
EFFECTS OF DIFFERENT RESISTANCE TRAINING VOLUMES ON STRENGTH AND POWER IN TEAM SPORT ATHLETES

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ABSTRACT

Naclerio, F, Faigenbaum, AD, Larumbe-Zabala, E, Perez-Bibao, T, Kang, J, Ratamess, NA, and Triplett, NT. Effects of different resistance training volumes on strength and power in team sport athletes. *J Strength Cond Res* 27(7): 1832–1840, 2013 –The aim of this study was to compare the effects of 3 different volume of resistance training (RT) on maximum strength and average power in college team sport athletes with no previous RT experience. Thirty-two subjects (20 men and 12 women, age = 23.1 ± 1.57 years) were randomly divided into 4 groups: low volume (LV; $n = 8$), 1 set per exercise and 3 sets per muscle group; moderate volume (MV; $n = 8$), 2 sets per exercise and 6 sets per muscle group; high volume (HV; $n = 8$), 3 sets per exercise and 9 sets per muscle group; and a non-RT control group ($n = 8$). The 3 intervention groups were trained for 6 weeks thrice weekly after a nonperiodized RT program differentiated only by the volume. Before (T_1) and after training (T_2), 1 repetition maximum (1RM) and maximal average power (AP) produced on the bench press (BP), upright row (UR), and squat (SQ) were assessed by progressive resistance tests. One repetition maximum-BP and 1RM-UR increased significantly in the 3 interventions groups ($p < 0.05$), whereas only the HV group significantly improved 1RM-SQ ($p < 0.01$). The MV and HV groups increased AP-BP ($p < 0.05$), whereas only the LV group improved AP-SQ ($p < 0.01$). Moderate effect sizes (ES; $>0.20 < 0.60$) were observed for the 1RM-BP and 1RM-UR in the 3 training groups. High-volume group showed the larger ES for 1RM-BP (0.45), 1RM-UR (0.60), and 1RM-SQ (0.47), whereas the LV produced the higher ES for SQ-AP (0.53). During the initial adaptation period, a HV RT program seems

to be a better strategy for improving strength, whereas during the season, an LV RT could be a reasonable option for maintaining strength and enhancing lower-body AP in team sport athletes.

KEY WORDS program design, strength gains, training dose, average power

INTRODUCTION

Resistance training (RT) is an essential component of training for health, fitness, and sports performance. Therefore, an appropriate quantification of program design variables (e.g., intensity and volume) and an understanding of the effects of different training protocols on strength and power is essential for optimizing training adaptations (32). Two published meta-analyses indicated that multiple-set programs are associated with greater strength gains (19) and hypertrophy (20) in both trained and untrained individuals regardless of the training duration. However, an appropriate management of the volume is required to obtain the desired proposed outcomes for any particular athletes in different part of the season (27). Regarding the effects of RT on performance in team sport athletes such as soccer or volleyball players, several studies have found moderate-to-high correlations between squat 1 repetition maximum (1RM) and the performance achieved in specific tasks including short sprints (5–40 m) and vertical jump (13).

In addition, the significant and inverse relationship between the 1RM strength and the rate of sports-related injury has been well documented (22). Only a few published reports have investigated the optimal volume to develop maximal strength (1RM) in untrained (4,6,14,23,24,30), moderately trained (5,12,17,18,26,28,31), or highly trained subjects (11). Two reports analyzed the effects of RT volume on both maximal strength and power. Ostrowski et al. (26) examined the effects of 3 different RT volumes over a 10-week program on muscle size, maximal strength, and peak power

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in moderately trained individuals and found that all 3 programs were equally effective in increasing maximum strength, hypertrophy, and upper-body peak power; however, no significant improvement were observed for the peak power as measured by the vertical jump test. Conversely, Sanborn et al. (30) reported that an 8-week multiple-set training regimen (2–10RM) was more effective than a single-set regimen (1–10 RM) for increasing vertical jump power but not 1RM strength in untrained women. Of note, in the later report, only the multiple-set group was trained with higher velocity movements, so these findings could be because of, at least in part, the specific design of the training protocol (30).

Although high-volume (HV) training could be more effective for enhancing maximal strength, the use of low-volume (LV) to moderate-volume (MV) training may be more appropriate for enhancing maximal power especially in athletes who are concurrently participating in their respective sport (2). To our knowledge, there are no studies that have examined the effects of different training volumes on strength and maximal average power performance in team sport athletes with no RT experience.

