

# The effect of resistance training set configuration on strength, power, and hormonal adaptation in female volleyball players

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**Abstract:** The primary purpose of this investigation was to determine the impact of altering the set structure during an 8-week resistance training program on anthropometric, hormonal, and strength power characteristics. Thirty female volleyball players were recruited for participation and then randomly assigned to 1 of 3 resistance training groups: (i) cluster sets (CRT;  $n = 10$ ), (ii) traditional sets (TRT;  $n = 10$ ), or (iii) control (CON;  $n = 10$ ). All athletes were evaluated for thigh and arm circumference, vertical jump, 20-m sprint, 4 × 9-m shuttle-run, 1-repetition maximum (1RM) back squat, bench press, military press, and deadlift prior to and after an 8-week periodized training intervention. Blood samples were taken before and after the 8-week training period to evaluate resting testosterone, cortisol, and insulin-like growth factor 1 responses to the training period. After 8 weeks of training the CRT group displayed a small but significant improvement in vertical jump (CRT: effect size (ES) = 0.38, 7.1%) performance when compared with the TRT group (ES = 0.34, 5.6%). Both the CRT and TRT training interventions resulted in very large increases in the 1RM squat (CRT:  $8.4\% \pm 1.2\%$ ; TRT:  $7.3\% \pm 0.6\%$ ), bench press (CRT:  $8.3\% \pm 2.0\%$ ; TRT:  $8.7\% \pm 1.9\%$ ), military press (CRT:  $5.7\% \pm 1.2\%$ ; TRT:  $5.5\% \pm 1.6\%$ ), and deadlift (CRT:  $8.2\% \pm 1.6\%$ ; TRT:  $8.3\% \pm 2.2\%$ ). There were no significant differences in 20-m sprint or 4 × 9-m shuttle run times between the CRT, TRT, and CON groups. These results suggest that cluster sets allow for greater improvements in vertical jump performance and equal improvements in strength gains to those seen with traditional sets.

**Key words:** inter-repetition rest, intra-set test, cluster set, strength training, testosterone, vertical jump.

**Résumé :** Le principal objectif de cette étude est de déterminer l'impact de la modification de la structure établie durant un programme d'entraînement en résistance de 8 semaines sur des variables anthropométriques, hormonales et musculaires (force, puissance). On recrute 30 joueuses de volleyball et on les répartit aléatoirement dans trois groupes d'entraînement en résistance : (i) séries groupées (« CRT »;  $n = 10$ ), (ii) séries traditionnelles (« TRT »;  $n = 10$ ) et (iii) contrôle (CON;  $n = 10$ ). On évalue chez toutes les joueuses les variables suivantes : tour de cuisse et de bras, saut vertical, sprint de 20 m, course-navette de 4 × 9 m, maximum sans répétition (« 1RM ») à l'accroupissement avec charge arrière, développé couché, développé militaire et soulevé de terre avant et après 8 semaines d'entraînement périodisé. Avant et après les 8 semaines d'entraînement, on prélève des échantillons de sang pour l'évaluation au repos de la concentration de testostérone, de cortisol et du facteur de croissance 1 analogue à l'insuline afin de déterminer les réponses à l'entraînement. Après 8 semaines d'entraînement, le groupe CRT présente une amélioration significative quoique faible au saut vertical (CRT : AE = 0,38, 7,1 %) comparativement au groupe TRT (ampleur de l'effet (AE) = 0,34, 5,6 %). Les groupes CRT et TRT présentent de fortes augmentations de 1RM à l'accroupissement (CRT :  $8,4 \pm 1,2\%$  ; TRT :  $7,3 \pm 0,6\%$ ), au développé couché (CRT :  $8,3 \pm 2,0\%$  ; TRT :  $8,7 \pm 1,9\%$ ), au développé militaire (CRT :  $5,7 \pm 1,2\%$  ; TRT :  $5,5 \pm 1,6\%$ ) et au soulevé de terre (CRT :  $8,2 \pm 1,6\%$  ; TRT :  $8,3 \pm 2,2\%$ ). On ne note pas de différences significatives entre les groupes (CRT, TRT et CON) au sprint de 20 m et à la course-navette de 4 × 9 m. D'après les résultats, les séries groupées susciteraient une plus grande amélioration au saut vertical et une amélioration égale de la force comparativement aux séries traditionnelles. [Traduit par la Rédaction]

**Mots-clés :** repos entre les répétitions, test intra-série, série groupée, entraînement à la force, testostérone, saut vertical.

## Introduction

When constructing a periodized resistance training program the ability to introduce training variation is an essential tool for stimulating recovery and adaptation, as well as translating adaptive responses into sport-specific performance gains (Haff et al. 2008b). Overall training variations can be introduced into a program through the manipulation of training load, number of sets, number of repetitions, set configurations, and the exercises selected. Through a logical introduction of training variation, novel training stimuli can be introduced into the athlete's training program, thus enhancing the physiological adaptations that underpin targeted performance gains (Hodges et al. 2005).

