EFFECTS OF PROGRESSED AND NON-PROGRESSED VOLUME-BASED OVERLOAD PLYOMETRIC TRAINING ON COMPONENTS OF PHYSICAL FITNESS AND BODY COMPOSITION VARIABLES IN YOUTH MALE BASKETBALL PLAYERS

Running head: Plyometric training in basketball players

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ABSTRACT

This study examined the effect of six weeks of progressed and non-progressed volume-based overload plyometric training (PT) on components of physical fitness and body composition measures in young male basketball players, compared with an active control group. Participants were randomly assigned to a progressed PT (PPT, n=7; age=14.6±1.1 years), a non-progressed PT (NPPT, n=8, age=13.8±2.0 years), or a control group (CG, n=7, age=14.0±2.0 years). Before and after training, body composition measures (muscle-mass, fat-mass), countermovement-jump with (CMJA) and without arms (CMJ), horizontal bilateral (HCMJ) and unilateral jump with right (RJ) and left (LJ) legs, 20-cm drop-jump (DJ20), sprint speed (10 m sprint), and change-of-direction speed (CODS [i.e., T-test]) were tested. ***Results:*** Significant effects of time were observed for muscle- and fat-mass, all jump measures, and CODS (all $p<0.01$; d=0.37-0.83). Significant training-group×time interactions were observed for all jump measures (all $p<0.05$; d=0.24-0.41). Post-hoc analyses revealed significant pre-post performance improvements for the PPT (RJ and LJ: Δ18.6%, d=0.8 and Δ22.7%, d=0.9, respectively; HCMJ: Δ16.4%, d=0.8; CMJ: Δ22.4%, d=0.7; CMJA: Δ23.3%, d=0.7; DJ20: Δ39.7%, d=1.1) and for the NPPT group (LJ: Δ14.1%, d=0.4; DJ20: Δ32.9%, d=0.8) with greater changes after PPT compared to NPPT for all jump measures (all $p<0.05$; d=0.21-0.81). The training efficiency was greater ($p<0.05$; d=0.22) after PPT (0.015% per-jump) compared to NPPT (0.0053% per-jump). The PPT induced larger performance improvements on measures of physical fitness as compared to NPPT. Therefore, in-season progressive volume-based overload PT in young male basketball players is recommended.

KEYWORDS: stretch-shortening cycle; young; team sports; athletic performance; anthropometry.

INTRODUCTION

It has previously been demonstrated that sprint speed, jumping, and change of direction speed (CODS) are major determinants of basketball performance from a physical demands point of view (42). Plyometric training (PT) is a well-accepted and useful training method which can induce physiological adaptations related to the force-velocity relationship, muscle pennation angle, and muscle fiber type transition (15). This can result in improvements in the aforementioned physical fitness traits in youth athletes (13, 38, 44).

To implement safe, effective and efficient PT programs, several factors should be considered by coaches (29). Amongst these factors are the type of jump drill (i.e. vertical vs. horizontal) (32, 33), the intensity of the jumps (i.e. drop height) (3) and the training surface (i.e. grass vs. court) (31). In addition, the training volume (i.e. number of jumps) (6, 31, 34, 35), which can be gradually increased over time, also seems to be of considerable importance (5, 35). However, the safety and effectiveness of volume-based overload in a sport in which there is a relatively high load of jumps (such as basketball) have not been adequately addressed in the literature. Although several PT studies in young basketball players have been previously conducted, these investigations have not analyzed the effect of volume-based overload throughout the intervention (13, 17, 44). This is an important study design feature as progressive overload training (28, 39) represents a suitable approach to maximize performance adaptations over the course of a PT program (4, 5, 35). Despite this, to date just one pilot study has addressed the effects of a volume-based overload PT program on components of physical fitness in young male basketball players aged ~19 years (5). In that study, eight weeks of PT was applied with a progressive volume-based overload that transitioned from 351 jumps in the first week to 549 jumps in the last week of training. The main results showed that the progressive volume-based overload PT program significantly improved jump (vertical and horizontal jumping), CODS (T test; Illinois test), strength (leg press one repetition maximum), and sprint speed (60 m sprint test) performance (effect size [ES]=1.4-2.8) (5). However, the study of Asadi et al. (5) did not include a non-progressive volume-based overload PT control group. Considering the lack of well-controlled studies on the effects of progressive vs. non-progressive volume-based overload PT on young basketball athletes' components of physical fitness, further investigations are needed.

