Effect of a 16 week combined strength and plyometric training program followed by a detraining period on athletic performance in pubertal volleyball players

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Introduction

Volleyball is a complex sport with technical, tactical and athletic demands that require a variety of explosive physical attributes (speed, power and strength) and specific motor skills (37). Because of this, participants need to train and prepare to cope with the demands of play (37). For that reason, identifying optimal training methods to increase explosive performance is crucial to optimize performance in adolescent volleyball players.

Both plyometric and strength training are recognized as important components of fitness programs and are safe methods for improving explosive actions in young players (23, 38). Systematic strength training can be used to elicit increases in maximum strength and muscle hypertrophy (24) whereas plyometric training can enhance the functionality of the stretch-shortening cycle (SSC) and muscle power capacity (25). The combination of strength and plyometric training is growing in popularity. This blend of modalities is attractive to coaches as it is a time-effective method of combining two essential forms of training. Indeed, there is evidence to suggest that it may be superior to the independent (or isolated) effect of strength or plyometric training alone. Though combined training studies conducted in young players are scarce, Faigenbaum et al. (6) suggested that the addition of plyometric training to a strength training program may be more beneficial than strength training alone for enhancing selected measures of upper and lower body power in adolescent boys.

Research suggests that the effectiveness of training to enhance sprinting and jumping performance may be influenced by maturation in young boys (32, 33). Lloyd et al., reported that pre-pubertal boys benefitted more from plyometric training, while adolescents responded more favorably to a combined plyometric and traditional strength training stimulus (25). These authors proposed that maturity-dependent responses were indicative of "synergistic adaptation", which refers to the symbiotic relationship between specific adaptations of an imposed training demand and concomitant growth and maturity-related adaptations (25). However, the aforementioned study was limited in that the researchers investigated only the short-term effects of different combinations of power and resistance training on athletic performance in youth. Indeed, the available literature concerning long-term training dose responses in youth is relatively scarce. The current study differs from that of Lloyd et al. (25) in that it occurs over a much longer period of time and involves a detraining component that could serve to highlight the retention of gains resulting from a reduced dose.

Considering that the timing and tempo of maturation differs between individuals, the large variation in responsiveness to the combination of strength and power training seen in adults may be more pronounced within a youth population (15). Furthermore, the influence of detraining on athletic performance gains has received little attention among youth and is not completely understood. High levels of fitness during an in-season period are the result of several physiological adaptations in response to regular physical training. However, coaches believe that a significant reduction in fitness levels can occur if players stop training even for a short period of time. Indeed, detraining can cause a partial or complete loss of training-induced adaptations in response to an insufficient training stimulus (18). However, there have been few studies conducted to determine the effects of long-term detraining (more than 12 weeks of insufficient training stimulus) on adolescent players' fitness level (29).

Given the growing popularity of youth strength and conditioning programs, it is important to ascertain the most efficient method for enhancing motor performance and limiting detraining effects in adolescents. This information would be useful to physical educators, sport coaches and health care providers, particularly given the variable training responses during growth and maturation.

On the basis of these observations of current practice and literature, the aim of this study was to determine the effect of a combined strength and plyometric training program, or plyometric training alone, on athletic performance and how a period of detraining might modify the adaptations in response to training stimuli.

Method

Experimental approach to the problem

This study was designed to assess the effects of a 16-week pre-season plyometric training program on the athletic performance of young male volleyball players (aged 14 years old). Three groups (2 experimental groups; combined training group [CTG], plyometric training group [PTG] and control group [CG]) were selected. The CTG performed combined strength and plyometric training, twice weekly, along with their regular volleyball practice. The PTG performed a plyometric training program, twice weekly, also with the regular volleyball practice. The CG continued regular volleyball practice alone.

All subjects were tested on squat jump (SJ), countermovement jump (CMJ), multibound test for 15s (MBT), 5-m and 10-m sprint time, medicine ball throw (MT) and flexibility (SR) before and after the 16-week in-season training program. Subsequent to this period, the subjects of the two experimental groups underwent 16 weeks of detraining. To address the previously presented hypotheses, it was our goal to identify and compare the effects of detraining or reduced training periods on the functional performance levels of young male volleyball players. All subjects were tested on the same variables, after a 16-week in-season detraining/reduced training periods. Outcome variables were compared over time and between groups.

Subjects:

Sixty eight adolescent volleyball players (age: 14.6±0.6 yrs; height:176.5±6.4 cm; body mass : 66.5±12.2 kg) from a first division Tunisian volleyball club (Sidi Bousaid Club, Marsa Club and Carthage Club, Tunisia) volunteered to participate in this study. All participants were from similar socio-economic backgrounds and had the same daily school-training schedules. None were involved in any after-school activities or any formalized strength and conditioning programs. No subjects dropped out of the intervention due to any type of injury, but eight players were excluded from the study because they were absent from the post-intervention testing session. As a result, the training program was completed by 20 players in each group.