One novel technique for introducing variation into a resistance training program is the use of cluster sets (Haff et al. 2008a, 2008b). Cluster sets employ short periods of rest (e.g., 14–40 s) that are either placed between individual repetitions (i.e., inter-repetition rest intervals) or between cluster of repetitions (i.e., intra-set rest intervals) that are contained within an individual set (Tufano et al. 2016). In 2003, Haff et al. (2003) reported that using clusters sets (i.e., 5 repetitions with 30 s of rest between repetitions) can result in the maintenance of velocity across a set of clean pulls when compared with a traditional set. Similarly, Hardee et al. (2012) report that across 6 repetitions of the power clean the manipulation of the inter-repetition rest interval can slow the fatigue-induced velocity loss

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across a set when compared with a traditional set. More importantly the degree of velocity maintenance across a cluster set is largely impacted by the length of the inter-repetition and intra-set rest intervals used. Specifically, [Hardee et al. \(2012\)](#) demonstrated that utilizing a 20-s inter-repetition rest interval results in a greater velocity decline across a set when compared with a 40-s inter-repetition rest interval. Similarly, [Hansen et al. \(2011\)](#) demonstrate that over 6 repetitions there is a greater peak velocity decline in jump squats performed with a traditional set structure when compared with cluster sets of 1 (inter-repetition rest = 12 s), 2 (intra-set rest = 30 s), or 3 repetitions (intra-set rest = 60 s). Ultimately, based upon the available literature the use of cluster sets allows for higher velocities to be maintained across the training set, which can have a direct effect on the average power output achieved during each repetition. Based upon the ability of cluster sets to maintain movement velocity during resistance training, it has generally been recommended that cluster sets be used with exercises and training programs that target the development of power generating capacities ([Haff et al. 2008a, 2008b](#)). Conversely, when attempting to target the development of maximal strength it has been recommended that traditional sets are considered more effective ([Rooney et al. 1994](#)) or equally effective when compared with cluster sets. However, there is some research that suggests that cluster sets may also be an effective tool for developing muscular strength ([Oliver et al. 2013](#)).

One possible explanation for why cluster sets result in an increase in velocity is related to the ability of the inter-repetition or intra-set rest interval allowing for partial recovery of phosphocreatine (PCr) stores ([Haff et al. 2008a, 2008b; Iglesias-Soler et al. 2014](#)). With traditional sets of 5 to 10 repetitions there is a progressive decrease in PCr stores and a concomitant rise in lactate accumulation ([Gorostiaga et al. 2012](#)). The introduction of a 10–30-s inter-repetition or intra-set rest interval has been suggested to result in a lower acute lactate response ([Girman et al. 2014](#)), which may result in alterations in acute hormonal responses to a training bout that contains cluster sets ([Oliver et al. 2015](#)). In one of the few studies examining the acute hormonal responses to cluster sets, [Oliver et al. \(2015\)](#) report that cluster sets result in a significantly lower lactate, growth hormone, and cortisol response pattern. The results of this study suggest that the use of cluster sets results in less acute metabolic stress, when compared with traditional set structures.

While there are numerous studies that have examined the acute impact of cluster sets on various mechanical factors, there is limited research exploring the longitudinal impact of cluster sets on physiological and performance adaptations. In one of the first training studies looking at the use of cluster sets, [Oliver et al. \(2013\)](#) noted that more frequent inter-set rest intervals resulted in greater strength and hypertrophic gains when compared with traditional sets when employed as part of a 12-week resistance training program that focused on hypertrophic adaptations. More recently, [Asadi and Ramirez-Campillo \(2016\)](#) examined the impact of using cluster sets during a 6-week plyometric training intervention. After 6 weeks the cluster set intervention resulted in large significant improvements in countermovement jump ( $g = 1.23$ ) and t-test ( $g = 1.20$ ) performance, while the traditional set training program only demonstrated medium significant improvements in countermovement jump ( $g = 0.74$ ) and t-test ( $g = 0.70$ ) performance. When examining the 20-m sprint test both the traditional ( $g = 1.22$ ) and cluster ( $g = 1.10$ ) programs had a very large significant impact on 20-m sprint performance.

Based upon the limited longitudinal research examining cluster sets it appears that they may be a beneficial training tool that can impact muscular strength, sprinting speed, and explosive power during various jumping tasks. While this preliminary research seems promising, much more longitudinal research is warranted to fully understand the role cluster sets play in resistance training programs. Specifically, research that integrates cluster sets into the resistance training practices of athletes who are training

**Table 1.** Subject characteristics.

Characteristic	CRT group (n = 10)	TRT group (n = 10)	CON group (n = 10)	Total group (n = 30)
Age (y)	18.2±2.4	18.7±1.5	19.1±2.7	18.5±4.2
Height (m)	1.61±0.06	1.66±0.05	1.62.7±5.4	1.63±0.06
Weight (kg)	54.5±6.6	56.5±9.0	54.0±7.5	55.1±9.4
Training age (y)	5.5±2.1	4.7±1.4	5.1±1.8	5.2±1.7

**Note:** Values are means ± SD. CON, control; CRT, cluster set; TRT, traditional set.

for a specific sport, such as volleyball, is warranted. To our knowledge there are no current studies that have examined the longitudinal impact of using cluster sets on strength and power performance or hormonal adaptations in female athletes.