In addition to components of physical fitness, variables relating to body composition are of paramount importance to basketball players (42). For example, lower body fat levels can influence players' ability to perform better in certain playing positions (i.e. guard) (42) whilst greater height may enable players to reach a higher playing level (i.e. amateur to professional) (42). Moreover, changes in body composition variables such as reduced body fat and increased muscle fiber size seem to exert a positive effect on sprint and jump performance (14, 42). Accordingly, PT can induce favorable effects on body composition variables such as increased bone mass (15), muscle size (8, 9), and reduced fat mass (1). However, whether or not PT affects youth basketball players' body composition is currently unknown (29) and the effects of volume-based overload PT on related variables have not been previously investigated.

Given the above observations, the purpose of this study was to examine the effects of short-term, in-season progressed and non-progressed volume-based overload PT on components of physical fitness and body composition in young male basketball players. We hypothesized that both PT programs would improve components of physical fitness in basketball players compared to an active control group, with a greater effect after progressed than in non-progressed volume-based overload PT.

METHODS

Experimental Approach to the Problem

This was a randomized, single-blind, active-control study. It was designed to compare the effects of six weeks of progressive and non-progressive volume-based overload PT on countermovement jump with [CMJA] and without arm swing [CMJ], horizontal bilateral [HCMJ] and unilateral jump with right [RJ] and left [LJ] legs, 20 cm drop-jump [DJ20], linear speed [10 m sprint] and CODS (T-test). We also examined the effect on body composition variables including body mass, body fat, body water, total muscle mass, bone mass, trunk fat mass, and leg fat mass in youth male basketball players. The progressive volume-based overload involved 120 jumps per session during the first week of training, transitioning to 168 jumps per session during the last week. The non-progressed group undertook a constant volume of 120 jumps per session for the duration of the intervention.

Subjects

Twenty-two youth males (age, 13.5±2.0 years [range: 10 to 15 years]; height, 160.1±10.9 cm; body mass, 62.1±13.5 kg) from a regional basketball team volunteered for this study. None had any previous experience in strength training or PT on regular basis though all had more than four years of basketball training. All groups participated in the same basketball-training program, twice per-week. A typical basketball practice involved 40 minutes of technical/tactical drills and 40 minutes of simulated competition, small-sided games, and injury prevention drills. Participants were instructed to maintain their regular physical activity habits during the intervention. We did not recruit any individual with potential medical problems or a history of ankle, knee, or back injury that could compromise participation in the study. Participants, as well as their parents or guardians, were informed about the experimental procedures and possible risks and benefits associated with participation in the study. Parents or guardians as well as participants signed informed consent and assent forms. The study was conducted in accordance with the latest edition of the Helsinki declaration and it was also approved by the ethical review board from the responsible institutional department.

Procedures

The sample size was computed as previously described (30). A total of six participants per-group would yield a power of 80% and an alpha level of 0.05. After baseline measurements, participants were randomly allocated to an active control group (CG, n=7) whose participants followed regular basketball training, a progressed (PPT, n=7), and a non-progressed (NPPT, n=8) volume-based overload PT group. The randomization sequence was generated electronically (https://www.randomizer.org) and was concealed until the interventions were assigned. It is important to note that the overall training volume prescribed to each experimental group was different. To account for this, a training efficiency analysis was performed for the CMJA test (31).