To estimate the maturity status of participants, a maturity index (i.e., timing of maturation) was calculated according to Mirwald et al. (30). This is a non-invasive and practically approved method to predict years to/from peak-height-velocity (PHV) as a measure of maturity, using anthropometric variables (30). Legal guardians and subjects provided informed consent and assent after thorough explanation of the objectives and scope of the research project, including the procedures, risks, and benefits of the study. The protocol was fully approved by the local Institutional Review Board and procedures were in accordance with the Declaration of Helsinki. No player had any history of musculoskeletal, neurological or orthopedic disorders that might impair his ability to execute plyometric or strength training.

Procedure

All procedures were carried out during the second half of the competitive volleyball season (February to May and September 2016). One week before the commencement of the study, all subjects participated in 2 orientation sessions to familiarize themselves with the general environment, equipment and experimental procedures with a view to minimizing the learning effect during the course of the intervention. Subjects were assessed for upper and lower-body explosive strength, respectively, before and after a 16-week combined strength and plyometric or plyometric-only training program, and also after detraining and reduced training periods. This procedure allowed for the assessment of the following variables: (a) thigh muscle volume, (b) squat jump (SJ), (c) countermovement jump (CMJ), (d) Multiple Bounds jumps test (MBJ) (e) medicine ball throw (MT), (f) Sprint (5 and 10-m) and (g) Sit and reach (SR). Tests followed a general warm-up that consisted of running, calisthenics, and stretching. All tests were assessed after 2 trials with a 60-second rest between trials. Three trials were carried out and the best value was considered for statistical analysis.

Assessment of the lower limb muscle volume:

Muscle volume of the lower limbs (thigh) were calculated before and after the training period based on leg circumferences (three sites: distal, middle, and proximal), and skinfold measurements (21).

Muscle power tests

For the SJ, participants were instructed to assume a squat stance on the infrared timing system (Optojump Next, Microgate, Bolzano, Italy), while lightly interlocking their hands behind their head to control for arm assistance. Participants were told to jump as explosively as possible, and as high as possible, for the three repetitions performed. There was a passive rest of 1 min between two successive repetitions. Test-retest demonstrated high intra-session reliability of the SJ (ICC = 0.99; SEM = 7.93) (5).

CMJ has been shown to be a reliable and valid measure of lower limb power in pediatric populations (4) (typical error of measurement range from 0.3 to 3.2%). During the test, participants were instructed to jump as high as possible. Verbal encouragement was provided before each trial. Three repetitions were performed using an infrared timing system (Optojump Next, Microgate, Bolzano, Italy). There was a passive rest of 1 min between two successive repetitions**.**

The MBJ test has been shown to be valid and reliable in measuring vertical leg muscle power in youth (34). Jumping conditions were identical to the CMJ test with players required to jump for maximal height repeatedly for 15 seconds. Each player performed the test only once and mean height jumped (cm) was recorded (34). Participants were required to perform these jumps without any rest period. Jump height was measured with an infrared timing system Optojump (Next, Microgate, Bolzano, Italy).

Upper-body muscular power was estimated using an overhead MBT. Players stood 1 step length behind a line marked on the ground facing the throwing direction with a 3-kg medicine ball held in both hands behind the head. Participants were instructed to plant the front foot with the toe behind the line and throw the medicine ball overhead as far forward as possible. Each throw was measured from inside the line to the nearest mark made by the fall of the medicine ball. Throwing distance was measured to the nearest 1 cm, with the greatest value obtained from 2 trials used in the analysis. The intra-class correlation coefficient for test-retest reliability and typical error of measurement for the overhead MBT test were 0.96 and 5.4%, respectively (11).

The SR test is a valid test to asses trunk flexibility in both children (beta = 1.089, R^2 = 0.281, p = 0.001) and adolescents (beta = 0.690, R^2 = 0.333, p = 0.004) (3). Participants sat on the floor using a 30.5 cm wooden box with their legs together and fully extended. For each participant, the examiner positioned the wooden box so that it was touching the soles of the participant's feet which were aligned with the 22cm mark. Participants were instructed to place one hand on top of the other with palms facing down and to keep the knees and elbows extended. They were then instructed to reach forward along the measuring tape as far as possible and to hold the terminal position for 6 seconds. Participants repeated the testing procedures until their scores stabilized to within 1 cm for 3 successive efforts.

Sprint

Infrared photoelectric cells with polarizing filters and a handheld computer (Globus Italia, Codogne, Italy) were placed at the start mark and 5-m and 10-m marks to measure the 5-m (S5m) and the 10-m (S10m) sprint times to 0.01 of a second. The starting position was standardized for all subjects. Each started in a standing position (split stance) with the toe of the preferred foot forward 0.3-m behind the starting gate. This was intended to allow some forward lean and to provide triggering of the timing system as soon as the subject moved. The photocells were set approximately 0.6 m above the floor, which was typically around hip level to capture the trunk movement rather than a false trigger from a limb. The participants were not permitted to use a ‘‘rolling’’ start, to eliminate momentum, and they were instructed to sprint with maximum effort when they were ready. The intra-class correlation coefficient for test-retest reliability and typical error of measurement for the 10-m sprint test were 0.98 and 5.2%, respectively (16).