Therefore, the primary purpose of the present investigation was to determine the impact 8 weeks of resistance training with differing set configurations (i.e., cluster and traditional sets) on anthropometrics, power output, strength, and hormonal adaptations in female volleyball players. We hypothesized that cluster sets would result in greater changes to anthropometric characteristics and increases in muscular power when compared with traditional sets.

## Material and methods

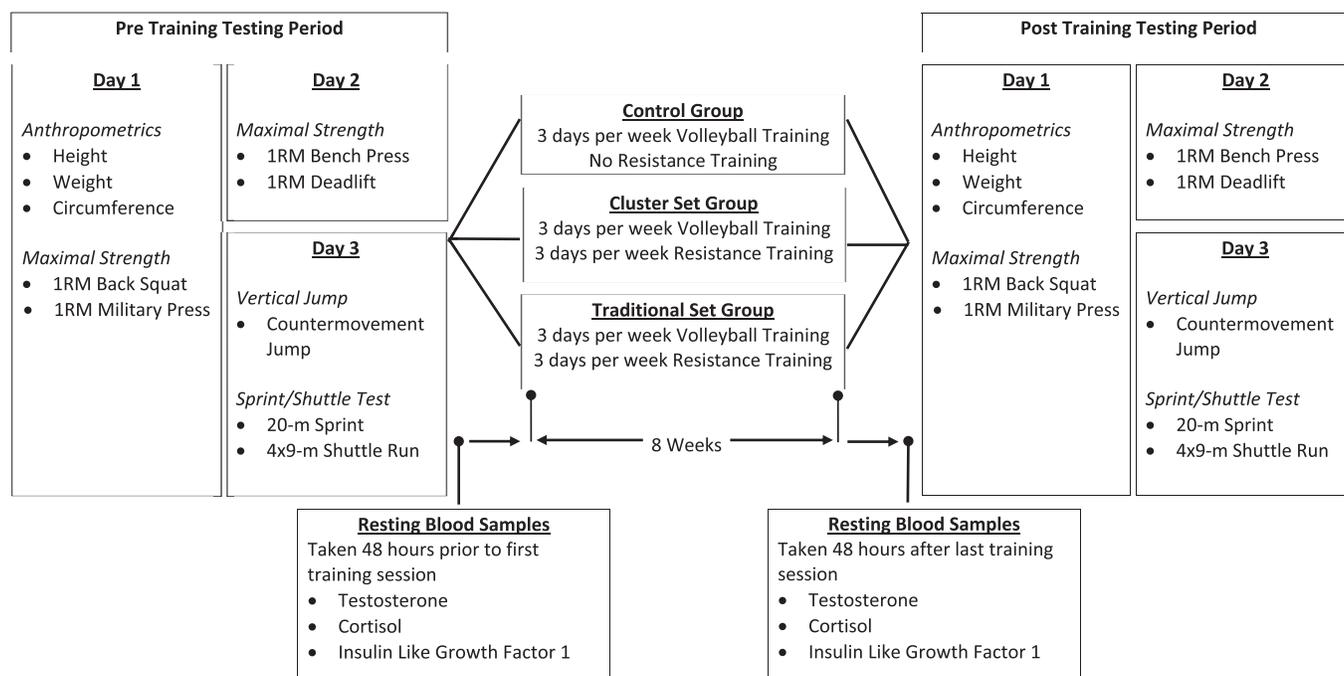
### Participants

A total of 30 female volleyball players were recruited for participation in the present study. All subjects were familiar with basic resistance training methods, but had not consistently performed resistance training over the past 6 months. Prior to participating in the present study all subjects provided written informed consent in accordance with the Declaration of Helsinki and the Institutional Ethics Review Committee for the University of Guilan and Islamic Azad University. If a subject was under the age of 18 years parental assent was also acquired in accordance with the Institutional Ethics Committee requirements. All subjects were informed that they were allowed to withdraw from this investigation at any time without penalty. Additionally, all subjects completed a questionnaire that examined their medical, injury, and performance histories. To ensure no subjects had any orthopedic or health related conditions that could preclude them from participating in resistance and high-intensity training, all subjects performed a supervised screening undertaken by a physician. Subjects were only included in the present investigation if they had no history of anterior cruciate ligament injuries or other lower limb injuries within the 6 months prior to the initiation of the study. A summary of subject characteristics can be found in [Table 1](#).

### Study design

The present study is a longitudinal research design with 3 randomly assigned parallel training groups. Thirty female volleyball players were randomly assigned into 1 of 3 training groups: (i) traditional set (TRT;  $n = 10$ ), (ii) cluster set (CRT;  $n = 10$ ), or (iii) control condition (CON;  $n = 10$ ). All training groups performed volleyball-specific training on 3 nonconsecutive days (Monday, Wednesday, Friday), while the CRT and TRT groups also performed resistance training on the days in which volleyball training was not completed (Tuesday, Thursday, Saturday). One week prior to the initiation of the 8-week training period all subjects were familiarized with the testing and training procedures. Across 3 consecutive days each subject underwent a battery of tests. On day 1 each subject had their anthropometric (i.e., height, weight, and circumferences) assessed. After completing these measures, the subjects were assessed for their 1-repetition maximum (1RM) back squat and military press. On day 2 each subject's 1RM bench press and deadlift were assessed. On day 3 each subject's vertical jump, 20-m sprint, and 4 × 9-m shuttle-run performance were measured.