Therefore, the purpose of this study was to compare the effects of 3 different RT volumes at a controlled exercise intensity on maximum strength and maximal average power achieved in college athletes with no previous RT experience using traditional external loads. In addition, a secondary aim was to examine the responses associated with different training volumes on the development of 1RM and maximal average power between upper- and lower-body exercises. We hypothesize that regardless of muscle groups, moderate and high RT volumes will produce greater strength improvement, whereas lower RT volume will favor power enhancement.

METHODS

Experimental Approach to the Problem

This study was designed to examine the effects of 3 different RT volumes with controlled exercise intensity on maximum strength and average power in college team sport athletes with no previous RT experience. Before (*T1*) and after (*T2*) training, each subject performed a progressive test to determine the 1RM load and maximal average power (AP) produced during the bench press (BP), upright row (UR), and squat (SQ) exercises. After *T1*, the subjects were randomly assigned to 1 of the 4 groups: LV, 1 set per exercise and 3 sets per muscle group; MV, 2 sets per exercise and 6 sets per muscle group; HV, 3 sets per exercise and 9 sets per muscle group; and a non-RT control group (C). The 3 intervention groups were trained for 6 weeks thrice weekly after a non-periodized RT program differentiated only by the volume. Each group performed 2 different training programs that focused on different muscle groups.

Subjects

Thirty-two team-sport athletes (20 male soccer and 12 female volleyball college players) with at least 3 years of experience as

regular team sports practitioner were randomly assigned to one of four groups: Low volume [(LV); $n = 6$, 23.3 ± 1.2 years, height = 169.9 ± 8.4 , body mass 66.4 ± 11.0 kg] 1 set per exercise and 3 sets per muscle group per session; moderate volume [(MV); $n = 6$, 23.3 ± 1.4 years, height = 173.3 ± 7.6 , body mass 71.4 ± 8.5 kg] 2 sets per exercise and 6 sets per muscle group per session; high volume [(HV); $n = 8$, 23.9 ± 2.0 years, height = 173.0 ± 9.8 , body mass 69.4 ± 12.5 kg] 3 sets per exercise and 9 sets per muscle group; and a non-resistance training control group [(C) $n = 7$, 22.1 ± 1.1 years, height = 169.7 ± 6.9 , body mass 71.1 ± 14.2 kg]. The study was approved by the University Scientific Committee, and all subjects signed an informed consent document before the start the study.

Subjects with a diagnosed injury or orthopedic limitation were excluded from participating in this investigation. Also, subjects were excluded if they participated in any structured RT program within the past 5 years.

Familiarization Period. Before the beginning of the study, all the subjects participated in a 3-week familiarization period, which consisted of 9 RT sessions performed 3 times a week on nonconsecutive days. During this period, each subject performed 3 sets of 8–10 repetitions on a total of 8 exercises for the upper body, torso, and lower body. Because the subjects did not have experience participating in a structured RT program, throughout the familiarization period they received close supervision and instruction on proper exercise technique and training principles.

Procedures

Testing Procedure. Before (*T1*) and after 6 weeks of training (*T2*), we assessed body mass and height on a standard scale and stadiometer according the methods described by Ross and Marfell-Jones (29). Body mass index (BMI) was calculated using body mass and height ($\text{kg} \cdot \text{m}^{-2}$). In addition, each subject performed a progressive resistance test (PRT) aimed to determine the 1RM and the maximal average power (AP) produced from light to heavy weights on 2 upper-body exercises (bench press [BP] and upright row [UR]) and 1 lower-body exercise (parallel squat [SQ]) (25). After a standardized warm-up, each subject started the PRT, which consisted of 8 sets of 2 repetitions performed with maximal acceleration, alternating with rest periods between 2 minutes for the light load, 3–4 minutes for the moderate load, and 5 minutes for the higher load. The first and second sets were performed with a light weight (approximately 25–45% of estimated 1RM), the third and fourth sets with a medium weight (approximately 50–65% of estimated 1RM), the fifth and sixth sets with a medium to heavy weight (approximately 70–80% of estimated 1RM), and the seventh and eighth sets with a maximum or near maximum weight (approximately 85–100% of estimated 1RM). In each set, the repetition that produced the greatest average power was selected for the analysis.