Participants completed two nonconsecutive familiarization sessions within a two-week period preceding baseline tests. Measurements were taken one week before and one week after the intervention. All tests were administered in the same order, between 18:00 and 20:00, and by the same investigator who was blinded to the training group of the participants. Testing sessions were scheduled ≥48 hours after a demanding physical training session or competitive game. All participants were instructed to: (a) have a good night sleep (≥8 hours) before each testing day; (b) have a meal rich in carbohydrates; (c) be well hydrated before measurements. Participants were encouraged to give their maximum effort during the physical fitness tests. All tests were completed in two days in the following order: on day one, body composition measures, CMJA, HCMJ, RJ, LJ, and DJ20 were measured; on day two; CMJ, 10 m sprint, and CODS tests were performed. A standard warm-up of 10 minutes was scheduled before each testing day (i.e., 5 minutes of running at 70% of age-predicted maximum heart rate; 5 minutes of light jumping for a total of 24 CMJs and 24 DJs from a 10 cm high platform) (2). Participants were instructed to use the same athletic shoes and clothes during the pre- and post-test sessions. All tests were conducted on a wooden indoor surface. At least 2 minutes of rest was allowed between each trial and test to reduce the effects of fatigue. The best of three trials was recorded for all physical fitness measurements.

Body composition measures. Stature and seated stature were measured as basic variables, using a stadiometer (Bodymeter 206; SECA, Hamburg, Germany). Body mass and composition were measured with an electrical bioimpedance scale (InBody120, model BPM040S12F07, Biospace, Inc., USA, to 0.1 kg). Furthermore, participants' maturity status was determined according to the predicted age at peak-height-velocity (APHV) (21), based on previous recommendations (22-25). A growth utility program (https://kinesiology.usask.ca/growthutility/phv_ui.php) was used to calculate participants' maturity status (21). The computed maturity offsets of each group were as follows: CG: -0.4±1.6 years (range: -2.2 to +1.7 years); NPPT: 0.3±1.9 years (range: -2.4 to +2.3 year); PPT 0.1±1.5 years from APHV (range: -2.4 to +1.9 years). It is noteworthy that there was a homogeneous distribution of subjects according to their maturity status between the three groups.

Vertical and horizontal jumps. Vertical jumps were measured using an electronic contact mat (Ergojump; Globus, Codogne, Italy) and maximal horizontal jump distance was measured using a 5-m long fiberglass metric tape on a wooden floor. Participants were instructed to perform a CMJ and CMJA, positioning their feet shoulder-wide apart. Participants were instructed to take-off and land in the same spot during vertical jumps. Aside from the CMJ and CMJA, participants performed a DJ20, with arms akimbo. They were instructed to maximize jump height after dropping down from the box. For the horizontal jumps, participants performed a HCMJ and RJ and LJ jumps with the use of their arms. Participants were instructed to perform a fast downward movement (approximately to a 120° knee angle) followed by a maximal horizontal jump, landing with a flat foot position.

Speed and CODS performance. Sprint time was assessed to the nearest 0.01 s using single-beam timing gates system (Brower Timing System, Salt Lake City, UT). Participants performed from a standing start with the toe of the preferred foot forward and behind the starting line. Timing was triggered when the participant voluntarily initiated the test. The timing gates were positioned at the start (0.3 m in front of the starting line) and at 10 m. They were also positioned ~0.7 m above the floor (i.e., hip level) to capture trunk movement instead of a false trigger from a limb. For the CODS test (i.e., T-test), the timing system and procedures were the same as for the 10 m sprint except that players had to run in a straight line, with several changes of direction, as quickly as possible. (5)

Training efficiency. Training efficiency was calculated as the relative (percentage) and absolute (cm) baseline to follow-up change in CMJA, divided by the total number of jumps per-leg for the whole PT program. For instance, if a participant increased their CMJA performance from 25 cm to 29 cm, and completed a total volume of jumps per-leg of 960, the training efficiency was 0.0041 cm or 0.0166% per jump. This approach was deemed important as it accounts for the training load difference between the PPT and NPPT groups and provides an objective comparison between conditions (31).