**Fig. 1.** Experimental design. All testing sessions were performed at the same time of day to control for diurnal effects on all measures. 1RM, 1-repetition maximum.



Finally, 48 h prior to the initiation of the training period blood draws were undertaken to determine resting hormone (i.e., testosterone, cortisol, and insulin-like growth factor (IGF-1)) levels. Forty-eight hours after the completion of the 8-week training period blood draws were again completed to determine resting hormonal levels. The same performance battery was then repeated across 3 successive days after the completion of the post-training period blood measurement. A summary of the experimental design is presented in Fig. 1.

### Testing procedures

Testing procedures were divided across 3 successive days prior to and after the completion of the 8-week training period. All testing sessions were conducted in the same order to account for accumulative fatigue. Additionally, all testing sessions were conducted at the same time of day in order account for diurnal performance effects that have typically been noted when assessing markers of strength and power (Sedliak et al. 2007, 2008).

### Anthropometric measures

Height was measured to the nearest 0.1 cm with the use of a wall-mounted stadiometer (Seca 222, Terre Haute, Ind., USA). Body mass was measured to the nearest 0.1 kg using a medial scale (Tanita, BC-418MA, Tokyo, Japan). Circumference measures were taken for the mid-arm and mid-thigh with previously established methods (Arazi et al. 2013). Briefly, the right arm and thigh were measured using an anatomical tape measure to the nearest 0.1 cm during a full muscle contraction.

### Maximal strength assessment

Upper and lower body strength were measured with the use of a series of 1RM tests using free weights (Nebula Fitness Inc., Versailles, Ohio, USA). Specifically, all subjects performed a warm-up with a light resistance that allowed the performance of 5 to 10 repetitions. The resistance was then increased with the athlete performing 2-3 repetitions. From this point forward the athlete performed 1 repetition with each progressive increased load until volitional failure was achieved (Haff and Triplett 2016). The goal

was to complete a maximal lift within 5 attempts. Two minutes of rest was provided between each set.

### Vertical jump assessment

Prior to the completion of the countermovement vertical jump performance test all subjects underwent a standardized warm-up, which consisted of the performance a 10-min warm-up protocol consisting of submaximal running, active stretching, and a 3 sub-maximal vertical jumps. After the completion of the warm-up protocol each subject performed 3 maximal countermovement vertical jumps, each separated by a 30-s rest period based upon previously established methods (Arazi et al. 2014). All countermovement vertical jumps were performed with a self-selected countermovement depth.

The highest vertical displacement determined from the 3 jumps was then used to estimate a peak power output with the use of the equation developed by Sayers et al. (1999):

$$\text{peak power} = 0.67 \times \text{jump height} + 45.3 \times \text{body mass} - 2055$$

where peak power is in W, jump height in cm, and body mass in kg. Even though this formula was developed for the static jump it has been shown to result in a very small measurement error when used with countermovement jumps (Carlock et al. 2004; Sayers et al. 1999). Additionally, the accuracy of this formula has been shown to be unaffected by sex differences and commonly produced high intra-class correlations (ICC = 0.99) (Haff et al. 2005). As such this equation is commonly used when estimating countermovement vertical jump peak powers when assessing athletes (Carlock et al. 2004; Haff et al. 2005).

### Sprint testing

A 20-m sprint test was selected because it is a common test used in the evaluation of an athlete's sprinting ability. After the completion of a standardized warm-up all subjects performed 3 maximal 20-m sprints, each separated by 120 s of rest to ensure maximal

**Table 2.** Resistance-training program.

Wk	Exercises	Set type	Set 1			Rest (s)	Set 2			Rest (s)	Set 3			Rest (s)	Total rest (s)
			Cluster × reps	% 1RM	Cluster rest		Cluster × reps	% 1RM	Cluster rest		Cluster × reps	% 1RM	Cluster rest		
1–2	Squat, bench press, deadlift, military press	CRT	1×10	60	0	120	2×5	65	30	90	2×5	70	30	90	360
		TRT	1×10		0	120	1×10		0	120	1×10		0	120	360
3–4	Squat, bench press, deadlift, military press	CRT	1×10	70	0	120	2×5	75	20–30	90	1×4	80	20–30	90	320–360
		TRT	1×10		0	120	1×10		0	120	1×6		0	120	360
5–6	Jump squat, explosive bench press, deadlift, power clean	CRT	1×6	80	0	180	2×3	85	20	120	2×3	90	20	120	420
		TRT	1×8		0	180	1×6		0	180	1×4		0	180	540
7–8	Jump squat, explosive bench press, deadlift, power clean	CRT	3×5 UB	30	30	180	3×3 UB	35	20	120	3×1 UB	40	10	120	420
			3×5 LB	45			3×3 LB	50			3×1 LB	55			
		TRT	1×6 UB	30	0	180	1×4 UB	35	0	180	1×3 UB	40	0	180	540
			1×6 LB	45			1×4 LB	50			1×3 LB	55			