Instrumentation

An optical rotary encoder (Real Power, Globus, Italy) with a minimum lower position register of 1 mm was used for measuring the position and calculating the velocity, force, and power applied during each repetition of PRT. For each of the 3 exercises, the cable of the encoder was connected to the bar in such a way that the exercise could be performed freely. The encoder's method of functioning enabled the cable to move in either vertical direction of the movement, sending the position of the bar every millisecond (1,000 Hz) to an interface that was connected to a computer. Proprietary software for the encoder (Real Power J110) was used to calculate the average force in Newtons, velocity in meters per second (v), and the average power (in watts) produced during the complete concentric phase of each repetition. Body weight plus the weight on the bar during the squat were used to calculate power (8). The highest average maximal power value (AP) measured along the PRT was used as a reference to indicate power performance on the 3 resistance exercises (3).

One Repetition Maximum Determination From Progressive Resistance Test

If a subject was able to do more than 1 repetition on the last set of the PRT, the subject rested for 3–5 minutes before he or she attempted another 1RM trial (10). All subjects were able to achieve their 1RM within 2 or 3 trials.

The PRT trials for the 3 exercises were performed on 3 different days with 48 hours of rest between trials. The test-retest intraclass reliability for the 3 exercise test was $R > 0.93$ to $R \leq 0.98$ ($p \leq 0.001$) with a coefficient of variation ranging from 0.8 to 2.1%.

Exercises

The BP and UR exercises were performed using Olympic bars and plates (1). For the BP, subjects had to maintain contact with the bench throughout the lift and perform each repetition with proper exercise technique. For the

UR, the subjects were instructed to keep the trunk as vertical as possible and avoid any uncontrolled movements during the lift.

The SQ was performed on a Smith machine. To standardize exercise technique, subjects were instructed to maintain a shoulder width stance and descend until the thighs were parallel to the floor.

Training Procedure

The study was carried out during the end of the preseason (September to the middle of October). The 3 RT groups were trained in a gym 3 times a week on nonconsecutive days for 6 weeks. All subjects performed a total of 18 RT sessions, which were split into 2 different training workouts (Table 1).

As each training routine was designed to train 3 different muscle groups, a total of 9 workouts per muscle group were accomplished along the intervention. Each routine was performed every 4–5 days. This training frequency has been shown to have a positive effect on strength development in novice and recreational lifters (27).

The training exercises were performed with free weights and a Smith machine and all training sessions were supervised and instructed by qualified research assistants. To improve the quality of supervision, a ratio of 1 instructor to 3 subjects was maintained during all the sessions.

Because all of the subjects were novice lifters, an 8-week nonperiodized training regimen was employed to provide an adequate stimulus for increasing strength and power (9). To equate the exercise intensity, all groups performed a program design of 8 repetitions per set with a load of approximately 75% 1RM with 3 minutes of rest between sets (10). If a subject could not reach the desired number of repetitions per set, an additional approximately 30 seconds of rest was allowed until the total number of prescribed repetitions was completed at every set.

To quantify the volume for each group, we used an index determined by the product of percent 1RM × repetitions ×

sets performed per exercise and per muscle group as a normalized reference to assess the effects of the 3 different RT volumes on performance (5,21). Table 2 summarizes the volume and intensity determined for each of the 3 intervention groups.

At the start of the study, there were no significant differences between groups in anthropometric or performance variables. However, during the study period, 5 subjects (1 male from C, 2 males from LV, and 2 females from

TABLE 1. Exercises performed in the 2 training routines.

Training program 1	Training program 2
Bench press	Smith machine parallel squat
Incline bench press	Leg press
Dumbbell fly	Knee extension
Upright row	Lat pull-down
Lateral raise	Seated row
Posterior lateral raise	1 arm dumbbell row
Barbell biceps curl	Machine triceps extension
Dumbbell biceps curl	Standing triceps pushdown
Machine biceps curl	1 arm triceps extension

TABLE 2. Acute program variables for the intervention groups.*

Variable	LV (n = 6)	MV (n = 6)	HV (n = 8)
Number of exercise per session	9	9	9
Exercise per muscle group	3	3	3
Set per exercise	1	2	3
Total set per session	9	18	27
Relative intensity (%1RM)	75	75	75
Repetition per set	8	8	8
Total repetition per exercise	8	16	24
Total repetition per muscle group and session	24 (72)	48 (144)	72 (216)
Relative volume per exercise (set × repetition × %1RM)	6	12	18
Relative volume per muscle group and session (∑ set × repetition × %1RM of every exercise)	18 (54)	36 (108)	54 (162)

*LV, low volume; MV, moderate volume; HV, high volume; 1RM, 1 repetition maximum.

