (3HSR).

For all of the above, it seems that for subjects who have already reached their peak height velocity and have a training background and high coordination development, a training program focused on plyometrics produces a tendency to improve the ability to perform actions of linear sprint in a distance of 25 meters.

Regarding the analysis of jumps performed unilaterally in the horizontal plane, significant improvements have been shown in post-PHV subjects.

Said improvement is due to the direct transfer in the application of force during the training program of the study with the evaluations carried out, both in the HSL, HSR and the 3HSL, 3HSR tests. However, the improvements are also produced since the PHV-subjects have already acquired a high coordination level that produces improvements in said adaptations in the horizontal jump.

We can say that this is one of the variables in which the most improvements have been produced, an aspect that is observed in several recent publications. In the study in which a group performs a vertical bilateral plyometric training and another group a horizontal unilateral training, both groups improve with each leg between 11 cm and 12 cm in a 6-week training (17), as occurs in another study that performed plyometric training combining bilateral and unilateral (27) and in another that performed vertical and horizontal bilateral plyometric training as well as vertical and horizontal unilateral (16).

Therefore, both bilateral and unilateral plyometric training planning, as well as vertical and horizontal, as well as combined, produces a great improvement in the jumps performed in the horizontal plane.

Another aspect analyzed in this study is the changes of direction, we can say that no substantial improvements have been observed as we can see in other tests such as linear sprints or horizontal jumps. These results are in contrast to this meta-analysis showing how plyometric training improves COD in basketball (29).

Only in the 180° CODR change of direction test have significant improvements been presented with respect to the V-cut test and 180° CODL test, data that is not in line with other publications with similar characteristics. In an article, the V-cut test improves after vertical bilateral training as well as horizontal unilateral training, although it improves more with the latter. However, the 180° COD test with vertical bilateral training improves by 2 seconds, but with horizontal unilateral training, time cannot be improved (17). In an-other article in which bilateral and unilateral training is combined, he improves the data for both the V-cut test, as well as for the 180° CODR and 180° CODL tests (10).

Regarding the limitations of the study, it is worth mentioning that the sample used is small and the data is limited to a certain group of athletes, so it would be interesting to carry out more studies to confirm the present results. Post-pubescent basketball players have particular characteristics that do not allow our results to be directly extrapolated to other sports. Future studies should extend these observations to other age groups, competitive levels, different sports, and larger samples in order to analyze whether the results are similar. It would also be interesting to look at different intensities and volumes in the plyometric training program, in order to determine the optimal dose for this training method, as well as to see if such a program can reduce the incidence of injuries. Finally, the importance of plyometric training of the upper limbs on basketball performance should be investigated in the future.

5.1. Conclusions

Nowadays, there are more and more publications that tell us about the benefits of plyometric training in the conditional aspect of team sports in the training categories as long as the total volume of load to be done is adequate (16, 17, 27).

Day by day this type of training is becoming more and more popular and for this reason it would be of special interest that coaches and physical trainers who do not know in depth the benefits of this type of training inquire about its great benefits in many determining factors of the game in the sport of basketball and in turn know the most effective way to develop it in order to optimize the performance and reduce risk of injury of a young basketball player in the short, medium and long term.

In conclusion, substantial improvements were achieved in the subjects who have carried out this type of plyometric training in all the parameters evaluated related to the improvement of the jump, linear speed and change of direction.

Footnotes

Authors' Contribution: Conceptualization, O.G.-S., O.V.-G., E.M.-P. and D.L.; Methodology, O.V.-G., E.M.-P., H.G.U., D.L., A.R.-M. and A.C.S.; Software, O.G.-S., O.V.-G., E.M.-P., A.C.S. and D.L.; Formal analysis, O.G.-S., O.V.-G., E.M.-P. and A.C.S.; Investigation, O.V.-G., E.M.-P., D.L., A.R.-M. and H.G.U.; Writing—original draft preparation, , O.V.-G., E.M.-P., A.R.-M. and H.G.U.; Writing—review and editing, O.G.-S., O.V.-G., E.M.-P., A.C.S., D.L., A.R.-M. and H.G.U. All authors have read and agreed to the published version of the manuscript.

Conflict of Interests: Elena Mainer-Pardos is editorial board members of this journal.

Data Reproducibility: The dataset presented in the study is available on request from the corresponding author during submission or after publication. The data are not publicly available due to its private nature.

Ethical Approval: The study was conducted according to the guidelines of the Declaration of Helsinki and ap-proved by the Local Ethics Committee of Clinical Research (REPORT No. PI14/00114, CEICA, Spain).