Training Program

The PPT and NPPT groups performed a plyometric intervention with and without a progressive increase in training volume, respectively. A detailed description of both training programs is presented in Table 1.

*****Table 1 near here*****

The plyometric interventions were designed based on previous research (5, 35, 36). Both groups used an arm-swing during jumps, combining cyclic and acyclic, in addition to unilateral and bilateral jumps. Participants were encouraged during each jump to achieve maximal jump intensity, vertical height, and horizontal distance. Maximal intensity for CMJA, HCMJ, RJ, and LJ was verified in a randomly assigned subsample of participants (two from each group) during two randomly assigned training sessions. This was done by measuring either the height using an electronic contact mat (Ergojump; Globus, Codogne, Italy) for CMJA or distance using a 5-m long fiberglass metric tape on a wooden floor for HCMJ, RJ, and LJ.

The order of exercises was randomized in each training session. The intervention was completed during the mid-portion of the in-season period. Participants in the PT groups performed plyometric drills as a substitute for some low-intensity technical-tactical basketball drills at the beginning of their usual basketball practice, twice per-week for six weeks. Plyometric sessions were performed after a warm-up which was identical for the training and control groups. Both plyometric groups trained on the same surface type, at the same time of day, and with the same rest intervals between sessions (i.e., 48 hours), sets (i.e., 60 s), and jumps (i.e., <15 s for acyclic jumps) (37). For the PPT, a progressive increase in the number of foot contacts was applied every two weeks (Table 1), whilst for the NPPT group, no such progressive increment in foot contacts was prescribed. Accordingly, the progressive volume overload applied in the PPT group facilitated the execution of a total of 1,152 jump repetitions per leg, whereas the NPPT group completed 960 jump repetitions per leg.

Statistical Analysis

Data are presented as group mean values ± standard deviations. Normality and homoscedasticity assumptions for all data, before and after the intervention, were checked with Shapiro-Wilk and Levene tests, respectively. To establish the effects of the interventions on the dependent variables, a 3 (group: PPT, NPPT, and CG) × 2 (test: pre, post) ANOVA with repeated measures was used. Post-hoc tests with a Bonferroni-adjusted α were conducted to identify comparisons that were statistically significant. Effect sizes were determined by calculating Cohen's *d* values (10). Cohen's *d* describes the effectiveness of a treatment and determines whether a statistically significant difference is a difference of practical value. Cohen's *d* values are classified as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large effects ($d \geq 0.8$) (10). Statistical analyses were conducted using STATISTICA statistical package (Version 8.0; StatSoft, Inc, Tulsa). Significance level was set at $\alpha = 5\%$. Tests' reliability was determined using the intraclass correlation coefficient and ranged from 0.83 to 0.98.

RESULTS

All participants received the treatment as allocated. No test or training-related injuries occurred over the course of the study, with an overall training compliance of ≥83% being achieved. There were no significant (all $p>0.05$, $d=0.0–0.2$) baseline differences between-groups for all measurements (Table 2). The main effects of group, test, and the group × test interactions are displayed in Table 2.

*****Table 2 near here*****

Results revealed significant main effects of test for height, sitting-height, body fat, body water, total muscle-mass, trunk fat-mass, and legs fat-mass ($p<0.001$; d=0.47-0.83). However, no significant group × test interactions were detected for all body composition variables ($p\geq0.3$; d=0.02-0.13).

Statistical results revealed significant main effects of test for LJ, HJ, HCMJ, CMJ, CMJA, DJ20, and CODS (all $p<0.01$; d=0.37-0.83). A group × test interactions were observed for LJ, RJ, HCMJ, CMJ, CMJA, and DJ20 (all $p<0.05$; d=0.24-0.41). For PPT, post hoc analyses revealed significant increases in RJ (Δ18.6%, d=0.8), LJ (Δ22.7%, d=0.9), HCMJ (Δ16.4%, d=0.8), CMJ (Δ22.4%, d=0.7), CMJA (Δ23.3%, d=0.7), and DJ20 (Δ39.7%, d=1.1). Additionally, post hoc analyses showed significant increases in only LJ (Δ14.1%, d=0.4) and DJ20 (Δ32.9%, d=0.8) for the NPPT group. Greater changes were observed after PPT compared to NPPT for all jump measures (all $p<0.05$; d=0.21-0.81). No performance improvements were observed in the control group.