MV) withdrew from the study for personal reasons not related to the training program leaving the composition and characteristics of the groups as follows:

- Low volume: $n = 6$ (3 men and 3 women) age, 23.3 ± 1.2 years; height, 169.9 ± 8.4 cm; body mass, 66.4 ± 11.0 kg; BMI, 22.9 ± 3.0 kg·m⁻².
- Moderate volume: $n = 6$ (5 men and 1 women) age, 23.0 ± 1.4 years; height, 173.3 ± 7.6 cm; body mass, 71.4 ± 8.5 kg; BMI, 23.7 ± 1.6 kg·m⁻².

- High volume: $n = 8$ (5 men and 3 women) age, 23.9 ± 2.0 years; height, 173.0 ± 9.8 cm; body mass, 69.4 ± 12.5 kg; BMI, 23.0 ± 2.3 kg·m⁻².
- Control (C) $n = 7$ (4 men and 3 women) age, 22.1 ± 1.1 years; height, 169.7 ± 6.9 cm; body mass, 71.1 ± 14.2 kg; BMI, 24.4 ± 3.1 kg·m⁻².

Analysis of the 27 subjects that completed the study showed no significant differences between groups in anthropometrics (height, body mass, or BMI) or performance (1RM or AP).

Statistical Analyses

Standard statistical methods were used for the calculation

of mean *SD*. The Kolmogorov-Smirnov, Shapiro-Wilk normality, and homogeneity tests (Levene's Statistic) were used to determine the degree of normality and homoscedasticity. All variables presented normal distribution and homoscedasticity.

An analysis of variance (ANOVA) 4×2 (group by time interaction) with repeated measures in the second factor was performed introducing the 1RM and AP as dependent variables measured in BP, UR, and SQ exercises. Effect

TABLE 3. Mean and *SD* before (T1) and after the training period (T2).†

Exercises	Variable	Test	Groups			
			LV (n = 6)	MV (n = 6)	HV (n = 8)	C (n = 7)
Bench press	1RM (kg)	T1	49.3 (19.1)	65.9 (24.5)	46.7 (19.6)	44.6 (21.0)
		T2	54.4* (22.1)	72.0* (28.4)	54.5** (18.2)	44.1 (21.9)
	Power (W)	T1	245.3 (146.9)	342.6 (142.7)	239.9 (111.0)	268.0 (175.2)
		T2	270.5 (126.7)	376.3* (133.2)	277.2** (118.4)	260.1 (168.5)
Upright row	1RM (kg)	T1	40.8 (10.7)	44.2 (9.9)	38.9 (10.7)	35.4 (12.2)
		T2	45.0* (13.8)	49.9** (12.9)	45.7** (13.5)	35.9 (11.7)
	Power (W)	T1	259.2 (89.6)	311.3 (82.4)	239.9 (111.0)	271.5 (136.7)
		T2	285.3 (99.8)	365.3 (99.1)	277.2 (118.4)	236.5 (138.3)
Squat	1RM (kg)	T1	103 (30.8)	126.3 (29.2)	102.1 (26.7)	100.7 (45.0)
		T2	107.1 (30.6)	129.8 (40.6)	119.8** (33.6)	101.3 (43.9)
	Power (W)	T1	959.9 (253.5)	1136.9 (272.6)	923.1 (213.3)	1006.2 (362.6)
		T2	1095.8** (303.2)	1153.4 (282.9)	974.8 (233.7)	1018.0 (364.1)

†Significant differences from T1 $p < 0.05$.

**Significant difference from T1 $p < 0.01$.

LV, low volume; MV, moderate volume; HV, high volume; 1RM, 1 repetition maximum.

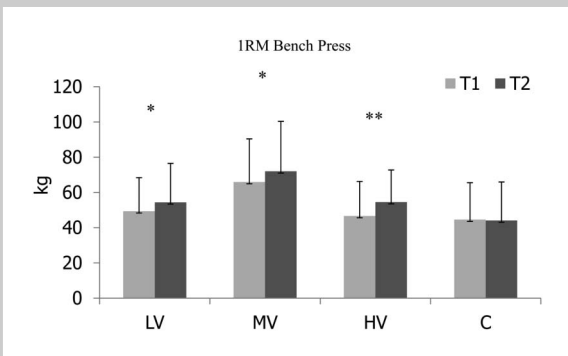


Figure 1. Comparison between 1 repetition maximum (1RM) bench press value achieved at T1 and T2 for all groups; * $p < 0.05$, ** $p < 0.01$. LV, low volume; MV, moderate volume; HV, high volume.

