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Research article

Effects of Plyometric Training on Neuromuscular Performance in Youth Basketball Players: A Pilot Study on the Influence of Drill Randomization

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Abstract

The aim of this single-blind randomized controlled trial was to compare the effects of plyometric jump training (PJT), with (RG) and without (NRG) between-session drill randomization, on performance measures (i.e., jumping and sprinting abilities, change of direction speed, and technical performance) in youth male basketball players (age, 10.2 ± 1.7 years), assigned to either the NRG (n = 7), RG (n = 6), or control group (n = 6). Before and after the intervention, countermovement jump, 20-cm drop jump, 30-m sprint (with or without ball dribbling), and change-of-direction speed tests were completed. The PJT was applied twice per week for seven weeks. The only difference between PJT groups was the order of drill execution. An ANOVA was used to detect differences between study groups. The analyses revealed significant main effects of time (all p<.01; d = 0.64-0.89) and group x time interaction (all p<.05; d=0.31-51) for all examined variables. Post hoc analyses revealed moderate-large significant improvements for the RG (countermovement jump: 18.8%, d = 0.6; 20-cm drop jump: 23.9%, d = 0.80; 30-m sprint: 11.6%, d = 1.13; 30-m sprint with ball dribbling: 9.3%, d = 0.54; change of direction speed test: 14.6%, d = 1.82). In contrast, post hoc analyses revealed only small improvements for the NRG (20-cm drop jump: 14.1%, d = 0.36; 30-m sprint: 6.8%, d = 0.45; 30-m sprint with ball dribbling: 8.8%, d = 0.35; change of direction speed test: 10.5%, d = 0.49). Application of PJT without randomization is effective for improving physical and technical qualities. However, PJT could be more beneficial when executed with between-session randomization of drills.

Key words: Explosive training, ballistic training, team sport, stretch-shortening cycle, maturation.

Introduction

Basketball is a high-intensity team sport requiring jump, sprint, and change of direction abilities, and demanding technical and tactical skills (Stojanovic et al., 2018; Taylor et al., 2017). Therefore, designing optimal training programs aimed at improving these qualities is of paramount importance for coaches and sport scientists. In this context, plyometric jump training (PJT) has been shown to induce meaningful improvements in jumping, sprinting, change of direction speed, and technical abilities (Shallaby, 2010). Among youth basketball players, PJT has also been shown to be effective in improving the aforementioned physical characteristics (Matavulj et al., 2001; Shallaby, 2010). However, the optimization of PJT programs and a better understanding about different plyometric training schemes and their possible influence on performance deserve further investigation. Some studies have demonstrated the importance of PJT specificity (Ramirez-Campillo et al., 2015a; 2015b) and volume-overload (Ramirez-Campillo et al., 2015c) among other relevant training factors (de Villarreal et al., 2009). However, it is still unknown if “training variability” (i.e., changing the order of plyometric drills within the session) may affect the adaptations provided by a PJT program.

For example, in resistance training, a programmed variation in training schemes (i.e., varying training loads and exercises) seems to exert an important stimulus, especially during long-term training interventions (Hartmann et al., 2015). Indeed, when the order of resistance training workouts was compared, variable acute responses relating to neuromuscular fatigue, lactate, and rating of perceived exertion (RPE) (Soares et al., 2016) were observed in addition to differences in long-term adaptation (Assumpcao et al., 2013; Simao et al., 2010). Regarding PJT studies, some training interventions have used a randomization approach, suggesting that this strategy could significantly optimize chronic adaptations (Ramirez-Campillo et al., 2016b; Rosas et al., 2016). On the contrary, other works have implemented only PJT interventions without drill randomization or modification throughout the interventional period (Kobal et al., 2017). Since the variation in training loads and stimulus seems to be very important for the effectiveness of a given training program (Assumpcao et al., 2013; Simao et al., 2010; Soares et al., 2016), it needs to be established whether randomization in training protocols during PJT would induce different adaptations when compared to a traditional pre-programmed PJT. This is especially important for youth athletes, who need to progressively develop their physical and technical abilities from the early stages of development.

To address the described issue, the aim of this single-blind randomized controlled trial was to compare the effects of PJT, with and without between-session drill randomization, on specific performance (i.e., jumping, sprint time, change of direction speed, and technical performance) of youth male basketball players. It was hypothesized that both PJT with and without drill randomization would improve youth basketball players’ performance, although the improvement would be greater with a between-

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session drill randomization approach.