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Informed Consent: Informed consent was obtained from all subjects and their parents involved in the study

References

1. Ben Abdelkrim N, El Fazaa S, El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med*. 2007;**41**(2):69–75. discussion 75. [PubMed ID: 17138630]. [PubMed Central ID: PMC2658931]. https://doi.org/10.1136/bjsm.2006.032318.
2. Stojanovic E, Stojiljkovic N, Scanlan AT, Dalbo VJ, Berkelmans DM, Milanovic Z. The Activity Demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic Review. *Sports Med*. 2018;**48**(1):111–35. [PubMed ID: 29039018]. https://doi.org/10.1007/s40279-017-0794-z.
3. McInnes SE, Carlson JS, Jones CJ, McKenna MJ. The physiological load imposed on basketball players during competition. *J Sports Sci*. 1995;**13**(5):387–97. [PubMed ID: 8558625]. https://doi.org/10.1080/02640419508732254.
4. Scanlan A, Dascombe B, Reaburn P. A comparison of the activity demands of elite and sub-elite Australian men's basketball competition. *J Sports Sci*. 2011;**29**(11):1153–60. [PubMed ID: 21777151]. https://doi.org/10.1080/02640414.2011.582509.
5. Caprino D, Clarke ND, Delextrat A. The effect of an official match on repeated sprint ability in junior basketball players. *J Sports Sci*. 2012;**30**(11):1165–73. [PubMed ID: 22697579]. https://doi.org/10.1080/02640414.2012.695081.
6. Fort-Vanmeerhaeghe A, Montalvo A, Latinjak A, Unnithan V. Physical characteristics of elite adolescent female basketball players and their relationship to match performance. *J Hum Kinet*. 2016;**53**:167–78. [PubMed ID: 28149421]. [PubMed Central ID: PMC5260586]. https://doi.org/10.1515/hukin-2016-0020.
7. Little T, Williams AG. Specificity of acceleration, maximum speed, and agility in professional soccer players. *J Strength Cond Res*. 2005;**19**(1):76–8. [PubMed ID: 15705049]. https://doi.org/10.1519/14253.1.
8. Fathi A, Hammami R, Moran J, Borji R, Sahli S, Rebai H. Effect of a 16-Week Combined Strength and Plyometric Training Program Followed by a Detraining Period on Athletic Performance in Pubertal Volleyball Players. *J Strength Cond Res*. 2019;**33**(8):2117–27. [PubMed ID: 29401199]. https://doi.org/10.1519/JSC.0000000000002461.
9. Meylan CM, Cronin JB, Oliver JL, Hopkins WG, Contreras B. The effect of maturation on adaptations to strength training and detraining in 11-15-year-olds. *Scand J Med Sci Sports*. 2014;**24**(3):e156–64. [PubMed ID: 24118076]. https://doi.org/10.1111/sms.12128.
10. Gonzalo-Skok O, Tous-Fajardo J, Suarez-Arrones L, Arjol-Serrano JL, Casajus JA, Mendez-Villanueva A. Single-Leg Power Output and Between-Limbs Imbalances in Team-Sport Players: Unilateral Versus Bilateral Combined Resistance Training. *Int J Sports Physiol Perform*. 2017;**12**(1):106–14. [PubMed ID: 27140680]. https://doi.org/10.1123/ijspp.2015-0743.
11. Meylan C, McMaster T, Cronin J, Mohammad NI, Rogers C, Deklerk M. Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. *J Strength Cond Res*. 2009;**23**(4):1140–7. [PubMed ID: 19528866]. https://doi.org/10.1519/JSC.0b013e318190f9c2.
12. Malina RM, Bouchard C, Bar-Or O. *Growth, Maturation, and Physical Activity*. Illinois, USA: Human Kinetics; 2004. https://doi.org/10.5040/9781492596837.
13. Mirwald RL, Baxter-Jones ADG, Bailey DA, Beunen GP. An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc*. 2002;**34**(4):689–94. [PubMed ID: 11932580]. https://doi.org/10.1097/00005768-200204000-00020.
14. Myer GD, Faigenbaum AD, Ford KR, Best TM, Bergeron MF, Hewett TE. When to initiate integrative neuromuscular training to reduce sports-related injuries and enhance health in youth? *Curr Sports Med Rep*. 2011;**10**(3):155–66. [PubMed ID: 21623307]. [PubMed Central ID: PMC3105332]. https://doi.org/10.1249/JSR.0b013e31821b1442.