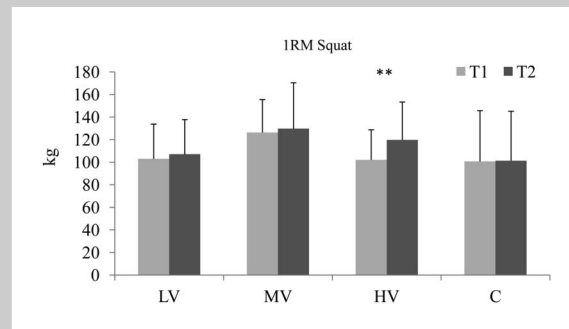


Figure 3. Comparison between 1 repetition maximum (1RM) squat value achieved at T1 and T2 for all groups; ** $p < 0.01$. LV, low volume; MV, moderate volume; HV, high volume. LV, low volume; MV, moderate volume; HV, high volume.

sizes (ES) were analyzed to determine the magnitude of an effect independent of sample size. Cohen’s ES (d) were measured by the formula:

$$\text{Cohen's } d = \frac{M_2 - M_1}{s}$$

For ANOVA, η^2 was calculated. Effect size benchmarks were considered for small ($d = 0.2$, $\eta^2 = 0.01$), moderate ($d = 0.5$, $\eta^2 = 0.06$), and large ($d = 0.8$, $\eta^2 = 0.14$). A multivariate analysis of effects was performed for the different treatment groups on all the dependent variables.

Analysis of Gender Interaction. To check the eventual bias introduced by the gender variable, because of differential dropout of men and women across the groups, an ANOVA $4 \times 2 \times 2$ (group by time by gender) with repeated measures in the second factor was performed introducing the 1RM and AP as dependent variables. Adding the gender as the third factor was a statistical control strategy to find significant interactions produced by this variable.

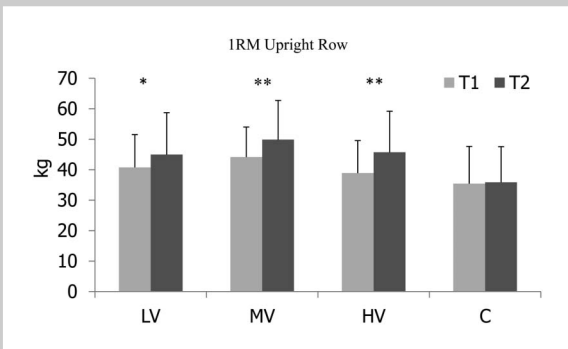


Figure 2. Comparison between 1 repetition maximum (1RM) upright row value achieved at T1 and T2 for all groups; * $p < 0.05$, ** $p < 0.01$. LV, low volume; MV, moderate volume; HV, high volume.

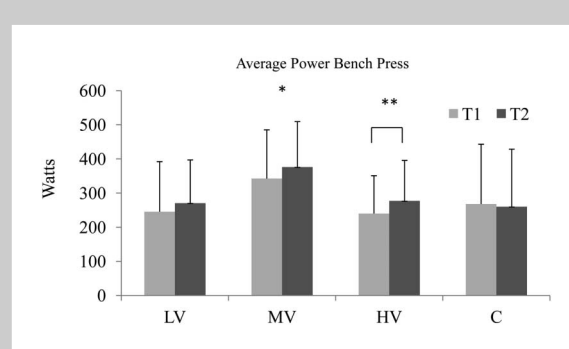


Figure 4. Comparison between average power bench press value achieved at T1 and T2 for all groups; * $p < 0.05$, ** $p < 0.01$. LV, low volume; MV, moderate volume; HV, high volume.

Analysis of Interaction Between Training Volume Levels and Time. Because there was sufficient suspicion that the effect was not consistent in the various treatment levels (groups), we conducted a specific contrast of changes between pre- and postmeasures for each level of treatment and for each of the performance-dependent variables (1RM and AP for the 3 exercise BP, UR, and SQ).