Note: 1RM, 1-repetition maximum; CRT, cluster set; LB, lower body; reps, repetitions; TRT, traditional set; UB, upper body.

recovery (Asadi and Ramirez-Campillo 2016; Rimmer and Sleivert 2000). Briefly, all subjects initiated the sprint from a standardized starting position that was 0.5 m behind the start line. The sprint start was automatically initiated as the subject passed the first timing gate at the 0-m mark. Timing continued until the subject passed through the final gate at 20 m. Running times were quantified with the use of photocell timing gates (JBL Systems, Oslo, Norway) with an accuracy of 0.001 s. The fastest sprint time obtained from the 3 trials was selected for analysis in this study (Rimmer and Sleivert 2000).

#### Shuttle-run test

To assess the subject's ability to sprint and change direction a 4 × 9-m shuttle run test was performed in accordance with previously published methods (Asadi 2013). Briefly, to initiate the test the subjects stood behind the starting line and upon command sprinted for 9 m. Upon the initiation of the sprint timing was automatically started with the use of photo cell timing gates (JBL Systems). Upon completing the 9-m sprint the subjects were asked to change direction with their preferred foot and then sprint back to the starting line. After the completion of the fourth 9-m section the subjects crossed the finish line and time was immediately recorded with the timing gate system. A total of 3 min was allotted between attempts for each subject to ensure adequate recovery and a maximization of performance.

#### Blood analyses

Baseline blood samples were taken 48 h prior to the initiation of the training period and 48 h after the completion of the last training session. At each sampling period 10 mL of blood were taken from an antecubital vein using standard venipuncture techniques. Based upon the work of Häkkinen et al. (1990), all samples were taken after 48 h of rest at the same time of day, after a 12-h fast and after 8 h of sleep to control of the circadian hormonal range. All blood samples were collected into a serum separator tubes by a trained phlebotomist using a vacutainer assembly.

Collected blood samples were then centrifuged at 1100g for 15 min. The resulting serum was frozen at –80 °C and later analyzed for testosterone, cortisol, and IGF-1. All analyses were performed with standardized procedures using commercially available enzyme-linked immunosorbent assays kits (Monobind Inc., Lake Forest, Calif., USA). The intra-assay variance was determined based upon a coefficient of variation <6%.

#### Training program

All subjects participated (CON, TRT, and CRT) in 3 days per week volleyball training for 60–70 min on Monday, Wednesday, and Friday. The TRT and CRT participated in 3 resistance training ses-

sions per week on Tuesday, Thursday, and Saturday. This resistance training program comprised a nonlinear undulating, multi-set, multi-exercise program that incorporated variation in intensity and volume throughout each week of training. All subjects in the present study were required to complete all training and each training session was monitored by a trained researcher to ensure that all training exercise were performed correctly with the appropriate loads and rest intervals. A summary of the training programs used by the TRT and CRT groups can be found in Table 2.

#### Statistical analysis

All values are presented as means ± SD. For each measure a percent change score was calculated ((post 8 weeks – baseline)/baseline × 100). A Shapiro–Wilk test was performed to determine if the data were normally distributed. To determine if significant differences existed between the 3 groups a 3 × 2 repeated-measures ANOVA was performed for each tested variable. Statistical significance was set at an  $\alpha \leq 0.05$  for these analyses. When significant *F* values were achieved pairwise comparisons in conjunction with a Bonferroni post hoc procedure were performed to determine where significant differences occur whilst controlling for type I errors. All statistics analyses were performed with the use of a statistics software package (SPSS version 16.0; SPSS, Chicago, Ill., USA).

Customized excel spreadsheets were used to calculate all effect-size (ES) statistics. Hedge's *g* was utilized to calculate an effect size for all measures (Lakens, 2013). This ES statistic was chosen as it corrects for bias that can typically be seen with small sample sizes. The magnitude of the ES statistics was considered as follows: trivial, <0.20; small, 0.20–0.50; medium, 0.5–0.80; large, 0.8–1.30; or very large >1.30 (Seitz et al. 2014b). The ES is reported in conjunction with the 95% confidence interval (CI) for all analyzed measures.

#### Results

There was a 100% compliance by all subjects within the present study and no injuries were noted in response to the training interventions used.