Methods

Participants

After parents or legal guardians providing a written informed consent form, nineteen male youth basketball players participated in this study. Due to the age of the participants (10.2 ± 1.7 years), they had no specific positions in the team. Participants underwent no regular strength training or PJT during the three-month period prior to the intervention, although they regularly performed basketball training. The sample size was determined according to changes in vertical jump performance in a group of team-sport players submitted to control (Δ = 0.5 cm; SD = 1.1) or short-term PJT (Δ = 2.6 cm; SD = 1.6) conditions (Ramirez-Campillo et al., 2015a) comparable with those adopted in this study. Six participants per group would yield a power of 80% and $\alpha<0.05$, with a detectable effect size (ES) ≥ 0.2. Exclusion criteria included (a) potential medical problems that compromised participation or performance in the study, (b) any lower-extremity surgery in the previous two years, and (c) ≤ 1 year of systematic basketball practice and competition. Based on these criteria, six participants were excluded. The participants included in the study were randomly assigned to either the PJT group without plyometric drill randomization (NRG, n = 7), PJT group with plyometric drill randomization (RG, n = 6), or a control group that performed solely the regular technical and tactical basketball training (CONTROL, n = 6). The randomization sequence was generated electronically (https://www.randomizer.org) and concealed until interventions were assigned. At baseline, no differences were observed in any descriptive (or dependent) variable between groups (Table 1). The study was conducted in accordance with the Declaration of Helsinki and was approved by the Local Ethics Committee.

Study design

This is a randomized single-blind controlled (i.e., active controls) study. Participants were familiar with the testing procedures, as they were a regular aspect of their training schedule. Measurements were taken one week before and after intervention and were completed in one day. All assessments were administered in the same order, at the same period of the day, and by the same experienced researchers, blinded to each participant's group assignment.

After height and body mass measurements, athletes completed ten minutes of a standard warm-up (Andrade et al., 2015) before countermovement jump, 20-cm drop jump, 30-m sprint, with and without ball dribbling, and change-of-direction speed (i.e., T-test) tests. Three maximal trials were allowed for all tests. At least two minutes of rest were permitted between each maximal trial to reduce possible effects of fatigue. Anthropometric measurements were taken using a stadiometer (Bodymeter 206, SECA, Hamburg, Germany) and weighing scales (InBody120, model BPM040S12F07, Biospace, Inc., USA, to 0.1 kg). The protocols for the jumps, 30-m sprint, change-of-direction speed (Asadi et al., 2017), and 30-m sprint with ball dribbling (Shallaby, 2010) tests were performed as previously described.

Vertical jumps

Briefly, for the jumps, players executed maximal effort jumps with arms akimbo on a contact mat (Ergojump; Globus, Codogne, Italy), with the obtained flight time (t) being used to estimate the height of the rise of the body's centre of gravity (h) during the vertical jump (i.e., $h = gt^2/8$, where $g = 9.81\ m \cdot s^{-2}$). Take-off and landing were standardized to full knee and ankle extension on the same spot. In addition, for the 20-cm drop jump, players were instructed to minimize ground contact time after dropping down from a 20 cm drop box.

Sprint performance

The sprint time was assessed to the nearest 0.01 s using timing gates (Brower Timing System, Salt Lake City, UT). For the 30-m sprints with and without ball dribbling, participants performed from a standing start with the toe of the preferred foot forward just behind the starting line. Timing began when athletes voluntarily initiated movement, triggering the timing apparatus. The timing gates were positioned at the beginning (0.3 m in front of the starting line) and at 30-m and were set ~0.7 m above the floor (i.e., hip level), to ensure the capturing of trunk movement rather than a premature trigger from a limb. The fastest sprint was considered for analysis.

Change-of-direction T-Test

The change-of-direction test was performed over a T-shaped course (Figure 1), by starting 0.3-m behind the timing gates (Brower Timing System, Salt Lake City, UT). The athletes started running forward 9.14-m, touched their hand on a cone and moved 4.57-m to the left in lateral shuffling and touched a cone. Next, they moved 9.14-m to the right in lateral shuffling and touched another cone. Finally, the athletes moved to the left 4.57-m, still in lateral shuffling, touched a cone and ran backwards a further 9.14-m in the direction of the starting line to finish the test. The test was repeated if an athlete failed in touch a cone or crossed his or her feet during the sidestep phases. The fastest of three trials was recorded as the criterion score.

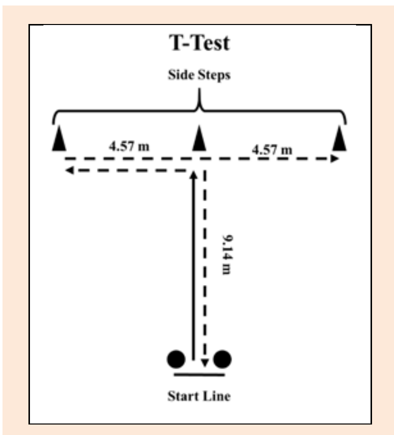

Figure 1. Schematic presentation of the T-test. Circles represent the position of the timing gates.

Table 1. Descriptive data of the control group (CONTROL, n = 6), non-randomized plyometric training group (NRG, n = 6) and randomized plyometric training group (RG, n = 7) and total training load accumulated during the interventional period.

	CONTROL	NRG	RG
Age (y)	9.7 ± 2.0	10.0 ± 1.5	11.0 ± 1.7
Body mass (kg)	39.4 ± 5.7	36.3 ± 5.8	38.3 ± 11.3
Height (m)	1.44 ± 0.08	1.41 ± 0.09	1.42 ± 0.1
Body mass index (kg·m^{-2})	19.1 ± 1.4	18.3 ± 1.0	18.6 ± 1.6
Session rating of perceived exertion (a.u.)[a]	440 ± 270	540 ± 346	583 ± 313

[a]Basketball training load was determined by multiplying the minutes of basketball training by the rating of perceived exertion after a randomly selected basketball training session.

Table 2. Plyometric jump training program for the non-randomized group across the seven weeks of intervention.

Exercises	Weeks						
	1	2	3	4	5	6	7
Wall jump (rep)	5	6	7	8	9	10	5
180° jump (rep)	4	6	8	10	12	14	4
Broad jump and hold (rep)	5	6	7	8	9	10	5
Bounding in place (rep per leg)	5	6	7	8	9	10	5
Bounding for distance (rep per leg)	5	6	7	8	9	10	5
Single leg hop and hold (rep per leg)	5	6	7	8	9	10	5
Lunge jump (rep)	4	6	8	10	12	14	4
Crossover hops (rep per leg)	5	6	7	8	9	10	5
Single-leg clock hop (rep per leg)	4	4	8	8	12	16	4
20-cm drop jumps (rep)	5	6	7	8	9	10	5

*For the randomized group the order of exercises for each session was randomized; rep: repetitions.

Training protocols

For both groups, the experiments were conducted during the competitive period (i.e., mid portion of the in-season). The participants also performed the same basketball training program, and the training loads were measured at a randomly assigned training session using RPE as previously described (Ramirez-Campillo et al., 2016a) (Table 1). Participants in the PJT groups performed plyometric drills immediately after the warm-up (Andrade et al., 2015) and as a substitute for some basketball drills (i.e., technical–tactical), within the usual 120-min practice, twice per week for seven weeks. The PJT intervention was determined based on previous research with youth team and basketball players (Carrasco-Huenulef et al., 2018, Ramirez-Campillo et al., 2015a; 2016a). A detailed description of the PJT program can be found in Table 2.

Briefly, PJT included unilateral, bilateral, horizontal, vertical, lateral, diagonal, turning, backward, cyclic, and acyclic jumps. Participants were encouraged to exert maximal effort for every jump and were instructed to aim toward maximal vertical heights and horizontal distances for acyclic jumps and minimum ground contact times for cyclic jumps (e.g., drop jumps). Before the training period, participants completed technical-oriented familiarization sessions for all the exercises completed in the PJT program (i.e., two sessions per week for two weeks before baseline measurements). All familiarization and training sessions were supervised with a coach to player ratio of 1:3-4, with particular attention paid to technique and individualized overload progression, with a taper toward the final week of training. The PJT sessions were separated by a minimum of 48 h (including games). Each PJT group completed the same number of jumps, used the same surface (i.e., wooden floor) and time of day for training, and the same rest intervals between jumps (i.e., 5-s for acyclic jumps) and sets (i.e., 60-s). The only difference between PJT groups was the sequential order of the drills. For the NRG, the order of execution for each session was the same as depicted in Table 2 while for the RG the order of execution for each session was randomized.

Statistical analyses

Data are presented as group mean values ± standard deviations. Analyses of variance (ANOVA) were used to detect differences between study groups in all variables for baseline and follow-up tests. Measures of dependent variables were analyzed with separate 3 (Groups) × 2 (Time: pre, post) ANOVA, with repeated measures on time. Post-hoc tests with a Bonferroni-adjustment were conducted to identify statistically significant comparisons. Effect sizes were determined and classified by calculating Cohen's d values (Cohen, 1988), as follows: small (d ≤ 0.49), medium (d = 0.50 to ≤ 0.79), and large effects (d ≥ 0.8) (Cohen, 1988). All analyses were carried out with STATISTICA statistical package (Version 8.0; StatSoft, Inc, Tulsa, USA). Significance levels were set at α = 5%.

Results

All participants carried out the training as allocated. No test or PJT-related injuries occurred over the course of the study. No significant between-group baseline differences were observed for any examined variable (Table 1 and Table 3). The main effects of group, time, and the group × time interaction are presented in Table 3 and relative (Δ) pre-post intervention changes are presented in Figure 2.

The analyses revealed significant main effects of time (all p<.01; d = 0.64-0.89) and group x time interaction (all p<.05; d = 0.31-51) for all examined variables. Post hoc analyses revealed significant (p<.05) improvements for the RG (CMJ: 18.8%, d = 0.6; 20-cm drop jump: 23.9%, d= 0.80; 30-m sprint: 11.6%, d = 1.13; 30-m sprint with ball dribbling: 9.3%, d=0.54; change of direction speed test: 14.6%, d = 1.82) compared to the NRG (CMJ: 12.0%, d = 0.43; 20-cm drop jump: 14.1%, d = 0.36; 30-m sprint: 6.8%, d = 0.45; 30-m sprint with ball dribbling: 4.6%, d = 0.19; change of direction speed test: 10.5%, d = 0.49), and significant (p<.05) improvements for the latter compared to the control group (CMJ: 5.7%, d = 0.17; 20-cm drop jump: 10.3%, d = 0.22; 30-m sprint: 3.7%, d = 0.22; 30-m sprint with ball dribbling: 1.6%, d = 0.11; change of direction speed test: 6.1%, d = 0.29).

Table 3. Physical fitness measures from pre- to post-training for the non-randomized plyometric training group (NRG, n=6), randomized plyometric training group (RG, n=7), and control group (CONTROL, n=6).

	NRG	RG	CONTROL	ANOVA outcomes: Group F(2, 16), p-value (ES)	ANOVA outcomes: Time F(1, 16), p-value (ES)	ANOVA outcomes: Group x Time F(2, 16), p-value (ES)
Countermovement jump (cm)						
Pre	24.1 ± 5.9	28.4 ± 8.3	26.2 ± 7.2	F=1.1,	F=33.9,	F=4.3,
Post	26.9 ± 5.8 #	33.5 ± 8.1 #*	27.5 ± 7.0	p=.4 (0.2)	p<.001 (0.68)	p<.03 (0.35)
20-cm drop jump (cm)						
Pre	19.6 ± 6.5	20.6 ± 5.1	21.5 ± 4.1	F=0.3,	F=75.0,	F=6.3,
Post	22.0 ± 6.0 #	25.4 ± 5.9 #*	23.5 ± 3.6	p=.8 (0.04)	p<.001 (0.82)	p<.01 (0.44)
Sprint 30-m (s)						
Pre	5.87 ± 0.51	5.71 ± 0.46	5.60 ± 0.38	F=0.7,	F=121.9,	F=4.6,
Post	5.48 ± 0.56 #	5.06 ± 0.52 #*	5.39 ± 0.39	p=.5 (0.09)	p<.001 (0.88)	p<.03 (0.37)
Sprint 30-m ball dribbling (s)						
Pre	7.57 ± 1.7	7.18 ± 1.1	6.82 ± 0.9	F=0.3,	F=28.6,	F=4.0,
Post	6.92 ± 1.6 #	6.52 ± 1.0 #*	6.70 ± 0.8	p=.8 (0.04)	p<.001 (0.64)	p<.05 (0.31)
T-Test (s)						
Pre	12.3 ± 1.1	12.1 ± 1.1	12.2 ± 0.9	F=0.7,	F=134.8,	F=8.2,
Post	11.0 ± 1.1 #	10.3 ± 0.7 #*	11.5 ± 1.1	p=.5 (0.08)	p<.001 (0.89)	p<.004 (0.51)

* denotes significantly greater improvement between the pre and post intervention period in the RG compared to the other groups. ES: effect size.
# denotes significant whiting-group improvement between the pre and post intervention period.

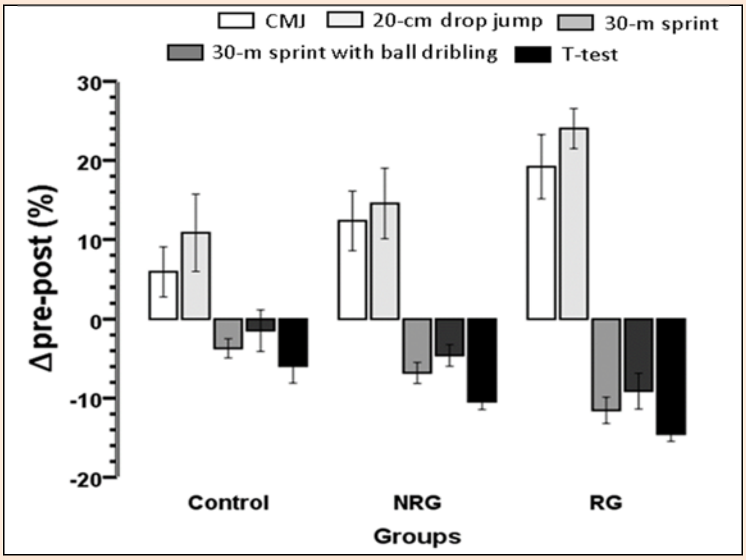

Figure 2. Relative (Δ) pre-post intervention changes in neuromuscular performance in youth basketball players assigned to a control group, or to a plyometric jump training intervention without (NRG) or with drill randomization (RG).

Discussion

The aim of this study was to compare the effects of PJT with and without between-session drill randomization on specific performance measures (i.e., jumping ability, sprint and change of direction speed, and technical performance) in youth male basketball players. As hypothesized, both PJT protocols (with and without drill randomization) were capable of enhancing young basketball players' performance; nonetheless, the improvements were greater in the RG than in the NRG.

Among youth basketball players, PJT has been shown to be effective for improving jumping capacity, sprint and change of direction speed, coordination, and technical abilities (Asadi, 2013; Matavulj et al., 2001; Shallaby, 2010). In this sense, some PJT studies have demonstrated the effects of manipulating volume-overload (Ramirez-Campillo et al., 2015c), and other relevant training variables on physical performance changes in athletes of different sports disciplines (de Villarreal et al., 2009). Others have demonstrated that a combination of jump drills executed horizontally and combined with vertical drills induced greater adaptations than when drills were executed only in vertical or horizontal planes (Ramirez-Campillo et al., 2015b). Similarly, a combination of jump drills executed unilaterally and bilaterally induced greater adaptations when compared with PJT programs executed only unilaterally or bilaterally (Ramirez-Campillo et al., 2015a). From a practical standpoint, these studies indirectly demonstrated that variation in drills might induce greater physical fitness adaptations in youth soccer players. However, these studies used different drills for different experimental groups. On the other hand, our methodological approach allows direct comparison between experimental groups exposed to the same drills with similar volume and intensity, differing only in the order in which these drills were executed. Under this design, we demonstrated that intra-session variability in PJT may induce larger increases in male youth basketball players' physical fitness than a traditional pre-programmed PJT.

In general, jumping ability is significantly improved after PJT interventions (Asadi, 2013; Asadi et al., 2017). Indeed, previous studies have observed improvements in jumping performance after interventions applied with (Ramirez-Campillo et al., 2016b; Rosas et al., 2016) or without (Kobal et al., 2017) PJT drill randomization between training sessions, although none of the aforementioned studies compared the effects of PJT with versus without drill randomization between sessions. Previous findings were corroborated in the current study, with both the RG and NRG presenting improved jumping performance in assessments involving elastic-energy components (i.e., CMJ) and reactive strength (i.e., DJ). However, the current study expands previous knowledge, showing that the improvements in jump tests were greater in the RG.

With regard to sprinting, improvements have been commonly reported after PJT interventions that incorporated horizontally oriented drills (Loturco et al., 2015; Ramirez-Campillo et al., 2015b), as in this study. However, in the current study, it is notable that the RG showed greater sprint speed enhancement in comparison to the NRG for both sprinting with and without the basketball. This suggests that performing PJT in a random fashion between sessions might enhance improvements in sprinting speed. Since maximal sprinting necessitates high levels of neural activation (Ross et al., 2001), repetitive-monotonous specific sequencing activities could induce central fatigue and impair neuromuscular capacities, which can, in turn, reduce sprinting speed (Rampinini et al., 2011; Rumpf et al., 2016; Sanchez-Sanchez et al., 2017). On the contrary, adequate variation in drills may enhance processes such as the temporal sequencing of muscle activation and rapid firing rates to recruit fast motor units, leading to optimal speed development (Seitz and Haff, 2016). Therefore, PJT performed in a monotonous way could lead to impaired transference of the benefits of jumping to sprinting abilities. We therefore conclude that to optimize increases in speed-related abilities, randomization of PJT drills between sessions may be an advantageous alternative.

As with linear sprint ability, change of direction speed has previously been observed to improve after PJT (Asadi et al., 2016; Ingle et al., 2006). However, in our study, only the RG presented improved performance to a large extent, whereas the NRG showed only moderate improvement. The ability to change direction directly depends on a number of neural and mechanical factors, such as sprinting speed (Ross et al., 2001; Rumpf et al., 2012). Hence, it would be reasonable to assume that PJT undertaken in a randomized fashion would further enhance the ability to change direction relative to the benefits of training in non-randomized and monotonous routines. In conclusion, traditional application of PJT (without randomization of drills) is effective for improving performance in physical and technical qualities. However, at least for youth male basketball players, this could be more beneficial when executed with between-session drill randomization.

This study is limited by the small number of subjects ($n = 19$); nonetheless, it is important to emphasize that the statistical power analysis revealed that six participants per group provided 80% power (at $\alpha < 0.05$) to detect an effect size of 0.2 when comparing changes in physical performance in youth basketball players. Therefore, this sample was appropriate to produce consistent and valid outcomes in our study. Finally, it is worth noting that this research was performed with competitive youth team-sport athletes during the "in-season training period", with all the inherent limitations related to this experimental design (i.e., number of players per team, training schedule, etc.).

Practical applications

The PJT program applied induced explosive adaptations, which could facilitate transference to game performance. Thus, a twice-weekly short-term high-intensity PJT program implemented as a substitute for some basketball drills within regular in-season basketball practice may enhance explosive performance in youth male basketball players compared with basketball training alone. These improvements are possibly maximized if PJT is conducted with jump drill randomization between training sessions. Considering that randomization of drills between training sessions may add variation and motivation, especially among youth athletes, we recommend that coaches conduct PJT with randomized jump drills within training sessions. Although in the current study we demonstrated that modifying the order of plyometric jump drills may be an effective strategy to maximize adaptations, an alternative strategy may be changing the type of exercise drill. However, with this latter training approach practitioners should consider that a proper learning period may be needed before increasing volume and intensity. One potential concern with this approach is that the execution of exercises that may not maximize power output at the beginning of the session could potentially reduce the performance of more complex jump drills later in the same session. Practitioners should be aware of the most important exercises in the PJT program and place them at the beginning of the training session. As a practical alternative to randomized drills coaches could categorize drills as primary, secondary, or complementary and randomize them within each category. Future studies may consider comparing the effects of PJT, modifying the order of plyometric jump drills versus changing the type of plyometric jump drills.

Conclusion

Application of PJT without randomization is effective for improving physical and technical qualities in youth basketball players. Nonetheless, PJT could be more beneficial when performed with between-session randomization of drills.

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Key points

- Plyometric training is an effective and safe strategy to improve physical performance in young basketball players;
- This training method seems to be more beneficial when executed with between-session randomization of drills;
- Plyometric drills randomization may add variation and motivation to training sessions, thus facilitating young athletes' training engagement;
- Plyometrics can be easily implemented during regular basketball training routines.

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