Training efficiency was 0.0053% for the NPPT group. For the PPT group, training efficiency was 2.8 times greater (0.015% per-jump completed during the intervention) than that recorded for the NPPT group ($p<0.05$; d=0.22). Similarly, when expressed in absolute values (i.e., changes in centimeters in the CMJA), the training efficiency for the NPPT group was 0.0071 cm, whereas it was 2.3 times greater (0.016 cm per-jump completed during the intervention) for the PPT group.

DISCUSSION

The purpose of this study was to examine the effect of a short-term in-season progressed and non-progressed volume-based overload PT program on components of physical fitness and body composition in young male basketball players. The main findings were: (a) PPT induced greater performance improvements than NPPT on measures of muscle power; (b) no significant between groups differences were found for measures of body composition variables; (c) training efficiency was significantly higher for the PPT compared to the NPPT group.

Jumping plays an important role in basketball performance (43) as it is a frequently performed movement of defensive and offensive maneuvers during training and competition (43). In this study, both PPT and NPPT induced significant improvements in various types of jump performance. In line with our findings, Matavulj et al. (17), studied the effect of six weeks of PT on jump performance in male basketball players' aged between 15 and 16 years. The authors revealed significant improvements in CMJ (4.8 to 5.6 cm) after training and concluded that a short-term, in-season PT program, added to regular basketball training, was effective in improving measures of muscle power. Results of the current study showed greater performance improvements on measures of muscle power following PPT, as compared to NPPT. This means that respecting one of the basic training principles (progressive overload) is recommended when conducting a PT program. Regular basketball practice, carried out in isolation, did not stimulate significant jump performance increases in the control group. Accordingly, the addition of PT to regular basketball training, specifically in a progressive volume-based overload manner, seems effective in improving jumping performance in male youth basketball players. This is particularly important in basketball as it is a sport in which jumping ability is paramount for achieving a high level of performance (43). Considering this, it seems that a PPT program serves as a sport-specific stimulus for performance improvements in young basketball athletes.

The possible mechanism explaining muscle power enhancements following PT seems to be related to the increased neural drive to the agonist muscles, improved intermuscular coordination, changes in the muscle-tendon mechanical-stiffness characteristics, changes in muscle architecture, and changes in single fiber mechanics (15). Another possible mechanism that could enhance jumping ability following PT could be related to muscle hypertrophy. Indeed, Nikolaidis et al (27) stated that there was a positive relationship between the levels of muscle mass and jumping ability in young basketball players. This is supported by other studies (8, 9) which observed increases in muscle mass after PT interventions in young subjects. Despite these findings, our results indicated that PT did not stimulate muscle hypertrophy since there were no differences in that variable between the three groups. Therefore, and considering the short-term duration of the present study, it may be reasonable to assume that power enhancements following PT occurred mainly due to neural mechanisms (15).

The greater increases in horizontal jump for the PPT, in comparison to the NPPT, could be due to the progressive nature of the training stimulus. Adopting a progressive volume-based overload approach during a PT program can result in the gradual increase of stresses placed upon the musculotendinous unit. These incremental stresses lead to progressive performance improvements (35) with findings of the current study demonstrating that PPT may arouse greater neuromuscular adaptations (e.g., motor unit recruitment, firing rates, and synchronization) than NPPT, resulting in larger horizontal jump performance enhancements (15).

In addition to jumping ability, speed and CODS ability are two key performance determinants in basketball (42). Greater speed allows players to cover on-court distances as fast as possible whilst higher CODS ability can enhance players' agility in various scenarios with and without the ball. In this study, a significant performance improvement was shown in CODS irrespective of the PT group. However, no significant changes were recorded for speed performance. The lack of improvement in 10 m sprint time performance after both PT programs may indicate that other training stimuli may be necessary to enhance the sprinting performance of young basketball players during the competitive period. For instance, training activities with a horizontal component, such as high-speed running, may have increased the likelihood of the participants improving 10 m sprint time. This relates to the specificity of the training stimulus which considers the nature and importance of horizontal force production and application during sprinting (26). In terms of CODS performance, the current findings support those previously reported (41). Thomas et al. (41) studied the effect of a six week PT program on CODS (505 test) in male youth soccer players aged 17 years. The authors demonstrated significant CODS performance improvements (up to 7.1%) after training, while no significant enhancements were observed for 10 m sprint-time (<1%). The CODS performance improvements could have been related to neural adaptations such as the enhancement of motor unit recruitment (20).

A novel feature of this study was the determination of adaptations to body composition variables after PT in youth basketball players. Irrespective of the training group, trunk and leg muscle mass increased and body fat decreased significantly after training. However, with significant increases in height for all groups after six weeks, some of these body composition changes could be related to the advancing maturity levels of the participants (11). Previous research has shown that hypertrophy of type II muscle fibers and increases in muscle tissue occur due to greater concentrations of anabolic hormones which can develop during the around-APHV (16). In this study all groups were around-APHV, therefore, it is possible that part of the observed changes in body composition may be attributed to natural biological changes.

Although some studies have previously established the potential role of PT volume on physical fitness adaptations (6, 31, 34, 35), none of these studies have included basketball players. In this sense, establishing if the volume of training plays a role in basketball players' physical fitness adaptations is a novel and relevant issue, especially for young players, who may be more at risk of developing injuries compared to their adult peers (18). This is a particular risk when inappropriate training loads are incorporated into their training routines. In light of this, the volume of work completed by the PPT group in our study, as compared to the NPPT group, differed only by 16 more jumps per training session. Moreover, our training efficiency analysis, which considered the differences in PT volume completed by the athletes from the PPT and NPPT groups, revealed that every plyometric jump completed by the NPPT group improved performance by 0.0053% (0.0071 cm) in the CMJA test. In contrast, the PPT improved performance by 0.015% (0.016 cm) which represented an improvement of between 2.3 and 2.8 times more than the NPPT. This resulted in a significantly greater training efficiency ($p<0.05$; $d=0.22$). Indeed, given these findings, it is possible that an *efficiency threshold* may exist, and this may be approached after a given amount of low-dose PT volume (23). However, further research would be required to further substantiate this concept. Independent from this, the current results offer value to the practitioner working with youth basketball players, indicating a safe, effective and efficient progression strategy for volume-based overload, an important consideration in basketball which is characterized by a high number of jumps in training and competition (40). This can elevate the risk of overreaching, overtraining and injuries if the volume of PT is not adequately progressed (7).

In conclusion, PPT induced larger performance improvements in measures of muscle power as compared to NPPT. Therefore, it is advisable to conduct in-season progressive volume-based overload PT in young male basketball players

PRACTICAL APPLICATIONS

The findings of this study illustrate that to increase the effectiveness of PT on young male basketball players' physical fitness during the in-season period, such activity should be conducted with a progressive increase in volume over time. Although NPPT program has been shown to be effective in improving muscle power, this was clearly less pronounced than that in the PPT group . Our study also revealed that short-term PT has no effect on body composition when compared to basketball training alone.

Although we recommend that practitioners apply a progressive change in PT load over time, in the form of volume increases (aside from other potential overload variables), caution is recommended regarding the total volume of PT. A misapplied volume of PT may increase the risk of injury (7) so, in this sense, we recommend that minimal effective doses should be identified at the beginning of the interventions carried out in youth athletes (23). From here, a moderate overload can be introduced with a strong focus on technical competence (19). In addition, long-term athlete development approaches should be considered (12), including those specific to PT (19). It is important to acknowledge the gap in the current PT literature regarding the potential long-term effects of PT, especially in youth athletes according to maturity (29). Therefore, although it is tempting to provide long-term recommendations regarding progressive overload for PT, more research is needed to solve deficits in knowledge.

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Table 1. Six weeks plyometric training program*

	Set × Repetitions (mode of execution)		
	Weeks 1-2	Weeks 3-4	Weeks 5-6
Horizontal left leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)
Horizontal right leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)
Vertical left leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)
Vertical right leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)
Bilateral vertical	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)
Bilateral horizontal	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)

*: the plyometric training group that did not progressively increase training volume use the volume depicted in weeks 1-2 during the six weeks of training; C: cyclic; A: acyclic. The order of exercises execution was randomized each training session, and all exercises were executed with the technique described as countermovement with arms.

Table 2. Changes in body composition and athletic performance indices.

	Control (n = 7)	NPPT (n = 8)	PPT (n = 7)	ANOVA outcomes		
				Group F(2, 19), p-value (*d*)	Time F(1, 19), p-value (*d*)	Group x Time F(2, 19), p-value (*d*)
Height (cm)				F=0.1. p=0.9 (0.01)	F=95.3. p<0.001 (0.83)	F = 1.4. p=0.3 (0.13)
Pre	159.0 ± 9.2	159.8 ± 13.4	161.4 ± 10.8			
Post	161.8 ± 8.3[a]	161.6 ± 13.1[a]	163.7 ± 10.6[a]			
Sitting height (cm)				F=0.8. p=0.5 (0.05)	F=32.4. p<0.001 (0.63)	F = 1.2. p=0.3 (0.11)
Pre	81.9 ± 5.1	85.8 ± 8.2	85.6 ± 5.3			
Post	82.8 ± 4.4[a]	86.4 ± 8.2[a]	86.7 ± 5.1[a]			
Body mass (kg)				F=0.1. p=0.9 (0.01)	F=1.9. p=0.2 (0.09)	F = 1.0. p=0.4 (0.09)
Pre	61.5 ± 15.0	62.6 ± 16.7	61.9 ± 9.1			
Post	59.8 ± 12.0	62.6 ± 15.4	61.3 ± 7.4			
Body fat (%)				F=0.5. p=0.6 (0.05)	F=44.8. p<0.001 (0.71)	F = 0.2. p=0.8 (0.02)
Pre	14.9 ± 4.5	14.5 ± 5.7	12.7 ± 3.4			
Post	12.0 ± 3.6[a]	12.2 ± 5.0[a]	10.1 ± 2.5[a]			
Body water (%)				F=0.2. p=0.8 (0.02)	F=17.9. p<0.001 (0.49)	F=0.4. p=0.7 (0.05)
Pre	58.0 ± 6.8	58.5 ± 6.0	59.3 ± 3.5			
Post	60.0 ± 5.6[a]	60.2 ± 5.6[a]	62.2 ± 3.2[a]			
Total muscle mass (%)				F=0.2. p=0.8 (0.02)	F=16.5. p<0.001 (0.47)	F=0.6. p=0.6 (0.06)
Pre	44.4 ± 5.1	45.0 ± 4.9	45.5 ± 2.8			
Post	45.9 ± 4.3[a]	46.1 ± 4.3[a]	47.5 ± 2.4[a]			
Bone mass (kg)				F=0.1. p=0.9 (0.01)	F=0.1. p=1.0 (0.01)	F=0.7. p=0.5 (0.07)
Pre	11.1 ± 1.4	11.3 ± 1.7	11.3 ± 1.0			
Post	11.0 ± 1.1	11.4 ± 1.6	11.3 ± 0.8			
Trunk fat mass (%)				F=0.9. p=0.6 (0.06)	F=53.5. p<0.001 (0.74)	F=0.7. p=0.5 (0.07)
Pre	16.2 ± 3.4	15.5 ± 6.5	13.9 ± 3.4			
Post	12.5 ± 2.9[a]	12.9 ± 5.2[a]	10.4 ± 2.6[a]			
Legs fat mass (%)				F=0.5. p=0.6 (0.05)	F=29.2. p<0.001 (0.61)	F=0.5. p=0.6 (0.05)
Pre	14.2 ± 5.1	13.7 ± 5.2	11.6 ± 3.5			
Post	11.5 ± 4.4[a]	11.6 ± 4.9[a]	9.9 ± 2.5[a]			
Horizontal jump, right leg (cm)				F=0.4. p=0.7 (0.04)	F=33.4. p<0.001 (0.64)	F=4.3. p<0.03 (0.31)
Pre	130.4 ± 33.8	138.2 ± 35.2	137.1 ± 29.8			
Post	127.6 ± 34.1	144.1 ± 46.5	155.5 ± 30.5[b,c]			
Horizontal jump, left leg (cm)				F=0.4. p=0.7 (0.04)	F=29.3. p<0.001 (0.61)	F=6.0. p<0.01 (0.39)
Pre	132.3 ± 32.5	135.6 ± 42.8	141.9 ± 24.6			
Post	134.9 ± 32.5	154.2 ± 45.2[a,d]	164.2 ± 28.1[b,c]			
Horizontal jump (cm)				F=0.8. p=0.5 (0.08)	F=14.3. p<0.01 (0.43)	F=6.5. p<0.01 (0.41)
Pre	149.5 ± 36.2	162.5 ± 42.5	161.1 ± 29.8			
Post	148.0 ± 37.8	172.7 ± 54.8	173.0 ± 36.1[b,c]			
Countermovement jump (cm)				F=0.2. p=0.8 (0.02)	F=11.3. p<0.004 (0.37)	F=3.9. p0<.05 (0.24)
Pre	27.8 ± 9.1	28.5 ± 10.4	28.4 ± 9.1			
Post	28.5 ± 9.1	31.4 ± 12.3	32.4 ± 7.2[b,c]			
Countermovement jump with arms (cm)				F=0.5. p=0.7 (0.05)	F=12.1. p<0.003 (0.39)	F=3.8. p0<.05 (0.29)
Pre	31.1 ± 9.3	33.9 ± 11.1	34.0 ± 12.1			
Post	32.5 ± 10.2	35.2 ± 13.7	37.6 ± 8.0[b,c]			
20 cm drop jump (cm)				F=1.0. p=0.4 (0.1)	F=32.8. p<0.001 (0.63)	F=3.6. p0<.05 (0.28)
Pre	20.9 ± 3.1	21.2 ± 6.9	22.5 ± 7.4			
Post	28.6 ± 10.7	28.2 ± 8.9[a]	31.2 ± 8.9[b,c]			
10 m sprint (s)				F=0.2. p=0.8 (0.02)	F=1.7. p=0.2 (0.08)	F=0.1. p=0.9 (0.02)
Pre	2.6 ± 0.2	2.6 ± 0.3	2.7 ± 0.3			
Post	2.5 ± 0.2	2.6 ± 0.3	2.6 ± 0.2			
Change of direction speed test (s)				F=0.0. p=1.0 (0.00)	F=28.2. p<0.001 (0.60)	F=0.3. p=0.8 (0.03)
Pre	13.0 ± 1.5	13.0 ± 2.1	13.0 ± 1.5			
Post	13.0 ± 0.9	12.0 ± 1.9[a]	11.8 ± 1.1[a]			

*: the index is calculated as flight time / contact time; PPT: progressive plyometric training group; NPPT: non-progressive plyometric training group; [a, b]: significantly different from Pre value at p<0.05 and p<0.01, respectively; [c]: greater pre-post change compared to NPPT and Control groups (p<0.05); [d]: greater pre-post change compared to Control group (p<0.05).