#### Anthropometrics

After the completion of the 8-week training period there were no significant changes in arm or thigh circumferences for the CON group ( $p > 0.05$ ). Conversely, after 8 weeks of training there was a significant ( $p \leq 0.05$ ) trivial increase in arm (ES = 0.17, 95% CI = –0.71 to 0.17) and thigh (ES = 0.17, 95% CI = –0.71 to 1.03) circumference in the TRT group. Similarly, the CRT group demonstrated significant trivial to small increases in the arm (ES = 0.34, 95% CI =

**Table 3.** Strength measures.

Strength (kg)	TRT group	CRT group	CON group
<b>1RM squat</b>			
Pre	44.1±1.2	44.6±0.70	44.1±1.1
Post	47.4±1.8*†	48.2±0.59*†	44±1.1
% Change	7.3±0.6†	8.4±1.2†	-0.25±1.0
ES	2.1 (0.94 to 3.09)b	1.8 (0.69 to 2.73)b	-0.1 (-0.97 to 0.78)a
<b>1RM bench press</b>			
Pre	24.3±0.6	24.7±0.7	24.6±0.7
Post	26.4±0.9*†	26.8±1.0*†	24.5±0.7
% Change	8.7±1.9†	8.3±2.0†	-0.4±1.2
ES	2.62 (1.33 to 3.68)b	2.23 (1.04 to 3.23)b	-0.13 (-1.15 to 0.75)a
<b>1RM military press</b>			
Pre	14.7±0.3	14.9±0.5	14.9±0.2
Post	15.6±0.4*†	15.8±0.4*†	14.8±0.2
% Change	5.5±1.56†	5.7±1.2†	-0.5±1.1
ES	1.9 (0.78 to 2.87)b	1.78 (0.68 to 2.73)b	-0.28 (-1.5 to 0.61)a
<b>1RM deadlift</b>			
Pre	23.3±0.5	23.6±0.6	23.8±0.5
Post	25.3±0.8*†	25.6±0.6*†	23.7±0.5
% Change	8.3±2.2†	8.3±1.5†	-0.6±1.6
ES	2.7 (1.45 to 3.84)b	3.06 (1.67 to 4.19)b	-0.27 (-1.14 to 0.62)a

**Note:** Values are means± SD. ES presented with 95% confidence intervals. Lowercase letters represent the following: a, trivial nonsignificant increase; b, very large significant increase. 1RM, 1 repetition maximum; CON, control; CRT, cluster set; ES, effect size; Post, after training; Pre, before training; TRT, traditional set.

\*Significant difference compared with Pre ( $p \leq 0.05$ ).

†Significant difference compared with CON group ( $p \leq 0.05$ ).

-0.55 to 1.21) circumference and trivial increases in the thigh (ES = 0.19, 95% CI = -0.69 to 1.06) circumference. There were no statistical differences ( $p > 0.05$ ) between the changes in circumference between the TRT and CRT.

### Strength measures

The CON group demonstrated trivial nonsignificant ( $p > 0.05$ ) decreases in all strength measures after the completion of the 8-week training period. Conversely, both the TRT and CRT groups demonstrated very large significant gains ( $p = 0.001$ ) in all strength measures (Table 3). Specifically, both groups demonstrated very large significant increases in 1RM squat (CRT: 8.4% ± 1.2%; TRT: 7.3% ± 0.6%), bench press (CRT: 8.3% ± 2.0%; TRT: 8.7% ± 1.9%), military press (CRT: 5.7% ± 1.2%; TRT: 5.5% ± 1.6%), and deadlift (CRT: 8.2% ± 1.6%; TRT: 8.3% ± 2.2%).

### Vertical jump measures

The CRT group demonstrated small but significant increase (12.3% ± 1.8%;  $p \leq 0.05$ ) in the peak power output achieved during the vertical jump in response to the 8-week training period, which was significantly greater than the trivial increase (8.2% ± 1.5%;  $p \leq 0.05$ ) demonstrated by the TRT group (Fig. 2). Additionally, the CRT and TRT groups both demonstrated small significant increases (CRT: 7.1% ± 2.9%;  $p \leq 0.05$ ; TRT: 5.6% ± 4.0%;  $p \leq 0.05$ ) in vertical jump displacement, with the CRT group demonstrating significantly greater improvements when compared with the TRT group (Fig. 3). The CON group did not significantly improve in either vertical jump displacement or peak power output after the 8-week training period.

### Sprint and shuttle measures

There were no significant differences noted in between the pre- and post-training time points for 20-m sprint time for either the CON (pretraining: 3.80 ± 0.27 s; post-training: 3.81 ± 0.27 s; ES = 0.04, 95% CI = -0.84 to 0.91), TRT (pretraining: 3.81 ± 0.31 s; post-training: 3.80 ± 0.31 s; ES = -0.03, 95% CI = -0.91 to 0.85), or CRT (pretraining: 3.86 ± 0.80 s; post-training: 3.83 ± 0.80 s; ES = -0.04, 95% CI = -0.91 to 0.84) groups. Additionally, there were no significant differences noted between the pretraining and post-training times achieved during the 4 × 9-m shuttle-run test for the CON (pretraining: 11.64 ± 0.50 s; post-training: 11.66 ± 0.50 s; ES = 0.04,

95% CI = -0.84 to 0.91), TRT (pretraining: 12.03 ± 0.70 s; post-training: 12.02 ± 0.70 s; ES = -0.01, 95% CI = -0.89 to 0.86), and CRT (pretraining: 11.53 ± 0.80 s; post-training: 11.52 ± 0.80 s; ES = -0.01, 95% CI = -0.89 to 0.86) groups.