All statistics were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 17; SPSS, Inc., Chicago, IL, USA). An α level of 0.05 was used throughout this study.

RESULTS

Twenty-seven subjects (6 in the LV group, 6 in the MV group, 8 in the HV group, and 7 in the C group) completed the aforementioned training protocols (Table 3), and no injuries were reported. The mean and SD for 1RM and AP data are presented in Table 3.

Gender Interaction

As expected, the significant main effect of gender over 1RM and AP was confirmed. However, this variable did not show

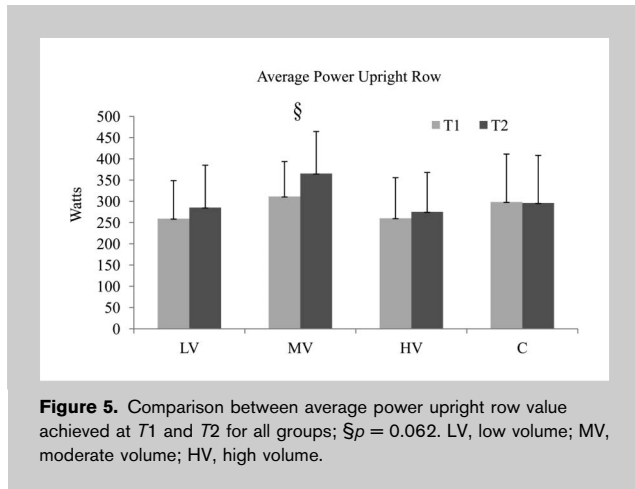


Figure 5. Comparison between average power upright row value achieved at T1 and T2 for all groups; $S_p = 0.062$. LV, low volume; MV, moderate volume; HV, high volume.

any significant interaction with the rest of independent variables. Consequently, the higher the number of men in a group, the higher 1RM and AP values are to be expected, but this will not affect the way the treatments are causing effect. As such, no relevant bias was confirmed for the gender variable, and the variable was considered a candidate for rejection from the analysis.

Training Effects

The overall effect of training showed significant differences for the total sample, $F(6, 18) = 11.042, p < 0.000$, whereas the ES was calculated $\eta^2 = 0.786$. The main effect of training group was not found significant for the global data, but significant differences were found for the interaction between groups and the effect of training across time, with a $F(18, 60) = 2.068, p < 0.019$, and ES of $\eta^2 = 0.383$.

A multivariate analysis of effects for the different treatment groups applied on all the dependent variables, showing that while the C obtained no improvement ($F(6, 18) = 0.5, p < 0.78$, and $\eta^2 = 0.152$), significant enhancement were found for the 3 training groups—LV: $F(6, 18) = 2.068, p < 0.019$, and $\eta^2 = 0.383$; MV: $F(6, 18) = 2.068, p < 0.019$,

and $d_p^2 = 0.383$; and HV: $F(6, 18) = 2.068, p < 0.019$, and $\eta^2 = 0.383$.

In line with the results of multivariate analysis, all dependent variables showed a change between the scores before and after treatment, which is attributable to the training groups. However, C effect is null or even going in the opposite direction, which explains the significant interaction effects found. The 1RM analysis shows that HV reaches significant differences in all the 3 exercises (1RM-BP, $p = 0.001$; 1RM-UR, $p = 0.000$; and 1RM-SQ, $p = 0.000$), whereas MV and LV reached significant improvement in 1RM for both upper-body exercise (1RM-BP, $p = 0.017$ and $p = 0.043$; 1RM-UR $p = 0.002$ and $p = 0.011$, respectively) but not for 1RM-SQ (Figures 1–3). These same contrasts in AP measures show that HV and MV only reach significant differences for AP-BP ($p = 0.007$ and $p = 0.030$, respectively), whereas LV shows significant difference for AP-SQ ($p = 0.002$) but not for the upper-body exercises (Figures 3–6).

The ES analysis revealed only low to moderate values for the before and after comparison for all the 4 groups. The LV group showed moderate ES for 1RM-BP (0.27), 1RM-UR (0.44), AP-UR (0.30), and AP-SQ (0.53). The MV group showed moderate ES for 1RM-BP (0.25), 1RM-UR (0.54), AP-BP (0.27), and 1RM-UR (0.65), and the HV group showed the moderate ES for 1RM-BP (0.45), 1RM-UR (0.60), 1RM-SQ (0.47), and AP-BP (0.45), whereas its ES for AP-SQ (0.25) was lower than that achieved by the LV group. The ES for C were low in all conditions. In general, the ES is greater in the HV group for all the 3 exercises, meanwhile the MV group shows the higher ES for UR-AP and the LV group for AP-SQ.

DISCUSSION

The main finding of this study was that the HV protocol was a more effective approach for improving maximum strength, whereas LV and MV seem to be the better strategies for enhancing lower-body or upper-body average power performance, respectively, in college team sport athletes with no previous RT experience using traditional external load such as free weight or weight machines. Figures 1–6 compare the 1RM and AP value measured at T1 and T2 for each exercise along all the 4 groups.

In addition, the ES analysis also indicates that the HV protocol would be a more appropriate strategy for increasing 1RM strength for all the 3 exercises and possibly for improving AP-BP. Furthermore, the MV and LV protocols could provide a better stimulus for increasing power performance for UR and SQ, respectively.

The results of our study are similar to those reported by Rhea et al. (28) after 12 weeks of RT for the lower limbs whereby 3 sets produced a 56% increase in strength compared with a 26% for the 1 set protocol (28). Also, Munn et al. (24) found that 3 sets of RT on the biceps curl exercise produced about twice the increase in strength (48%) with

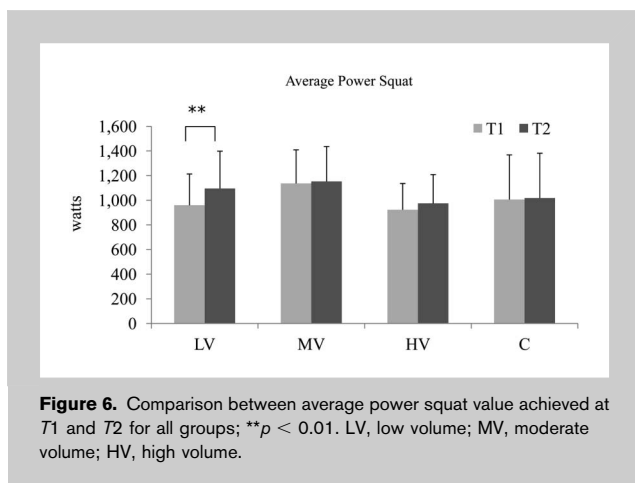


Figure 6. Comparison between average power squat value achieved at T1 and T2 for all groups; $**p < 0.01$. LV, low volume; MV, moderate volume; HV, high volume.

respect to training with 1 set (25%) at the same relative intensity (24). As noted in the present investigation, these findings also indicate greater strength gains resulting from higher training volumes during the early phase of RT. These results are of importance because maximum strength has been found to be a key factor for improving sport performance and reducing the incidence of sports-related injuries in team sport athletes (13). Conversely, our findings are in contrast to those reported by Ostrowski et al. (26), who reported that low, moderate, and high RT volumes were equally effective in enhancing 1RM strength in bench press and squat exercises after 10 weeks of training. However, using the data provided by the Ostrowski et al. (26) to calculate the ES, the LV and MV groups were found to have similar and moderate ES values ranging from 0.32 to 0.48 for the 1RM-BP and 1RM-SQ, respectively. Conversely, in the later report, the HV group showed a lower ES (0.16) for 1RM-BP and a somewhat larger ES (0.68) for 1RM-SQ with respect to the value reported for the HV group in our study. These differences could be explained by the characteristic of the program design and the training status of the subjects.

Both training protocols were similar in the number of sets per exercise and muscle group and the rest periods. However, unlike the study of Ostrowski et al. (26) in which the intensity was varied over time, in our study, this variable was kept constant (75% of 1RM) throughout the entire training period. Also, subjects who participated in the study of Ostrowski et al. (26) were encouraged to train until failure in every set. In the present study, however, only some subjects in the HV group reached volitional fatigue during the last set on several upper-body exercises but not on lower-body exercises. Research has demonstrated that training to failure after 6 weeks of RT resulted in superior gains in strength and hypertrophy in both untrained and trained subjects (16). These adaptations were attributed to greater activation of motor units and secretion of growth-promoting hormones (33). Of note, the training period in the study by Ostrowski et al. (26) lasted 10 weeks, which may have been long enough for continuously training to failure. Although speculative, this may have caused a plateau in performance (33).

Also, the significant improvements on the AP-BP by the HV and MV groups and on the AP-SQ by the LV group were found in our study, and the lack of significant improvement on power production by the subjects reported by Ostrowski et al. (26) could be explained by the greater number of sets performed until failure. Training to muscular exhaustion has been associated with a greater and nonselective activation of all motor units (types I and II) that can produce a better stimulus to improve strength and hypertrophy (33) but may not be the best strategy for improving muscular power. Fatigue during multiple sets to failure may also result from changes in central nervous system drive to the motor neurons, changes in neuromuscular propagation, dehydration, and the availability of various metabolic substrates (16). Regardless of mechanism of fatigue, it is generally accepted

that exercising in a fatigued state is likely to compromise the quality of speed and power performance in resistance trained or team sport athletes (3). Also, the subjects in the study by Ostrowski et al. (26) had a higher level of strength performance than the male soccer players or female volleyball athletes of our study. This is an important consideration because in novice lifters, the application of high-intensity loads in regard to the velocity of the movement can be a positive stimulus to enhance strength and power, but as the level of performance increases, the needs to introduce periodized training strategies are warranted (33).

In regard to power performance, both the MV and the HV groups seem to be more effective for improving AP for the upper-body exercises, meanwhile the LV was the only group that significantly enhances AP-SQ. Because of the relatively high physical demands on the lower body compared with upper body in soccer and volleyball training, it seems that MV or HV would be appropriate for improving upper-body power, whereas the LV protocol may have been advantageous to accomplish lower-body training and perhaps reduce the potential of overreaching or overtraining.

The significant improvements made by the LV group for AP-SQ could be explained by the low number of repetitions per session that allow the athletes to avoid the negative effects of fatigue on velocity and power performance (7). This situation could be taken as a positive factor to integrate different training loads commonly applied to improve various physical capabilities, such as speed and endurance, in team sport athletes.

The mechanisms by which HV of training influence larger strength gains was not investigated in this study, but it was speculated that there is a plateau in strength gains once more than 3 sets per exercise are performed (19,20). The reasons for this plateau have not been currently explained. It is known that mechanical loading stimulates protein synthesis in skeletal muscle and increasing loads result in greater responses until a plateau is reached (21).

On the other hand, the significant improvements made by the 3 groups on the upper-body exercise 1RM-BP and 1RM-UR could be explained by factors related to testing and training specificity. Unlike the SQ exercise whereby some movements are similar to exercises performed during a dynamic warm-up, upper-body exercises are not commonly integrated in the training session and therefore the possibility for greater training-induced gains is possible.

Although speculative, to achieve a rapid increase in strength during the preseason, it seems advisable for team sport athletes to follow a HV RT program as a part of their preparatory conditioning period. Conversely, during the season in which the focus of physical conditioning is on the maintenance of physical fitness and performance measures (15), the LV RT protocols could be a reasonable strategy for team sport athletes.

In conclusion, for team sport college athletes with previous RT experience using traditional external loads, a HV of RT

seems to be the best strategy for improving 1RM strength. However, to enhance average power performance in this population, an LV program seems to be a better option for the lower-body power, whereas an MV or a HV program seems to be more effective for improving upper-body power. This strategy could be a reasonable approach for integrating RT into the in-season training to maintain and possibly enhance performance (3). However, additional research with a larger sample size is needed to further our understanding of different training volumes on strength and power in athletes.

PRACTICAL APPLICATIONS

By using the HV RT protocols during the early phase of training, team sport athletes with no previous RT experience may be able to enhance strength performance in a relatively short period of time (6 weeks).

Therefore, it is recommended to use HV programs (3 sets per exercise and 9 sets per muscle group) instead of LV (1 set per exercise and 3 sets per muscle group) programs if the aim was to maximize strength gains. However, to increase power, an LV training programs should be adopted. Based on this recommendation, we could speculate that to maintain the initial gain in strength achieved during the preparatory period, an LV resistance protocol should be integrated with other specific tasks during the in-season. This strategy will allow coaches to have more time for other sport-specific exercises with a minimum risk of losing the level of physical conditioning achieved during the preseason.

It is important to note that the present findings were done in a relatively short preseason period of 6 weeks. Because the competition period is typically of longer duration, it will be necessary to monitor strength and power performance at the end of every mesocycle (about 6 weeks) to know how these capabilities progress throughout the season.

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