Training program

The 16-week in-season training program consisted of a series of plyometric exercises. Sessions took place twice weekly on nonconsecutive days. A standardized warm up including jogging, dynamic stretching exercises, calisthenics, and preparatory exercises (e.g., fundamental weightlifting exercises specific to the training program) was provided for all experimental groups before the beginning of each training session. Each training session ended with 5 minutes of cool-down activities including dynamic stretching. After the pre-training testing session, participants were randomly assigned to one of the three groups: two experimental groups (combined strength and plyometric group [CTG], plyometric group [PTG]) or control group (CG). The control group did not participate in any training program and was limited to normal daily activities only. Groups were matched for age, maturation status, and physical characteristics. The groups did not significantly differ in any pre-experimental measures meaning that post-training differences could not be attributed to unequal group composition or to pre-experimental biases.

The PTG followed a structured plyometric training program using bodyweight as resistance. According to the training guidelines for pediatric populations (1, 23, 25), the plyometric training was performed with 3 to 5 sets of 8 to 10 repetitions. Plyometric drills lasted approximately 5 to 10 seconds and at least 90 seconds of rest was allowed after each set (Table 1). To minimize the risk of injury, all sessions progressed from low to moderate to high intensity drills, thus gradually imposing a greater eccentric stress on the musculo-tendinous unit. The intensity of the program was increased in accordance with previous plyometric training guidelines (1). Training volume was defined by the number of foot contacts made during each session. The progressive overload principle was incorporated into the program by increasing the number of foot contacts and varying the complexity of exercises (hurdle jump and drop jump) for all rapid stretch shortening cycle (SCC) exercises. Owing to the relative lack of plyometric training experience, verbal feedback focused on ingraining correct take-off and landing mechanics. Additionally, and even in the early stages of the program, subjects were exposed to repeated submaximal hopping in an effort to maximize the likelihood of simultaneous development of fast elastic recoil and stretch reflex utilization.

The CTG group trained with additional loads or free weights using slower speed movements. The eccentric, isometric, concentric contraction pacing for the CTR was 1s-1s-1s, respectively. The CTG performed strength exercises (i.e. half squat) followed by plyometric exercises in each session. In addition, the CTR replaced 50% of the rapid SSC plyometric exercises with a combination of strength exercises. Thus the CTG would have approximately half of its training program involving strength exercise and half involving rapid SSC takeoffs. The strength training program employed exercises with an intensity between 40 and 70% of 1 RM with 1 to 2 sets of 8 to 12 repetitions. The intensity was progressively increased over the 16-week training period from 40 to 70°/° of 1 RM. Each strength training session was preceded by a 10-minute warm up and lasted ~35 minutes. The strength training exercises were half squat, Bulgarian split squat, bench press and behind-the-neck press. The plyometric training was performed with 2 to 3 sets of 6 to 8 repetitions (Table 1). In terms of overall volume, the CTG performed 50% rapid SSC movements and 50% strength-based movements (4 of the 5 exercises had 1/2 the repetitions with a deep hold and 1/2 the repetitions with short contact times, with the fifth exercise maintaining a singular strength emphasis). The PTG group utilized rapid SCC plyometric exercises for all sets and exercises (Table 1).

At the end of the 16-week in-season training program, all groups were randomly assigned to a detraining or a reduced training period. All 3 groups pursued regular volleyball practice throughout the study.

Table 1. Training program for each group

Week	**Combined Group**		**Plyometric group**
1-4	1 x 10 at 40%	2 x 6 (30cm)	3 x 8 (30cm)
5-8	2 x 12 at 50%	3 x 8 (40cm)	5 x 10 (40cm)
9-12	1 x 8 at 40%	2 x 6 (40cm)	3 x 8 (30cm)
13-16	2 x 10 at 70%	3 x 8 (50cm)	5 x 10 (40cm)

Statistical Analyses

Data were analyzed using Statistica for Windows software (version 6.0; StatSoft, Inc, Tulsa, OK, USA). Data distribution normality was confirmed with the Shapiro-Wilk W-test. Means and SDs were calculated using standard statistical methods. Independent samples T-tests were executed to analyze differences between the two experimental groups for age, APHV, MO and anthropometrics (height, weight, BMI, % body fat).). A three-way analysis of variance (ANOVA) with repeated measures (Group × Time) was used to analyze anthropometric and performance variables after training (pre and post intervention) and after the detraining period. When the ANOVA revealed significant main effects or interactions, a Newman–Keuls post hoc test was applied to test the discrimination between means. The statistical significance level was set at $p<0.05$. Results are presented in the text and tables as means ± SDs. The change (increase or decrease) of all physical performance values at post-training and detraining was evaluated by calculating the delta percentage for each parameter (i.e; Delta SJ% as DSJ% = 100* (Post-Training-Pre-training)/Pre-training); Delta SJ% as DSJ% = 100* (Detraining-Post-training)/Post-training). Effect sizes were interpreted using previously outlined ranges (<0.2 = trivial; 0.2-0.6 = small, 0.6-1.2 = moderate, 1.2-2.0 = large, 2.0-4.0 = very large, >4.0 = extremely large) (17). The smallest effect was classified as 0.2 of the between-subject standard deviation (17).

Results

Morphological characteristics

Forty participants completed the training program and attended all training sessions. None reported any training or test-related injury. Table 2 describes pre-intervention results for all outcome variables. There were no statistically significant differences in pre-training values between the two experimental groups. The independent samples t-test showed no statistical differences for age (p=0.99) height (p=0.58), mass (p=0.79), BMI (p=0.66), MO (p=0.79), %body fat (p=0.66) and APHV (p=0.34). Subjects' anthropometric characteristics and muscle volumes are presented in Tables 3 and 4. A two-way ANOVA showed a significant main effect of Time factor ($p<0.001$) and group-by-time interaction ($p<0.01$) for the estimated measures of percent body fat. Both experimental groups experienced a significant decline over the training period for body fat % (7.8%; $p<0.01$ and 7.5%; $p<0.01$ in the CTG and PTG respectively), followed by a significant increase over the detraining period (9.5%; $p<0.001$ and 7%; $p<0.05$ in the CTG and PTG respectively). The CG showed no change in these characteristics.

Statistical analysis showed a significant main effect of time ($p<0.001$), a significant main effect of group ($p<0.05$) and a significant group by time interaction ($p<0.001$) on muscle volume. The post hoc analysis revealed that both combined training (34.6%; $p<0.001$) and plyometric training (13.9%, $p<0.01$) significantly increased thigh muscle volume. However, the CG showed no changes. After detraining, three-way ANOVA demonstrated that the CTG showed significant decreases in thigh muscle volume (21.19%; $p<0.001$). However, the PTG and CG showed no changes.

Table 2. Morphological characteristics of the two experimental groups in pre-training

	Combined group	**Plyometric group**	***p-value***
Age (years)	14.7±0.6	14.6±0.5	0.99
Height (cm)	177±7.7	178.1±4.5	0.58
weight (kg)	68.7±11.2	67.9±9.7	0.79
BMI (kg/m^2)	21.8±2.8	21.4±3	0.66
Body Fat (%)	20.5±4	19.9±4.5	0.79
MO (years)	0.81±0.5	0.98±0.6	0.66

APHV (years)	13.8±0.5	13.6±0.5	0.34

Table 3. Anthropometric characteristics following training and detraining in the control and the experimental group (Mean ± SD)

	Combined group (n=20)			**Plyometric group (n=20)**			**Control Group (n=20)**		
	Pre-training	**Post-training**	**Detraining**	**Pre-training**	**Post-training**	**Detraining**	**Pre-training**	**Post-training**	**Detraining**
Age (years)	14.7±0.6	14.8±0.6	15.2±0.7	14.6±0.5	15.1±0.6	15.3±0.7	14.5±0.6	14.8±0.7	15.3±0.7
Height (cm)	177±7.7	177.3±7.4	178±7.2	178.1±4.5	178.4±4.2	179.1±4.2	173.9±7.1	174.1±7.1	174.7±7
Weight (kg)	68.7±11.2	66.6±11.1**	70.6±10.4*$^{\#\#\#}$	67.9±9.7	65.6±9.4**	69.5±9.2$^{\#\#\#}$	63.4±15.3	64.4±13.6	66.6±14.2**$^{\#}$
BMI (kg/m^2)	21.8±2.8	20.9±2.6***	22.2±2.4$^{\#\#\#}$	21.4±3**	20.6±2.8$^{\#\#\#}$	21.7±2.8	20.9±4.5	21.2±3.9	21.7±3.9**
Body Fat (%)	20.5±4	18.9±3.7**	20.7±3.5$^{\#\#\#}$	19.9±4.5	18.4±4.3**	19.7±4.2$^{\#}$	19.2±6.7	19.5±5.8	19.9±5.9
MO (years)	0.81±0.5	0.91±0.5	1.25±0.5	0.98±0.6	1.19±0.6	1.44±0.6	0.61±0.5	0.74±0.6	1.12±0.6
APHV (years)	13.8±0.5	13.9±0.4	14±0.4	13.6±0.5	13.8±0.5	13.9±0.5	13.9±0.5	14±0.5	14.2±0.6

**p*< .05, ***p*< .01, ****p*< .001, compared with pre-training values; $^{\#}$ *p*< .05, $^{\#\#}$*p*< .01, $^{\#\#\#}$ *p*< .001compared with post-training values and detraining values.

APHV = age at peak height velocity; BMI: Body mass index; MO: Maturity offset*****

Table 4. Between group effect sizes and confidence intervals for muscle volume of thigh at pre-training, post-training and detraining sessions.

Thigh muscle volume (cm^3)	**Combined group**	**Plyometric group**	**Control group**
Pre-training	3740.3±1814.5	3303.4±1153.6	2991.3±1499.2
Post-training	5034.9±1829.3*** 0.71 (0.17; 1.24) Moderate increase	3764.8±1052.4** 0.42 (-0.11; 0.94) Small increase	3075±1332 0.06 (-0.46; 0.58) Trivial increase
Detraining	3968.3±1817.2$^{\#\#\#}$ -0.58 (-1.12; -0.05) Small decrease	3640.2±1090.7* -0.12 (-0.64; 0.40) Trivial decrease	3069.1±1527.2 0.00 (-0.52; 0.52)

**p*< .05; ***p*< .01; ****p*< .001, compared with Pre-training session values. $^{\#\#\#}$ *p*< .001 significant difference between post-training and Detraining sessions values.