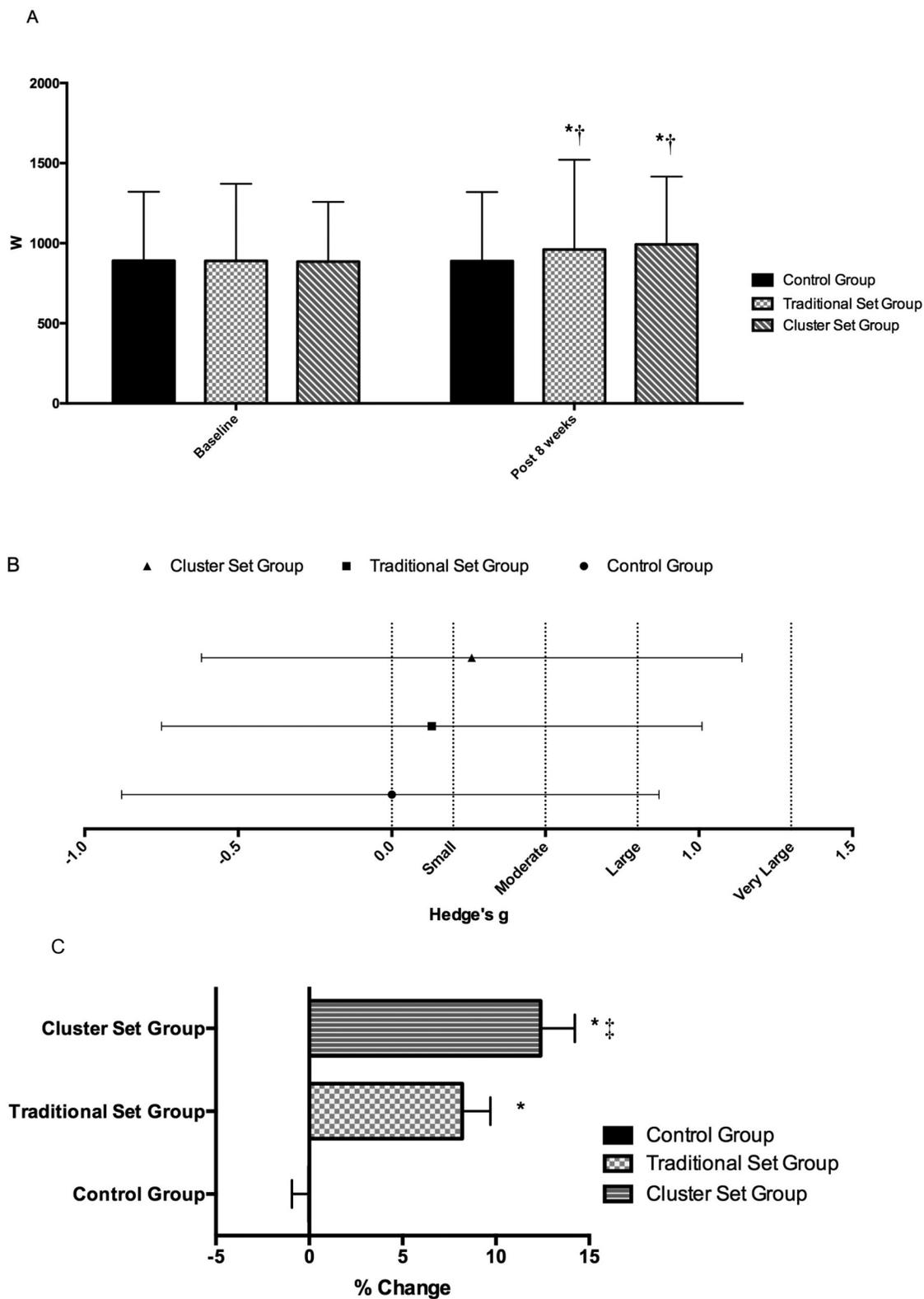
### Hormonal measures

After the completion of the 8-week training intervention both the TRT and CRT groups displayed significantly higher testosterone levels than the CON group (Table 4). Specifically, there was a significant medium increase in testosterone for the TRT group (ES = 0.49; 14.6% ± 5.7%) and a small increase for the CRT group (ES = 0.34; 10.6% ± 4.7%). Additionally, both the TRT and CRT groups displayed significantly greater IGF-1 concentrations after the 8-week training intervention when compared with the CON group. The CRT group demonstrated a medium significant increase in IGF-1 concentrations (ES = 0.74; 16.6% ± 12.1%) when compared with the small increases noted in the TRT (ES = 0.44; 15.5% ± 19.7%) group. When examining the cortisol responses, it was noted that both the TRT and CRT groups demonstrated significant decreases in response to the training period whilst the CON group displayed a small but significant increase. The CRT group exhibited a large significant decrease (ES = -0.87; -18.5% ± 9.7%) in resting cortisol when compared with the moderate significant decrease (ES = -0.74; -13.4% ± 6.8%) displayed by the TRT group. Finally, a significant very large increase in the testosterone to cortisol (T/C) ratio was noted for both the TRT (ES = 1.85; 40.8% ± 4.3%) and CRT (ES = 1.56; 39.7% ± 7.5%) groups when compared with the CON group.

### Discussion and conclusion

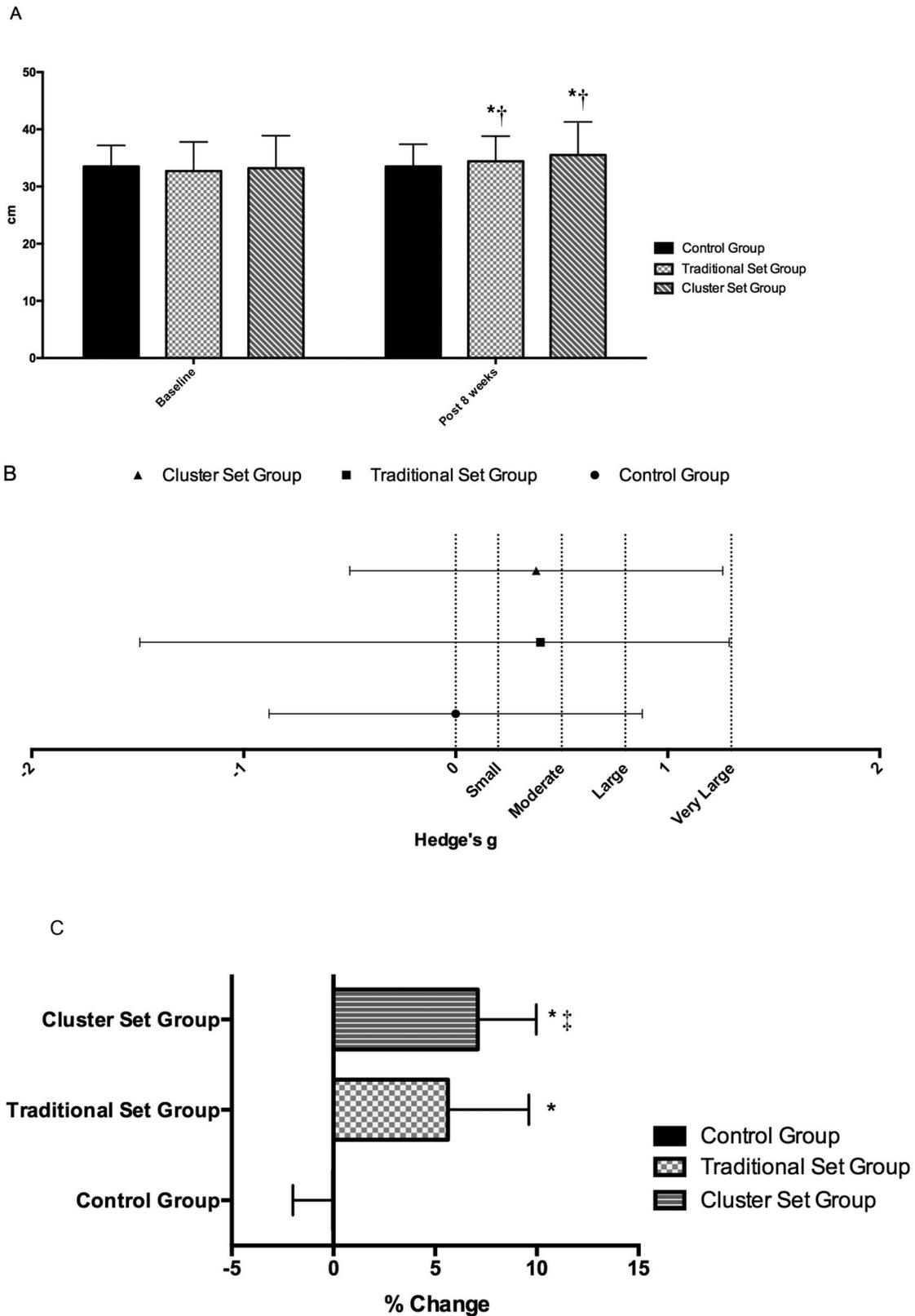
The primary finding of the present investigation was that the TRT and CRT training models both demonstrated significant increases in vertical jump performance after the completion of the 8-week resistance training program. However, the CRT group displayed significantly greater improvements in vertical jumping performance and power outputs when compared with the TRT group. Secondly, the TRT and CRT groups also demonstrated significant increases in muscular strength in response to 8 weeks of training when compared with the CON group. Conversely, there were no significant differences between any of the measurements of maximal strength gains achieved in response to the TRT and

**Fig. 2.** Peak power output. (A) Change in peak power output. \*, Significantly different from baseline ( $p \leq 0.05$ ). †, Significantly different from control group ( $p \leq 0.05$ ). (B) Effect Sizes and 95% confidence intervals for peak power output. (C) Peak power output percent change from baseline to after 8 weeks. \*, Significantly different from control group ( $p \leq 0.05$ ). ‡, Significantly different from traditional group ( $p \leq 0.05$ ).



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**Fig. 3.** Vertical jump displacement. (A) Change in displacement. \*, Significantly different from baseline ( $p \leq 0.05$ ). †, