

Review article

**EFFECTS OF PLYOMETRIC PROGRAMMS ON
BIOMECHANICAL PARAMETERS IN TRACK AND FIELD,
BASKETBALL AND VOLLEYBALL: A SYSTEMATIC REVIEW**

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Abstract. *Plyometric movement improves athletes' muscular performance and is used in the plyometric training method as an unavoidable principle of explosive power and speed development training. The aim of this study is to determine the effects of plyometric programs on biomechanical parameters, including any differences between them. The study focused on three sports, junior age group athletes, and was based on a systematic analysis of previous results. Electronic databases such as PubMed, MEDLINE, Google Scholar, ScienceDirect, ERIC were searched for studies from 1999 to 2022. The results from 15 studies are summarized in detail. They show the positive effects of the plyometric programs on biomechanical parameters equally in the three sports. Training duration ranges from 20 to 90 min, and is directly related to the intensity of training and the number of jumps. Shorter sessions are of very high intensity with fewer jumps, while longer sessions are moderate and high intensity with fewer jumps (more than 138 to more than 2976). The most frequent training duration is 45 to 60 min, with high intensity and 600 to 900 different jumps. Greater improvements in explosive power and speed are seen in the parameters of sprint and jump tests. High intensity programs lasted from seven to 12 weeks, with a frequency of two to four times a week (CMJ 6,2% to 16,9%, while for SJ 7,6% to 19,8%), while lower intensity programs lasted from three to six weeks (CMJ 6,3% to 9,1%, and for SJ 6,6% to 8,9%). It is concluded that longer programs, of a moderate and high intensity and training sessions from 45 to 60 min, enable the best progress, regardless of sport.*

Key words: *Plyometrics, effects, biomechanics, track and field, basketball, volleyball*

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1. INTRODUCTION

There are numerous types of training programs, with different aims, but programs aimed at developing and improving motor skills attract special attention from researchers and coaches. A key principle of training is the development of explosive power and speed, which requires a plyometric training program (Verkhoshansky & Siff, 2009). According to Komi (1992), plyometric action and “short-stretching cycles” occur in various types of running, jumping, hitting, hurdling, and other takeoff moments in sport; but plyometric training includes plyometric activities as the key modality of training (Komi & Nicol, 2000). Plyometric activity consists of five phases (the initial impulse phase, electromechanical delay phase, amortization phase, rebound phase, and the final phase) (Zatsiorsky, 2008; Chu & Meyer, 2013; Davies et al., 2015). Merging these phases leads to plyometric movement meant to improve the muscle performance of an athlete. The rapid alteration between speeding up and slowing down creates an explosive reaction that increases the speed and power of muscles during a sports activity, which is a precondition for success in every explosively demanding sport at whose core we find rapid body movement and jumps (Zatsiorsky, 2008; Verkhoshansky & Siff, 2009; Siff, 2001; Davies et al., 2015).

In most track and field disciplines the basic criterion of success is the development of the greatest possible reactive force during the shortest possible contact with the surface, known as the contact phase, which is why plyometric exercise is essential in training cycles (Kurelić, 1954; Čoh, 2008). Sprinting is a complex cyclical movement defined by step frequency and length (Čoh & Tomažin, 2005). Sprinting as a movement stereotype involves repeating steps over a unit of time. Step length depends on body height and leg length, as well as the force developed by the extensor muscles of the hip, knee, and ankle during the contact phase. The contact phase is one of the most important generators of sprint effectiveness (Lehmann & Voss, 1997). It must be as short as possible, approximately 90–100 ms (Mero & Komi, 1985), and marked by an optimum relationship between the stop and start phase (Mero, Komi, & Gregor, 1992). In addition to sprint disciplines, jumping disciplines are based on explosive and rapid movements of the muscle apparatus during the contact phase and the throwing phase, when the muscle no longer exerts force on the object (Kurelić, 1954; Čoh, 2008).

In addition to track and field, collective sports such as basketball extensively rely on plyometric exercise for the development and impact of explosive power and speed (Bobbert, 1990; Željaskov, 2004; Lehnert, Hülka, Malý, Fohler, & Zahálka, 2014). During a game, basketball players spend 34% of their time running and jumping, 56.8% walking, and 9% standing, while the intensity of movement or its form takes place approximately every 2s (Jakovljević et al., 2011). During a game, a player on average achieves 46 ± 12 jumps (Castagna, Chaouachi, Rampinini, Chamari, & Impellizzeri, 2009), performing as many as 100 different jumps during the entire game (Manojlović & Erčulj, 2013).

Volleyball is also based on explosive power, speed, and the performance of different jumps (Sheppard, Gabbett, & Stanganelli, 2009). When the overall activity during a game is analyzed, approximately 50 – 60% involves various jumps, 30% rapid changes in direction, and 15% falls. A professional volleyball player can make as many as 120,000 jumps during an entire season (García-de-Alcaraz, Ramírez-Campillo, Rivera-Rodríguez, & Romero-Moraleda, 2020). The height of the vertical jump among volleyball players correlates the most with success in volleyball, and is directly linked to the performance of the spike, block, or serve (Sheppard, Gabbett, & Stanganelli, 2009; Ramirez-Campillo, et al., 2021).

In order to improve the height of takeoff, rapid increase in body velocity is needed prior to the jump (Wagner, Tilp, Von Duvillard, & Müller, 2009). The aforementioned confirms that volleyball training is based on the plyometric concept which has been shown to be most successful compared to other types of training aimed at developing and improving explosive power, that is, takeoff height (Silva, Clemente, Lima, et al., 2019).

The applicability of plyometrics in sport is complex and depends on several factors. Therefore, varying results can be found in the relevant literature, all of which depend on the duration of the program, its frequency, type of exercise, type of sport, as well as the age of the athletes (Ramirez-Campillo et al., 2021). Consequently, the aim of this study was to determine the effects of plyometric programs on the biomechanical parameters in three sports, including any differences between the programs. The study involved junior age groups of athletes, and relied on a systematic analysis of existing results.

2. METHODS

To search the existing literature, the following electronic databases were used: PubMed, MEDLINE, Google Scholar, ScienceDirect, ERIC. The search was for papers published from 1996 to 2022, and included the following key terms: *plyometrics, effects, biomechanics, track and field, basketball, volleyball*. The research strategy was modified for each electronic database, where possible, with the aim of increasing sensitivity. All the titles and abstracts were reviewed for potential studies which could be included in the systematic review. In addition, the lists of references of previous reviews and original research papers were also analyzed. The relevant studies were identified following a detailed overview of the inclusion criteria. The exclusion criteria are defined later in the text.

2.1. Inclusion criteria

2.1.1. Type of study

Non-controlled randomized and non-randomized longitudinal studies on the effects of plyometric programs on biomechanical parameters of different athletes, along with studies written in English were all included in the analysis.

2.1.2. The sample of participants

The included participants are sprinters, volleyball players, and basketball players of both sexes aged 15 to 19, experienced athletes (participants in competitions at the international and national level). They were healthy, and had no deformities and artificial aids that affect the normal performance of jumping and movement.

2.1.3. Type of intervention

Studies that assess the effects of plyometric programs on the development of explosive power and speed of the lower extremities of the participants were included.

2.1.4. Type of output results

Studies were included if they showed the assessment, effects, and current state of the explosive power and speed of the lower extremities of the participants.

2.2. Exclusion criteria

The exclusion criteria were the following: 1) lack of plyometric exercise programs; 2) participants under the age of 15 or over the age of 19, due to a lack of studies examining sprinters aged 15 to 19; only studies that examined sprinters under the age of 25 were included; and 3) participants who did not compete in track and field, basketball, or volleyball.

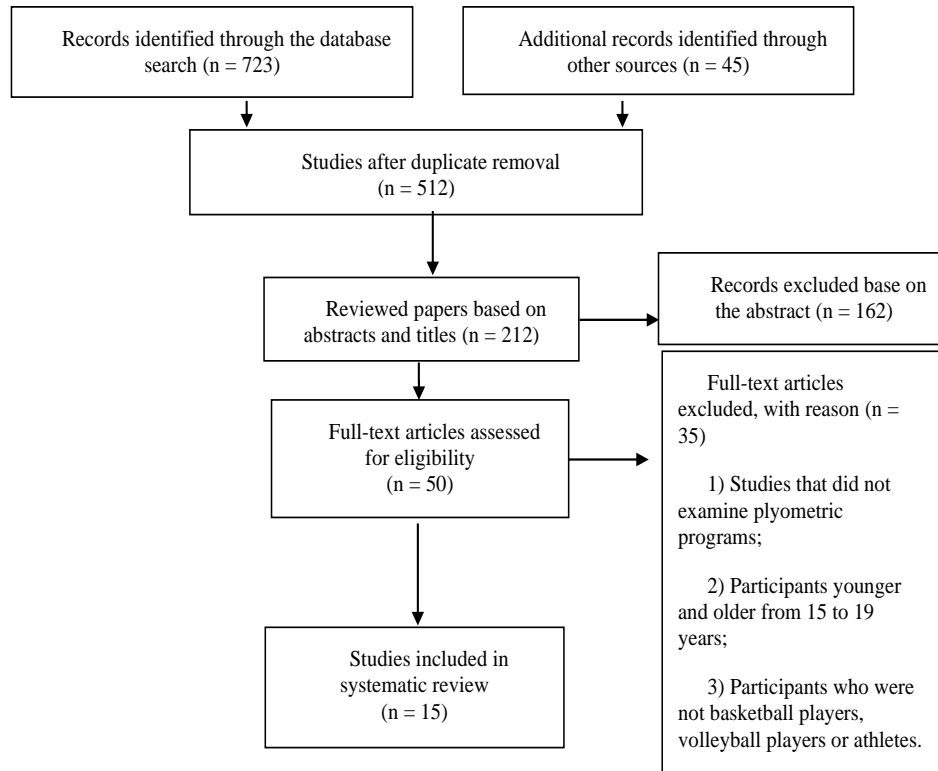


Fig. 1 PRISMA Flow Diagram for Systematic Reviews for the research related to the given topic

3. RESULTS

The final analysis included 15 studies which were compiled and analyzed based on the previously mentioned parameters and methods. The studies included young male and female participants who took part in track and field, basketball, and volleyball. All of the studies had the following aim: to assess the effects of plyometric programs on the biomechanical parameters of junior age groups of participants. The search identified 723 potentially relevant studies, and another 45 were identified by reviewing the references. After the duplicate studies were removed, and the titles and abstracts analyzed, 212 studies remained. By reviewing their entire texts, based on the criteria for inclusion, 15 studies remained.

Table 1 An overview of 15 studies which met the set requirements.

Reference	Number of participants, sex, age and sport	Group	Program duration, frequency (per week) and training duration	Program characteristics: intensity (%), exercise (type and description) and number of jumps per training	Results	Conclusion
1. Idrizovic et al., (2018)	n = 47 F 16.6 years Volleyball	G1-13 PI G2-17 NPI C-17	2/12 Td-40-60 min	L, MOD and H CMJ; DJ (20-60 cm); 20 m sprint and Dr UnS-613 Os-120-300 s	G1-20 m = 5.7% ↑; CMJ = 16.9% ↑ G2-20 m = 0.2% ↑ CMJ = 9% ↑ C-20 m = 0.1% ↑ CMJ = 8.5% ↑ G1 ↑- 20 m sprint ($\eta_2 = .09$; small ES), CMJ ($\eta_2 = .29$; large ES), relative to G2. C = 4.0% ↑, p < .05	PI for 2/12 weeks ↑ all measured parameters.
2. Martel et al., (2005)	n = 19 F 15 ± 1 years Volleyball	G1-10 PI C-9 NPI	2/6 Td-40-60 min	H CMJa; DJ (61 cm); and Dr UnS- > 138 Os-30 s	G1-CMJ = 11.1% ↑, C = 4.0% ↑, p < .05	Combination PI and volleyball training leads to ↑ in VJ relative to C.
3. Krističević et al., (2016)	n = 54 F 15 ± 1 years Volleyball	G1-27PI C-27NT	1/5 Td-40-60 min	MOD and H CMJ; DJ (20-40 cm); SJ; Block jump; Spike and Dr UnS- > 645 Os-x	G1-SJ ↑-Mean = 21.80 cm ± 4.22 to 24.28 F Volleyball players for cm ± 3.4 relative to C1-Mean = 24.32 cm ± 4.10 to 24.8 cm ± 4.09 and CMJ ↑-Mean = 28.08 cm ± 4.83 to 30.72 cm ± 3.74 relative to C1-Mean = 33.04 cm ± 6.18 to 33.32 cm ± 5.62, p < .05	1/5 weeks of PI ↑ for all measured parameters.
4. Usman & Shenoy, (2015)	n = 120 M = 60 and F = 60 19.2 years Volleyball	G1-30 PI G2-30 PI C1-30 NPI C2-30 NPI	2/8 Td-40-60 min	L, MOD and H CMJa; DJ (30-80 cm); SJ; VJ; and Dr UnS- > 2976 Os-60-300 s	G1-VJ ↑ = 67.33 cm ± 1.64 relative to C1 = 57.22 cm ± 1.06 and G2-VJ ↑ = 50.08 cm ± 1.83 relative to C1 = 42.36 cm ± 1.07, p < .001	PI lower extremities for 2/8 weeks leads to ↑ in VJ and cardiovascular capacity are equally to both sexes.

5. Newton et al. (1999)	n = 16 M 19.2 years Volleyball	G1-8 P1 C1-8 NPL	2/8 Td-40-60 min	MOD and H CMJ; SJ; VJ; DJ (30-80 cm); and Dr UnS- > 576 Os-x	G1-VJ ↑ = 5.9 % ± 3.1 relative to C1-1.3 % ± 2.5, p < .001, G1-CMJ = for kinetic parameters, relative to C1 and for SJ = for kinetic parameters, relative to C1 except for contact time G1 ↑ = 14.6 % ± 9.7 and flight time -4.7 % ± 3.4, relative to C1 C1 =, p = .006 and p = .01.	PI for 2/8 weeks leads to ↑ VJ in elite athletes.
6. Arazi & Asadi (2011)	n = 18 M 18 years Basketball	G1-8 P11 G2-8 P12 C1-8 NPL	3/8 Td-40 min	MOD and H SJ; 36.5 m and 60 m sprint and Dr UnS- > 1188 Os-30-180 s	G1 and G2-36.5 and 60 m sprint ↑ = 0.67 s and 0.7 s; and 0.8 s and 0.93 s, relative to C1, p < .05.	Both PI for 3/8 weeks leads to ↑ in basketball players for strength parameters, sprint and balance tests. Also, PI can lead to injury if due to great external load, which leads to micro trauma in the bones structure, ligaments and tendons.
7. Meszler & Vaczi (2019)	n = 18 F 15.7 years Basketball	G1-9 P1 C1-9 NPL C1-8 NPL	2/7 Td-20 min	MOD and H CMJ; sprint; VJ; DJ (25-50 cm); and Dr UnS- > 600 Os-120-300 s	G1-CMJ ↓ = 33.52 cm ± 3.89 to 31.96 cm ± 3.48 (-2.0 %) relative to C = 28.72 cm ± 6.66 to 29.06 cm ± 6.81, p < .007 and for kinetic parameters isometric contractions = between G1 and C1.	For 2/7 weeks PI ↑ contractile ability of quadriceps muscle, agility and jump capacity, and balance ↓ in basketball players. During the season, it is recommended to avoid additional high-intensity training.

8. Arede et al., (2019)	n = 16 M 15 years Basketball	G1-9 P1 C1-7 NPL	4/8 Td-35 min	MOD CMJ; DJ (30 cm); SJ; 10 m sprint; and Dr UnS- 1120 Os-15-120 s	G1-CMJ ↑ = 30.31 cm ± 3.48 to 32.34 cm ± 4.94 (6.2 % 90 % CL = -2; 13.0) relative to C1 = 29.45 cm ± 3.27 to 30.56 cm ± 3.40 (3.8 % 90 % CL = 2.1; 5.5); SJ ↑ = 27.24 cm ± 2.91 to 29.37 cm ± 3.72 (7.6 % 90 % CI 0.8; 14.8) relative to C1 = 26.92 cm ± 2.95 to 27.45 cm ± 3.22 (1.9 % 90 % CI = 2.0; 6.0), and 10 m sprint ↑ = 2.3 s ± 0.11 to 1.95 s ± .07 (-4.9 % 90% CI = 0.9; -8.7) relative to C1 2.03 s ± 0.12 to 2.10 s ± 0.12 (3.7 % 90 % CI = 9.1; -1.5)	During the season, P1 with basketball training leads to ↑ in VJ and sprint relative to C in basketball players.
9. Bouteraa et al., (2020)	n = 26 F 16.5 years Basketball	G1-16 P1 C1-10 NPL	2/8 Td-45 min	MOD and H CMJ; SJ; 5 m, 10 m, 20 m sprint; DJ (30-60 cm); and Dr UnS- 794 Os-30-90 s	G1-SJ = 20.4 cm ± 3.9 to 22.5 cm ± 3.5, 10.3 % and C1 = 20.4 cm ± 2.5 to 20.0 cm ± 1.9 -1.81 %, and CMJ = 26.8 cm ± 3.8 to 28.8 cm ± 3.3, 7.3 % and C1 25.2 cm ± 2.9 to 24.4 cm ± 3.1, -3.52 % (p = .58, d = .006), relative to C1 for SJ = (p = .19, d = .035) and for CMJ (p = .14, d = .044). DJ ↑ 24.7 cm ± 2.9 to 28.4 cm ± 3.0, 15.2 % and for C1 = 24.8 cm ± 1.9 to 24.6 cm ± 2.8, -0.75 % (p = .02, d = .09) relative to C1, and from beginning to the end in G1-(p = .001, d = 2.1). G1-5 m, 10 m and 20 m sprint = (p = .05; d = .068, .063, and .064), relative to C1.	Additional 2/8 weeks of P1 in season leads to ↑ in DJ, balance and agility in female basketball players relative to effects of only basketball training.
10. Fontenay et al., (2013)	n = 18 F 15.5 years Basketball	G1-8 P11 G2-4 P12 C1-6 NPL	3/8 Td-80 min	MOD and H HJ; VJ; and DJ (31 cm); Dr UnS- > 420 Os-20-50 s	G1-VJ ↑ for 12 % relative to G2 and C1, and kinetic parameters = between groups just 36 % ↓ in dynamic vagus.	PL can contribute to a combination of injury prevention and improvement of sport performance, compared to a normal basketball training program.

11. Mackala & Fostiak, (2015)	n = 14 M 18 years Track and field-sprint	3/2 Td-90 min	H CMJ; SJ; HJ; VJ; 20 m and 60 m sprint; and Dr UnS- 1:311 Os-60-360 s	G1-CMJ ↑ Mean = 73.93 cm ± 5.03 to 81.57 cm ± 5.60, dif = 7.643 p = .00 CI 95 % = 9.406 to 5.880, for SJ ↑ Mean = 62.86 cm ± 4.29 to 69.43 cm ± 5.68, dif = 6.571 p = .00 CI 95 % = 8.365 to 4.778, for HJ ↑ Mean = 2.89 m ± 0.11 to 2.96 m ± 0.10, dif = .069 p = .00 CI 95 % = .091 to .048, 60 m sprint ↓ Mean = 7.10 s ± .12 to 7.04 s ± .11, dif = .061 p = .00 CI 95 % = .048 to .075, and velocity of strides ↑ for 1.8 %.	PI (180 to 250 jumps) in high intensity, for 3/2 is sufficient to lead ↑ in explosive power of lower extremities of VJ and HJ. Improvement in VJ is larger relative to HJ which is visible in 20 m.
12. Chelly Hermassi & Shephard, (2015)	n = 27 M 12.1 years Track and field-sprint	2/10 Td-90 min	H CMJ; SJ; DJ (30 cm); 10 m and 50 m sprint; and Dr UnS- 600 Os-60 s	G1-CMJ ↑ = 0.23 m ± .03 to 0.25 m ± .03 relative to C1 = .21 m ± .03 to .22 m ± .03, for SJ ↑ = .21 m ± 2.8 to .24 m ± .03 relative to C1 = .20 m ± .02 to .21 m ± .02, for DJ ↑ = .22 m ± .3 to .25 m ± .02 relative to C1 = .20 m ± .02 to .20 m ± .02, p < .01-.001. G1-5 m sprint ↑ = 2.0 m/s ± .5 to 2.2 m/s ± .05 relative to C1 = 2.3 m/s ± .6 to 2.4 m/s ± .5, p < .01, and G1-kinetic parameters, strength during DJ relative to BM = 28.5 W ± 5.2 to 33.3 W ± 4.6 relative to C1 = 24.8 W ± 4.2 to 25.5 W ± 4.3, p < .01	Additional PI during the standard training season, leads to ↑ in sport performance compared to NPI in sprinters
13. Mackala et al., (2019)	n = 14 M 18.1 years Track and field-sprint	2-3/4 Td-90 min	H CMJ; HJ; 20 m, 40 m and 60 m sprint; and Dr UnS-x Os-60-360 s	G1-7 PI G2-7 PI G1-CMJ- ↑ = 76.43 cm ± 4.89 to 82.71 cm ± 5.34, dif = 6.29 cm, p = .00 CI %, -7.862 to -4.709 and in G2-CMJ- ↑ = 81.57 cm ± 2.57 to 87.86 cm ± 1.07, dif = 6.28, p = .001, CI %, -8.189 to -4.382, G1-HJ- ↑ = 2.91 m ± .06 to 2.99 m ± .07, dif = .08 m, p = .002, CI %, -.120 to -.039 and in G2-HJ- ↑ = 3.15 m ± .10 to 3.23 m ± .11, dif = .07 m, p = .007, CI %,	PI for 2-3/4 is sufficient to lead to ↑ in 60 m and 20 m sprint like as to for lower extremities in explosive power determined through VJ and HJ scores. Concludes that there is larger progress in CMJ for (7.95%) relative to

14. El-Ashker et al., (2019)	n = 18 M 19.5 years Track and field-sprint	G1-18 P1 C1-10 NPI	3/8 Td-90 min	H CMJ; VJ; HJ; 30 m and 60 m sprint; and Dr UnS- >860 Os-x	-1.18 to -.027, and G1-20 m sprint ↓ = .06 s and G2- ↓ = .11 s, G1-60 m sprint ↓ = .08 s, and G2- ↓ = .06 s, p < .05. G1-30 m sprint ↓ = F (1, 26) = 55, p = .00, nᵖ = 67, HJ ↑ = F (1, 26) = 37.3, p = .00, nᵖ = 59, VJ ↑ = F (1, 26) = 11.5, p = .00, nᵖ = 30, and kinetic parameters H and V and t of jump and flight ↑, compared to C1, and, when comparing pre- and post-values. Between G1 and G2 = in all parameters, G1-CMJ ↑ = 50.8 cm ± 9.0 to 54.6 cm ± 8.5, dif = 7.9 % and G2 ↑ = 52.8 cm ± 11.5 to 58.4 cm ± 9.3, dif = 12.9 %, for G1-SJ- ↑ = 38.7 cm ± 7.7 to 45.8 cm ± 7.4, dif = 19.8 % and G2- ↑ = 40.4 cm ± 10.2 to 47.1 cm ± 10.0, dif = 18.6 %, for G1-40 m sprint ↑ = 5.49 s ± 0.38 to 5.56 s ± 0.22 dif = 1.7 % and G2- ↓ = 5.48 s ± 0.22 to 5.44 s ± 0.20, dif = 0.8 %, and Dr parameters and the like kinetic ↑ between G1 and G2 relative to C1, p < .05	Pl is more effective ↑ in lower extremities for explosive P and VJ, compared to a traditional jump training program. Both programs have equal effects on different sport parameters such as jumps, sprints, throwing and lifting.
15. Lyttle et al., (1996)	n = 33 M 23.9 years Track and field, swimmers and rugby players	G1-11 P11 G2-11 P12 C1-11 NT	2/8 Td-45 min	MOD and H CMJ; VJ; SJ; DJ (20-60 cm); 20 and 40 m sprint; and Dr UnS- G1-496 and G2-680 Os-180-300 s		

Legends: n – Number of participants; M – Male; F – Female; Dr – Other program; G(1, 2) – Experimental group; C(1,2) – Control group; UnS – Total number of jumps in the program; Td – Duration of training; NT – No training; NPI – Nonplyometric program; PI – Plyometric program; CMJ – Countermovement jump without arm swing; CMJa – Countermovement jump with arm swing; SJ – Squat jump; DJ – Drop jump; VJ – Vertical jump on box; HJ – Standing long jump; Mean – Mean value; x – No data.; m – Meter; cm – Centimeter; s – Seconds; L – Low intensity; MOD – Moderate intensity; H – High intensity; = – No change or differences; ↑ – Increasing; ↓ – Decreasing; CI – Confidence interval; p – Statistical significance; dif – Differences; BM – Body weight; W – Watt; t – Time.

4. DISCUSSION

The aim of this systematic review was to collect and analyze studies with effects of plyometric programs on the biomechanical parameters of junior age groups of athletes. Table 2 shows the results of 15 studies which met the set inclusion criteria. The duration of the studies ranged from two to 12 weeks. The shortest study lasted two weeks, Mackala & Fostiak (2015), the longest 12, Idrizovic, Gjinovci, Sekulic et al., (2018), while the most frequent duration was eight weeks (nine studies) (Lyttle, Wilson, & Ostrowski, 1996; Newton, Kraemer, & Haekkinen, 1999; Fontenay, Lebon, Champely, et al., 2013; Arazi & Asadi, 2011; Usman & Shenoy, 2015; Arede, Vaz, Franceschi, Gonzalo-Skok, & Leite, 2018; El-Ashker, Hassan, Taiar, & Tilp, 2019; Bouteraa, Negra, Shephard, & Chelly, 2020). There was one study each of four weeks (Mackala, Fostiak, Schweyen, Osik, & Coch, 2019), five weeks (Krističević, Krakán, & Baić, 2016), six weeks (Martel, Harmer, Logan, & Parker, 2005), seven weeks (Meszler & Vaczi, 2019), and ten weeks (Chelly, Hermassi, & Shephard, 2015). The training frequency ranged from one to four training sessions a week, while the duration of the sessions ranged from 20 to 90 min. The most frequent duration was from 45 to 60 min. The training intensity ranged from low to high, and was most often moderate and high. Due to a lack of studies on the topic, a study from 1996 was included in the analysis (Lyttle, Wilson, & Ostrowski, 1996). In addition to targeted factors which studied the level of explosive power and speed, all the studies also included some form of specific exercises which were then measured.

One study indicated weak results of an eight-week plyometric exercise program with a frequency of two times a week (Meszler & Vaczi, 2019). The authors studied 18 female basketball players aged 15.7 years. Even though moderate and high intensity training sessions were carried out with an optimum number of all jumps (600), the duration of the training sessions was only 20 min. The parameters of the CMJ ($33.52 \text{ cm} \pm 3.89 \text{ cm}$) decreased by 2.0 % to $31.96 \text{ cm} \pm 3.48 \text{ cm}$ compared to the control group which displayed similar results (from $28.72 \text{ cm} \pm 6.66 \text{ cm}$ to $29.06 \text{ cm} \pm 6.81 \text{ cm}$, $p < .007$). The researchers also studied kinetic parameters during isometric contractions, where no significant changes between the groups were noted.

In an eight-week study which analyzed the effect of a plyometric program on 26 junior female basketball players, Bouteraa et al. (2020) noted no significant improvement in the studied parameters of the CMJ, the squat jump, and sprint speed compared to the control group. Even though the training session duration was an optimum 45 min, and the sessions were of moderately high intensity with a greater number of jumps (794) than in the previous study (7), the results from the initial measurement ($24.7 \text{ cm} \pm 2.9 \text{ cm}$ to $28.4 \text{ cm} \pm 3.0 \text{ cm}$) showed a 15.2 % increase only in the values of the depth jump. The control group followed a different training program without any noted change (from $24.8 \text{ cm} \pm 1.9 \text{ cm}$ to $24.6 \text{ cm} \pm 2.8 \text{ cm}$, -0.75% , $p = .02$, $d = .09$).

Contrary to the length and success of the previous two studies, the plyometric program outlined in Mackala & Fostiak (2015) lasted only two weeks and led to a significant improvement in all the accompanying parameters. The researchers studied 14 junior sprinters who trained at high intensity three times a week for 90 min. Even though the program was shorter, it had a greater overall number of jumps (1.311), which could be a sign of significant progress. The values of CMJ are represented as the means for all the participants, and indicate an improvement of 7.64 cm compared to the initial measuring

(73.93 cm \pm 5.03 cm, $p = .00$). For the squat jump, an improvement of 6.57 cm, $p = .00$ was noted compared to the initial value of 62.86 cm \pm 4.29 cm, and for the standing high jump 2.89 m \pm 0.11 m to 2.96 m \pm 0.10 m, $p = .00$. In the case of sprint test times at 60 m, the time was significantly reduced from 7.10 s \pm 0.12 s to 7.04 s \pm 0.11 s, $p = .00$, while the speed of the steps improved by 1.8 %, $p = .00$.

The greatest improvements were noted for the longest study, Idrizovic et al. (2018), which involved 47 junior female volleyball. The program lasted 12 weeks, with training sessions two times a week for 60 min. The plyometric program consisted of a low, moderate, and high intensity exercises, and included 613 different jumps. This led to an improvement in the values of the 20 m sprint by 5.7 %, as well as in the CMJ by 16.9 %, all compared to the control group. When the results are presented in Effect size values, for the 20 m sprint test the plyometric program led to ($\eta^2 = .09$) low ES, and for the CMJ ($\eta^2 = .29$) low ES, compared to the other group that trained following a different type of jump training.

The study with the highest frequency plyometric training of four times a week for eight weeks included 16 junior female basketball players (Arede et al., 2019). With somewhat shorter training sessions, 35 minutes of moderate intensity training, the players reached 1.120 jumps, which led to an improvement in all the accompanying variables. For the CMJ, the initial measurement of 30.31 cm \pm 3.48 cm significantly improved to 32.34 cm \pm 4.94 cm, that is, increased by 6.2 % compared to the control group which showed a 3.8 % improvement (from 29.45 cm \pm 3.27 cm to 30.56 cm \pm 3.40 cm). The squat jump showed the greatest improvement of 7.6 % (27.24 cm \pm 2.91 cm to 29.37 cm \pm 3.72 cm), compared to the improvement of 1.9 % noted for the control group (from 26.92 cm \pm 2.95 cm to 27.45 cm \pm 3.22 cm). The sprint time test at 10m decreased by 4.9 % (90 % CL -0.9; -8.7), compared to the control group for which a decrease of 3.7 % was noted (90 % CL 9.1; -1.5).

One of two studies that recorded the greatest height of the depth jump of 30 – 80 cm, Newton et al. (1999), noted an improvement in takeoff height of 5.9 % \pm 3.1 compared to the control group (-1.3% \pm 2.5, $p < .001$). Eight junior basketball players achieved this improvement during an eight-week plyometric exercise program of moderate and high intensity, exercising two times a week, and performing at least 576 different jumps. Furthermore, the studied kinetic parameters of the CMJ and the squat jump showed no changes except for duration of contact time (14.6% \pm 9.7) and flight time (-4.7 % \pm 3.4) compared to the control group ($p = .006$ and $p = .01$, respectively). Usman & Shenoy (2015), who noted the second greatest height, analyzed mostly junior volleyball players (120) during an eight-week plyometric program which included the highest number of various jumps, more than 2.976. Low, moderate and high intensity exercise led to an improvement in both plyometric groups for takeoff height: 67.33 cm \pm 1.64 cm for the first experimental group compared to the control group, 57.22 cm \pm 1.06 cm; and 50.08 cm \pm 1.83 cm for the second experimental group compared to the control group, 42.36 cm \pm 1.07 cm, $p < .001$. Unlike Usman & Shenoy (2015), whose study recorded the most jumps during training, the fewest jumps were recorded by Martel et al. (2005), only 138 different jumps of high intensity. They recorded one of the greatest improvements for the CMJ (11.1 % compared to the 4.0 % improvement recorded for the control group, $p < .05$). Ten junior volleyball players achieved this improvement following a six-week exercise program with sessions twice a week. During a single 60 min training session they relied on 30 s breaks between series and optimum height of the depth jump of 61 cm.

Even though Krističević et al. (2016) recorded the fewest training sessions, five during the course of five weeks, significant positive effects were still noted among 27 (of the 54) junior female volleyball players. Through moderate and high-intensity exercise they performed more than 645 different jumps, which led to an improvement in the squat jump. The results were presented as the means of all the jumps: the values for the experimental group at the beginning were $21.80 \text{ cm} \pm 4.22 \text{ cm}$ and by the end were $24.28 \text{ cm} \pm 3.48 \text{ cm}$, compared to the control group whose values ranged from $24.32 \text{ cm} \pm 4.10 \text{ cm}$ to $24.8 \text{ cm} \pm 4.09 \text{ cm}$. For the CMJ the values were initially $28.08 \text{ cm} \pm 4.83 \text{ cm}$ and went up to $30.72 \text{ cm} \pm 3.74 \text{ cm}$, compared to the control group whose values ranged from $33.04 \text{ cm} \pm 6.18 \text{ cm}$ from $33.32 \text{ cm} \pm 5.62 \text{ cm}$, $p < .05$.

In addition, the youngest twelve-year-old sprinters managed to improve their performance during a ten-week high intensity plyometric program, where they exercised twice a week and performed 600 different jumps. The CMJ values for the sprinters went from $0.23 \text{ m} \pm .03 \text{ m}$ at the initial measurement to $.25 \text{ m} \pm 0.03 \text{ m}$ at the final, compared to the control group whose values ranged from $.21 \text{ m} \pm 0.03 \text{ m}$ to $.22 \text{ m} \pm .03 \text{ m}$; for the squat jump test the values went from $.21 \text{ m} \pm 2.8 \text{ m}$ to $.24 \text{ m} \pm .03 \text{ m}$, compared to the values of the control group which ranged from $.20 \text{ m} \pm .02 \text{ m}$ to $.21 \text{ m} \pm .02 \text{ m}$; for the 30 cm depth jump the values ranged from $.22 \text{ m} \pm .3 \text{ m}$ to $.25 \text{ m} \pm .02 \text{ m}$, compared to the control group which ranged from $.20 \text{ m} \pm .02 \text{ m}$ to $.20 \text{ m} \pm .02 \text{ m}$, $p < .01-.001$; for the sprint test at 5 m, the sprint speed went from $2.0 \text{ m/s} \pm .5 \text{ m/s}$ to $2.2 \text{ m/s} \pm .05 \text{ m/s}$, compared to the control group whose values ranged from $2.3 \text{ m/s} \pm .6 \text{ m/s}$ to $2.4 \text{ m/s} \pm .5 \text{ m/s}$, $p < .01$. The kinetic parameter of strength, measured in relation to the weight of the participants, also indicated positive changes during the depth jump: $28.5 \text{ W} \pm 5.2 \text{ W}$ to $33.3 \text{ W} \pm 4.6 \text{ W}$, compared to the control group with values of $24.8 \text{ W} \pm 4.2 \text{ W}$ to $25.5 \text{ W} \pm 4.3 \text{ W}$, $p < .01$ (Chelly et al., 2015).

Unlike the youngest participants, the oldest, aged 23.9 years, also experienced positive effects following a moderate and high intensity eight-week plyometric exercise program. The optimum number of over 680 different jumps was noted for two groups which were equal in number of participants (11). Various plyometric programs led to an improvement in relation to the control group, but not between the two groups. For the first group, an improvement of 7.9 % was noted for the CMJ, while for the second group it was 12.9 %; for the squat jump, the first group improved by 19.8 % and the second by 18.6 %; for the 40 m sprint test, the first group improved by 1.7 % while the second by 0.8 %; the kinetic parameters compared to the control group also differed, $p < .05$ (Lyttle, Wilson, & Ostrowski, 1996).

For seven to 12 weeks, two or four times a week, researchers analyzed the performance of basketball players (Arazi & Asadi, 2011; Fontenay et al., 2013; Arede, Vaz, Franceschi, Gonzalo-Skok, & Leite, 2018; Meszler & Vaczi, 2019; Bouteraa, Negra, Shephard, & Chelly, 2020), volleyball players (Newton, Kraemer, & Haekkinen, 1999; Usman & Shenoy, 2015; Idrizovic, Gjinovci, Sekulic et al., 2018), and track and field athletes (Lyttle, Wilson, & Ostrowski, 1996; Chelly et al., 2015; El-Ashker et al., 2019) of both genders, and obtained mixed results. The improvement for the CMJ ranged from 6.2 % to 16.9 %, while for the SJ it was 7.6 % to 19.8 % (the upper values of progress for CMJ were measured in the study which included exercise programs during the off season). Programs of a shorter duration, lasting from three to six weeks, which gave individual results with positive effects in all the parameters, led to a greater improvement in the vertical jump tests compared to horizontal jump tests (Martel et al., 2005;

Krističević et al., 2016; Mackala et al., 2019). The CMJ improved from 6, 3 % to 9, 1 % and the SJ 6, 6 % to 8, 9 %. These studies were carried out during the competitive season of the participants. The duration of training sessions, ranging from 20 to 90 min, is directly related to the intensity of the training and number of jumps. Shorter training sessions are high intensity with a smaller number of jumps, while longer training sessions are moderate and high intensity with a smaller number of jumps (more than 138 in the study of Martel et al., 2005, and up to more than 2976 in the study of Usman & Shenoy, 2015). The most frequent duration of a training sessions is 45 to 60 min, with high intensity, and 600 to 900 different jumps.

5. CONCLUSION

It can be concluded based on the results of 15 included studies that the plyometric way of training has positive effects on the biomechanical parameters of junior age groups of athletes. Greater progress of these athletes was noted following plyometric programs that lasted for more than eight weeks. The weekly training frequency and the intensity of exercise have a decisive influence on improving the performance of athletes. Also, longer programs, of a moderate and high intensity and training sessions from 45 to 60 min, enable the best progress, regardless of sport. No differences in the development of biomechanical parameters between the three sports was noted.

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EFEKTI PLIOMETRIJSKIH PROGRAMA NA BIOMEHANIČKE PARAMETRE ATLETSKIH DISCIPLINA, KOŠARKE I ODBOJKE: SISTEMATSKI PREGLED

Pliometrijski pokret služi za poboljšanje mišićnih performansi sportiste i koristi se u pliometrskom načinu treniranja koji je nezaobilazni princip treninga razvoja eksplozivne snage i brzine. Cilj ovog istraživanja je utvrđivanje efekta pliometrijskih programa na biomehaničke parametre i njihove razlike, u tri sporta juniorskog uzrasta pomoću sistematske analize dosadašnjih rezultata. Za pretraživanje literature korišćene su sledeće elektronske baze: PubMed, MEDLINE, Google Scholar, ScienceDirect, ERIC od 1996. do 2022. Sumirani su rezultati iz 15 uključujućih studija koje su detaljno prikazani u tabeli. Rezultati uključenih studija pokazuju pozitivne efekte pliometrijskih programa na biomehaničke parametre podjednako kod tri sporta. Opseg dužine treninga iznosi od 20 min do 90 min, i u direktnom odnosu je sa intezitetom treninga i brojem skokova. Kraći treninzi su u veoma visokom intezitetu sa manjim brojem skokova, dok su duži treninzi sa umerenim i visokim intezitetom i manjim brojem skokova (više od 138 do više od 2976). Najčešća dužina trajanja treninga je 45 min do 60 min u visokom intezitetu sa 600 do 900 različitih skokova. Veći napredak eksplozivne snage i brzine vidljiv je u parametrima testova sprinta i skokova; programi od sedam do 12 nedelja sa dva do četiri puta u toku nedelje (SMJ 6,2% do 16,9%, dok za SJ i 7,6% do 19,8%), programi sa kraćom dužinom trajanja, od tri do šest nedelja (SMJ 6,3% do 9,1% a za SJ 6,6% do 8,9%). Zaključuje se da duži programi, sa umerenim i visokim intezitetom i trajanjem treninga od 45 min do 60 min daju najbolje napretke bez obzira na sport.

Ključne reči: pliometrijski trening, efekti, biomehanika, atletske discipline, košarka, odbojka