Effect sizes

Effect sizes and their descriptors for all performance parameters are shown in Tables 5 (within-group) and 6 (between-group).

Muscle power

Vertical jumps tests

Significant main effects of time on SJ ($p<0.001$), CMJ ($p<0.001$) and MBJ ($p<0.001$) and a significant group by time interaction on SJ ($p<0.001$), CMJ ($p<0.001$) and MBJ ($p<0.05$) were observed. However, no significant effect of group on jump tests was observed. Post-hoc results showed that there were no statistically significant differences in pre-training values between groups. The post-hoc analysis revealed that combined training significantly increased SJ by 2.05 cm (7.07%; $p<0.001$), CMJ by 2.04cm (6.27%; $p<0.001$) and MBJ by 2.43 cm (9.13%; $p<0.001$). Similarly, the plyometric training significantly increased SJ by 1.21 cm (4.12%, $p<0.05$), CMJ by 1.1 cm (3.39%, $p<0.001$) and MBJ by 1.19 cm (4.41%; $p<0.01$). Differences were found in the improvements between experimental groups in CMJ ($p<0.01$) and MBJ ($p<0.05$) after training in favor of the combined group. The CG showed no changes

A three-way ANOVA demonstrated that the CTG showed significant decreases in SJ by 2.11cm (6.79%; $p<0.001$), in CMJ by 2.35 cm (6.8%; $p<0.001$) and in MBJ by 2.86 cm (9.87%; $p<0.001$). Similarly, the PTG showed significant regression in SJ by 1.64 cm (5.36%; $p<0.001$), in CMJ by 1.48 (4.38%; $p<0.001$) and MBJ by 1.64 cm (4.22%; $p<0.001$). However, the CG showed no changes.

Medicine ball throw

Significant main effects for group ($p<0.05$) and time factors ($p<0.001$) as well as a significant group by time interaction ($p<0.001$) on MBT were observed. Statistical analysis showed that there were no statistically significant differences in pre-training values between groups. The post hoc analysis revealed that the combined training significantly increased (14.99%; $p<0.001$) MBT by 0.78 cm. Likewise, the plyometric training significantly increased (6.70%; $p<0.001$) MBT by 0.35 cm. However, the CG group showed no changes in MBT. Differences were found in the improvements between experimental groups in MBT (ES: 0.67; $p<0.001$) after training in favor of the CTG. Three-way ANOVA demonstrated that the CTG showed significant decreases of 0.64cm (10.74%; $p<0.01$) while the PTG showed a regression of 0.23 cm (4.01%; $p<0.001$) in MBT.

Table 5. Within-group analysis pre-training, post-training and detraining means, effect sizes, confidence limits, and effect description for performance data

Variables	Group	Pre-training	Post-training	Detraining	Training effect			Detraining effect		
					Effect size	Confidence limits	Effect description	Effect size	Confidence limits	Effect description
SJ (cm)	CTG	29±5.9	31.1±5.5***	29±5.9###	0.35	-0.16 to 0.89	Small increase	-0.37	-0.89 to 0.15	Small decrease
	PTG	29.4±3.8	30.6±3.9*	28.9±4.6 ###	0.31	-0.21 to 0.84	Small increase	-0.40	-0.93 to 0.12	Small decrease
	CG	29.8±5.9	29.4±5.4	28.8±5.8	0.02	-0.50 to 0.54	Trivial increase	-0.10	-062 to 0.42	Trivial decrease
CMJ (cm)	CTG	32.5±5.9	34.5±5.7***	32.2±5.6###	0.35	-0.17 to 0.88	Small increase	-0.41	-0.94 to 0.11	Small decrease
	PTG	32.6±6.8	33.7±6.8***	32.2±6.7###	0.16	0.38 to 0.68	Trivial increase	-0.22	-0.74 to 0.30	Small decrease
	CG	32.2±6	32.4 ±5.8	32±5.8*#	0.04	-0.48 to 0.56	Trivial increase	-0.07	-0.59 to 0.45	Trivial decrease
MBJ (cm)	CTG	26.6±5.1	29±5.8***	26.1±4.5###	0.44	-0.08 to 0.97	Small increase	-0.53	-1.06 to 0.00	Small decrease
	PTG	27 ±6	29.2±6.2**	26.5±6.5###	0.36	-0.17 to 0.88	Small increase	-0.42	-0.94 to 0.11	Small decrease
	CG	26.3±4.6	26.5±4.5	25.9±4.7	0.05	-0.47 to 0.57	Trivial increase	-0.13	-0.65 to 0.39	Trivial decrease
S5m (s)	CTG	0.8±0.1	0.8±0.1***	0.8±0.1###	-0.69	-1.22 to -0.15	Moderate increase	1.10	0.54 to 1.66	Large decrease
	PTG	0.8±0.1	0.8±0.1*	0.8±0.1##	-0.46	-0.99 to 0.07	Small increase	0.52	-0.01 to 1.05	Small decrease
	CG	0.8±0.1	0.8±0.1	0.8±0.1	0.00	-0.52 to 0.52	Trivial increase	0.13	-0.40 to 0.65	Trivial Decrease
S10m (s)	CTG	1.9±0.1	1.8±0.1***	1.9±0.1###	-0.31	-0.83 to 0.22	Small increase	0.69	0.16 to 1.23	Moderate decrease
	PTG	1.8±0.1	1.8±0.1*	1.9±0.1###	-0.3	-0.82 to 0.23	Small increase	0.48	-0.05 to 1.01	Small Decrease
	CG	1.9±0.2	1.9±0.1	1.9±0.2	0.06	0.46 to 0.58	Trivial increase	0.12	-0.40 to 0.65	Trivial decrease
MBT	CTG	5.2±0.6	6±0.5***	5.4±0.6###	1.32	0.75 to 1.89	Large	-1.14	-1.70 to -0.58	Large

(m)							increase			decrease
	PTG	5.3±0.5	5.6±0.5***	5.4±0.4$^{\#\#}$	0.70	0.16 to 1.23	Moderate increase	-0.49	-1.02 to 0.04	Small decrease
	CG	5.13±0.6	5.2±0.6	5.1±0.6	0.05	-0.47 to 0.57	Trivial increase	-0.19	-0.71 to 0.33	Trivial decrease
SR (cm)	**CTG**	-3.2±9	-2.1±8.7**	-2.5±8.5*	0.12	-0.40 to 0.64	Trivial increase	-0.04	-.056 to 0.48	Trivial decrease
	PTG	-3.1±8.4	-2.1±8.2**	-2.3±8.6*	0.11	-0.41 to 0.63	Trivial increase	-0.02	-0.54 to 0.50	Trivial decrease
	CG	-3.5±10.1	-3.3±10.5	-3.2±9.6	0.02	-0.50 to 0.54	Trivial increase	0.00	-0.52 to 0.53	Trivial decrease

*p< .05, **p< .01, ***p< .001, compared with pre-training values; $^{\#}$ p< .05, $^{\#\#}$$p$< .01, $^{\#\#\#}$ p< .001compared with post-training and detraining values.

Abbreviations: Squat jump (SJ); countermovement jump (CMJ); multi jump (MBJ); Sprint times at 5 m (S5m) and at 10 m (S10m); medicine ball throw (MBT), sit and reach (SR); CTG: Combined training group; PTG: Plyometric training group; CG: Control group

Speed

A three-way ANOVA showed significant main effects of time on S5m ($p<0.001$) and S10m ($p<0.001$), as well as a significant group by time interaction on S5m ($p<0.05$) and S10m ($p<0.05$). However, no significant effects of group factor for any sprint tests (S5m, $p=0.56$; S10m, $p=0.46$) were found.

Statistical analysis showed that there were no statistically significant differences in pre-training values between groups. The post hoc analysis revealed that the combined training significantly improved S5m and S10m by 0.05 seconds (6.47%; $p<0.001$) and 0.07 seconds (3.47%; $p<0.001$) respectively. Similarly, plyometric training significantly improved 5m sprint and 10m sprint by 0.04 seconds (4.35%, $p<0.05$) and 0.04 seconds (2.39%, $p<0.05$) respectively. The CG showed no changes.

After detraining, the CTG, via a three-way ANOVA, demonstrated significant decreases in 5m and 10m sprint performance by 0.08 seconds (10.93%; $p<0.001$) and 0.09 (4.8%; $p<0.001$) respectively. Similarly, the PTG showed significant regression in 5m and 10m sprint performance by 0.04 seconds (5.53%; $p<0.01$) and 0.06 seconds (3.42%; $p<0.001$) respectively. However, the CG showed no changes.

Sit and reach test

A significant main effect of time on the SR test ($p<0.001$) was observed. However, there were no significant effects for group or group by time interaction on the SR test.

Our results showed that there were no statistically significant differences in pre-training values between groups. The post hoc analysis revealed that, after training, both experimental groups showed a significant ($p<0.001$) increase in SR. This performance was still increased at detraining ($p<0.001$) compared to pre and post-training.

Table 6. Differences between the three groups in the training and detraining effects (with confidence limits) on physical performances.

		Training effect			Detraining effect		
		Effect size	**Confidence limits**	**Effect description**	**Effect size**	**Confidence limits**	**Effect description**
CMJ	CTG vs PTG	0.13	-0.39 to 0.65	Trivial increase	0.00	-0.52 to 0.52	Trivial increase
	CTG vs CG	0.37	-0.16 to 0.89	Trivial increase	0.04	-0.49 to 0.56	Trivial increase
	PTG vs CG	0.21	-0.31 to 0.73	Small increase	0.04	-0.48 to 0.56	Trivial increase
SJ	CTG vs PTG	0.11	-0.41 to 0.63	Trivial increase	0.01	-0.51 to 0.53	Trivial increase
	CTG vs CG	0.31	-0.21 to 0.83	Small increase	0.03	-0.49 to 0.55	Trivia increase
	PTG vs CG	0.25	-0.27 to 0.77	Small increase	0.02	-0.50 to 0.54	Trivia increase
MBJ	CTG vs PTG	-0.03	-0.05 to 0.49	Trivial increase	-0.07	-0.59 to 0.45	Trivial increase
	CTG vs CG	0.47	-0.05 to 1.00	Small increase	0.04	-0.48 to 0.56	Trivial increase
	PTG vs CG	0.48	-0.05 to 1.01	Small increase	0.1	-0.42 to 0.62	Trivial increase
S5m	CTG vs PTG	-0.36	- 0.89 to 0.16	Small increase	0.22	-0.30 to 0.47	Small increase
	CTG vs CG	-0.9	-1.44 to -0.35	Moderate increase	0.12	-0.40 to 0.64	Trivial increase
	PTG vs CG	-0.57	-1.10 to -0.04	Small increase	0.12	-0.64 to 0.40	Trivial increase
S10m	CTG vs PTG	0.00	-0.52 to 0.52	Trivial increase	0.17	-0.35 to 0.69	Trivial increase
	CTG vs CG	-0.59	-1.12 to -0.06	Small increase	-0.14	-0.66 to 0.38	Trivial increase
	PTG vs CG	-0.57	-1.10 to -0.04	Small increase	-0.27	-0.79 to 0.25	Small increase
MBT	CTG vs PTG	0.67	0.14 to 1.21	Moderate increase	-0.12	-0.64to 0.40	Trivial increase
	CTG vs CG	1.43	0.85 to 2.01	Large increase	0.51	-0.02 to 1.04	Small increase
	PTG vs CG	0.88	0.33 to 1.42	Moderate increase	0.67	0.13 to 1.20	Moderate increase
SR	CTG vs PTG	0.00	-0.52 to 0.52	Trivial increase	-0.03	-0.55 to 0.49	Trivial increase
	CTG vs CG	0.12	-0.40 to 0.64	Trivial increase	0.08	-0.44 to 0.60	Trivial increase
	PTG vs CG	0.13	-0.39 to 0.65	Trivial increase	0.1	-0.42 to 0.62	Trivial increase

Discussion

The most important finding in this study was that a 16 week program of combined strength and plyometric training was generally more effective for decreasing body fat percentage and improving 5- and 10-m sprint time and muscle power performance than plyometric training alone in male adolescent volleyball players. Muscle flexibility was unchanged. Furthermore, detraining negatively affected athletic performance.

There were favorable changes in body fat % and body mass following combined training. The changes in body fat % across experimental groups were small and significant declines were observed (p<0.01, ES: -0.42 for CTG and p<0.01, ES:-0.31 for PTG) over the training period followed by a significant and a small increase (p<0.001, ES: 0.5 for CTG and p<0.05, ES: 0.31 for PTG) over the detraining period. This suggests a return to pre-training values similar to the CG. Combined training could be considered as a safe and effective option for exercise prescription in adolescents. However, the importance of maintaining training stimuli was highlighted by increases in body fat % after detraining (18).

After a 16-week intervention, an improvement in thigh muscle volume was observed only in experimental groups (34.6%, p<0.001, for CTG; 13.9%, p<0.01, for PTG). These results were in agreement with previous studies reporting enlargements of muscle cross sectional area (CSA) in children following resistance training lasting between ten to twelve weeks for the upper (9) and the lower limbs (27). Mersmann et al. (2014) reported significantly higher muscle volume in adolescent male elite volleyball players (16.1±0.7y) when compared to former still active elite male (16.9±3.3y) volleyball players (28). This clearly shows the adaptive potential of muscle morphology in adolescent athletes (22). It has been found that muscle volume and CSA similarly increase during maturation with the highest rate of muscle growth occurring between 13 and 15 years (19) which corresponds to the age of the players in the current study. Morphological changes following strength training include an increase in muscle fiber size, potential hyperplasia and changes in fiber-type composition and connective tissue (22).

The combined training significantly decreased S5-m and S10-m by 0.05 seconds (ES: 0.69; 6.47%; $p<0.001$) and 0.07 seconds (ES: 0.31; 3.47%; $p<0.001$) respectively. These results agreed with those in a previous study showing a significant improvement in 30 m sprint (3.5%, 0.15 s, $p<0.05$) after a 13-week combined strength and speed training in youth (20). It has been reported that short-distance sprinting is highly dependent on the ability to generate muscular power in the extension of the ankle, knee, and hip joints (8). Therefore, in the present study, combining the half squat and the Bulgarian split squat with vertical jumps seems to have provided the greatest effect in sprint performance because these exercises consisted of simultaneous triple-extension at these joints. This could be explained by the possible transfer of gains in leg muscular power to sprint performance which was previously reported by Gorostiaga et al. (1999) (12). Children experience a natural increase in neural coordination and central nervous system maturation during childhood (26) which, in combination with the fast muscle actions demonstrated during plyometric training, may provide an augmented training response (10).

Our results revealed that, compared with pre-training, the CTG significantly increased muscle power performance by 2.05 cm, (ES: 0.35; 7.07%; $p<0.001$) for SJ, 2.04cm (ES: 0.35; 6.27%; $p<0.001$) for CMJ, 2.43 cm (ES: 0.44; 9.13%; $p<0.001$) for MBJ and 0.78 cm (ES: 1.32; 14.99%; $p<0.001$) for the MBT. These findings were in agreement with those of a study in which an improvement in vertical jump height after explosive strength or plyometric training was 5.1%, or approximately 2 cm (31). Studies (13, 31) in young soccer players have shown the beneficial effects of strength training combined with plyometric exercises on CMJ (1.2–5.1 %; ES: 0.28–0.35). Ingle, Sleap [18] found significant improvements in dynamic strength and throwing performance in 12 year old boys. Santos et al. (39) found improvements in measures of lower and upper body explosive strength in 14-15 years old male basketball players. Overall, the present study demonstrates that the varied stimulus for the CTG increased a wider range of motor performance outcomes whereas improvements from independent forms of plyometric training or traditional strength training appear to be more task specific. On this, adaptations in lower body power probabaly occur because of improved stored elastic energy utilization resulting in a higher jump and increased flight time (and thus reduced ground time) (7). Previous studies showed no improvement in vertical jump after strength training when slow or normal muscle action speed was used (13). These results suggest that the speed of movement could be as, or more, important than the load and positively affects the jump performance of adolescent volleyball players. On the whole, the importance of a varied training stimulus is emphasized.

In addition to the above points, several researchers (25, 35) have demonstrated a performance spurt in strength and power development around 0.5 to 1.0 years after PHV, similar to that shown in this study. As mentioned above, improvements in muscle power performance may be attributed to the rise of hormone levels (testosterone and growth hormones) associated with puberty around PHV (1). Radnor et al. (36) demonstrated that combined training and traditional strength training resulted in more positive responders in tasks that required higher levels of reactive strength and maximal running velocity in post-PHV boys. By comparison, in a pre-PHV group, plyometric training and combined training resulted in more positive responders than traditional strength training in sprinting. These researchers showed that individual responsiveness to stimuli are training mode dependent with adaptations being specific to the type of training stimulus that is applied (25). Combined training typically involves relatively slower movement velocities involving both concentric and eccentric muscle actions (25) whereas our plyometric training program incorporated a number of exercises which stressed the SSC, a rapid muscle action using eccentric-concentric coupling (25).

Also likely to affect adaptations are variations in individual responses to training which could potentially be explained by differences in the timing, tempo and magnitude of maturation (2). Lloyd et al. (25) showed that the effectiveness of combined strength and plyometric training in enhancing sprinting and jumping performance in young boys may be influenced by maturation. Authors reported that pre-PHV boys benefitted more from plyometric training, while boys who were post-PHV responded more favorably to a combined plyometric and traditional strength training intervention (25). Maturity-dependent responses are indicative of “synergistic adaptation”, which refers to the symbiotic relationship between specific adaptations of an imposed training demand and concomitant growth and maturity-related adaptations (36).

Following detraining in the combined strength and plyometric training groups, all motor performance parameters returned to baseline values after 16 weeks. Consequently, between-group differences were not expected following detraining. Our results were in line with those of Ingle et al. 2006 reporting a detraining effect in vertical jump, chest strength and 40-m sprint time performances after a 12-week program of complex training and detraining in pre-pubescent basketball players (18). The force production of strength-trained athletes has been shown to decline by between 7 and 12% during periods of inactivity ranging from 8 to 12 weeks, in addition to reductions in fiber cross-sectional area and muscle mass (14). Similarly, in our study a decline of 6 to 11% was found during the 16-week detraining period though this could potentially be upheld through growth and maturation of the subjects. This could potentially distort the real effect of detraining. Mechanisms responsible for the effect of detraining on anaerobic performance characteristics have yet to be elucidated although for dynamic strength performance reduced motor unit activation and losses in motor coordination (40) have been suggested.

Practical application

The current study shows that 16 weeks of upper and lower body combined training resulted in larger improvements in strength, power, throwing and sprinting performances in adolescent volleyball players. Combining a number of elements into one training session seems to be a safe training modality in this age cohort. Given the long-term nature of the current study, it should be stressed that the resistance training stimulus should be varied, combining strength with plyometric workouts to facilitate continued progressive neuromuscular adaptation. Practitioners should include specific strength and power exercises such as bilateral and unilateral, vertical and horizontal, and strength exercises to optimally enhance all aspects of explosive athletic performance. In this sense, our recommendations demonstrate the possibility for the coaches to safely choose a multidimensional, progressive combined strength and plyometric training program, with each workout lasting 30 minutes.

Following 16 weeks of detraining/reduced training, the previously achieved performance levels were retained. That volleyball is a sport with an emphasis on strength and power components allows for the maintenance of neuromuscular adaptation attained by way of previous application of specific training programs. Nevertheless, simultaneous to volleyball practice, the application of an abbreviated combined strength and plyometric training program allows the athletes not only to maintain previously achieved gains, but also to achieve further development of strength, jumping, throwing and sprinting abilities. Thus, if total training time is scarce, the coach may choose to omit strength and power training stimuli in the knowledge that previously attained strength and power levels can be maintained. Nevertheless, the coach must be mindful that the absence of a combined strength and plyometric training program throughout the youth volleyball season may not be an optimal strategy owing to potentially impaired continuous development. Indeed, the small gains obtained through regular volleyball practice were reflective of those prior to the intervention. On that basis, young athletes' coaches are advised to retain combined strength and plyometric training in their training routines with a view to maintaining, and enhancing, physical development in an optimal fashion.

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