15. Wagner H, Finkenzeller T, Wurth S, von Duvillard SP. Individual and team performance in team-handball: a review. *J Sports Sci Med*. 2014;**13**(4):808–16. [PubMed ID: 25435773]. [PubMed Central ID: PMC4234950].
16. Gonzalo-Skok O, Sanchez-Sabate J, Izquierdo-Lupon L, Saez de Villarreal E. Influence of force-vector and force application plyometric training in young elite basketball players. *Eur J Sport Sci*. 2019;**19**(3):305–14. [PubMed ID: 30058461]. https://doi.org/10.1080/17461391.2018.1502357.
17. Ramirez-Campillo R, Burgos CH, Henriquez-Olguin C, Andrade DC, Martinez C, Alvarez C, et al. Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *J Strength Cond Res*. 2015;**29**(5):1317–28. [PubMed ID: 25474338]. https://doi.org/10.1519/JSC.0000000000000762.
18. Asadi A. Effects of in-season short-term plyometric training on jumping and agility performance of basketball players. *Sport Sci Health*. 2013;**9**(3):133–7. https://doi.org/10.1007/s11332-013-0159-4.
19. de Villarreal ES, Kellis E, Kraemer WJ, Izquierdo M. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *J Strength Cond Res*. 2009;**23**(2):495–506. [PubMed ID: 19197203]. https://doi.org/10.1519/JSC.0b013e318196b7c6.
20. Gonzalo-Skok O, Serna J, Rhea MR, Marin PJ. Relationships between Functional Movement Tests and Performance Tests in Young Elite Male Basketball Players. *Int J Sports Phys Ther*. 2015;**10**(5):628–38. [PubMed ID: 26491613]. [PubMed Central ID: PMC4595916].
21. Aztarain-Cardiel K, Lopez-Laval I, Marco-Contreras LA, Sanchez-Sabate J, Garatachea N, Pareja-Blanco F. Effects of Plyometric Training Direction on Physical Performance in Basketball Players. *Int J Sports Physiol Perform*. 2023;**18**(2):135–41. [PubMed ID: 36889323]. https://doi.org/10.1123/ijspp.2022-0239.
22. Delextrat A, Grosgeorge B, Bieuzen F. Determinants of performance in a new test of planned agility for young elite basketball players. *Int J Sports Physiol Perform*. 2015;**10**(2):160–5. [PubMed ID: 24956606]. https://doi.org/10.1123/ijspp.2014-0097.
23. Pardos-Mainer E, Casajus JA, Julian C, Bishop C, Gonzalo-Skok O. Determining the reliability and usability of change of direction speed tests in adolescent female soccer players: a systematic review. *J Sports Med Phys Fitness*. 2020;**60**(5):720–32. [PubMed ID: 32438788]. https://doi.org/10.23736/S0022-4707.20.10178-6.
24. Gonzalo-Skok O, Tous-Fajardo J, Suarez-Arrones L, Arjol-Serrano JL, Casajus JA, Mendez-Villanueva A. Validity of the V-cut Test for Young Basketball Players. *Int J Sports Med*. 2015;**36**(11):893–9. [PubMed ID: 26134663]. https://doi.org/10.1055/s-0035-1554635.
25. Bompa T, Buzzichelli C. *Periodization of strength training for sports*. Illinois, USA: Human Kinetics; 2021.
26. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;**41**(1):3–13. [PubMed ID: 19092709]. https://doi.org/10.1249/MSS.0b013e31818cb278.
27. Pardos-Mainer E, Ustero-Pérez O, Gonzalo-Skok O. [Effects of upper and lower body plyometric training on physical performance in young tennis players]. *Rev Int Cienc Deporte*. 2017;**13**(49):225–43. Spanish. https://doi.org/10.5232/ricyde2017.04903.
28. Gonzalo-Skok O, Sanchez-Sabate J, Tous-Fajardo J, Mendez-Villanueva A, Bishop C, Piedrafita E. Effects of Direction-Specific Training Interventions on Physical Performance and Inter-Limb Asymmetries. *Int J Environ Res Public Health*. 2022;**19**(3). [PubMed ID: 35162053]. [PubMed Central ID: PMC8834310]. https://doi.org/10.3390/ijerph19031029.
29. Asadi A, Arazi H, Young WB, Saez de Villarreal E. The Effects of Plyometric Training on Change-of-Direction Ability: A Meta-Analysis. *Int J Sports Physiol Perform*. 2016;**11**(5):563–73. [PubMed ID: 27139591]. https://doi.org/10.1123/ijspp.2015-0694.

Table 1. Eight Week Training Program with Increased Intensity and Volume

Week	Session 1	Session 2
1	3 × 5 Drop Jump 10 cm	3 × 5 Drop Jump 10 cm
	Hover	Dynamic birddog
	2 × 5 SJ with arms swing	2 × 5 SJ
	Lumbar bridge	Lumbar bridge
	2 × 5 CMJ with arms swing	5 × 2 Unilateral Jumps
	Plank	Dynamic deadbug
	5 × 2 Tuck Jump	5 × 2 Triple Jumps
	3 × 5 Hurdle jump	Plank
2	3 × 5 Drop Jump 10 cm	3 × 5 Drop Jump 10 cm
	Superman	Front plank
	2 × 5 SJ with arms swing	2 × 5 SJ
	Static birddog	Superman
	2 × 5 CMJ with arms swing	2 × 5 SJ without CMJ
	Plank	Quadruped knee lift
	5 × 2 Tuck Jump	3 × 5 Triple Jumps
	3 × 5 Hurdle jump	Deadbug
3	3 × 5 Drop Jump 20 cm	3 × 5 Drop Jump 10 cm
	Dynamic birddog	Hover
	2 × 5 SJ with arms swing	2 × 5 SJ
	Dynamic deadbug	Lumbar bridge single leg
	2 × 5 CMJ with arms swing	2 × 5 SJ without CMJ
	Plank	5 × 2 Unilateral Jumps
	5 × 2 Tuck Jump	3 × 5 Triple Jumps
	3 × 5 Hurdle jump	Dynamic Birddog
4	4 × 5 Drop Jump 20 cm	4 × 5 Drop Jump 10 cm
	Dynamic birddog	Hover
	3 × 5 SJ with arms swing	3 × 5 SJ
	Dynamic deadbug	Lumbar bridge single leg
	3 × 5 CMJ with arms swing	3 × 5 SJ without CMJ
	Plank	5 × 2 Unilateral Jumps
	5 × 2 Tuck Jump	4 × 5 Triple Jumps
	4 × 5 Hurdle jump	Dynamic Birddog
5	4 × 5 Drop Jump 20 cm	4 × 5 Drop Jump 10 cm
	Dynamic birddog	Static superman
	3 × 5 SJ with arms swing	3 × 5 SJ
	Standing up disturb partner	Lumbar bridge single leg
	3 × 5 CMJ with arms swing	3 × 5 SJ without CMJ
	Plank e × tended arms	5 × 2 Unilateral Jumps
	5 × 2 Tuck Jump	4 × 5 Triple Jumps

	4 × 5 Hurdle jump	Front plank touching shoulders
6	4 × 5 Drop Jump 20 cm	4 × 5 Drop Jump 10 cm
	Dynamic birddog	Plank e × tended arms
	3 × 5 SJ with arms swing	3 × 5 SJ
	Standing up disturb partner	Dynamic lumbar bridge
	3 × 5 CMJ with arms swing	3 × 5 SJ without CMJ
	Plank e × tended arms	5 × 2 Unilateral Jumps
	5 × 2 Tuck Jump	4 × 5 Triple Jumps
	4 × 5 Hurdle jump	Front plank touching shoulders
7	4 × 5 Drop Jump 20 cm	4 × 5 Drop Jump 10 cm
	Dynamic birddog	Plank e × tended arms
	4 × 5 SJ with arms swing	4 × 5 SJ
	Standing up disturb partner	Dynamic lumbar bridge
	4 × 5 CMJ with arms swing	4 × 5 SJ without CMJ
	Plank e × tended arms	5 × 4 Unilateral Jumps
	5 × 4Tuck Jump	4 × 5 Triple Jumps
	4 × 5 Hurdle jump	Front plank touching shoulders
8	4 × 5 Drop Jump 20 cm	4 × 5 Drop Jump 10 cm
	Dynamic lubar bridge	Plank e × tended arms
	4 × 5 SJ with arms swing	4 × 5 SJ
	Standing up disturb partner	Dynamic lumbar bridge
	4 × 5 CMJ with arms swing	4 × 5 SJ without CMJ
	Plank e × tended arms	5 × 4 Unilateral Jumps
	5 × 4Tuck Jump	4 × 5 Triple Jumps
	4 × 5 Hurdle jump	Front plank touching shoulders

Abbreviations: SJ, squat jump; CMJ, counter movement jump.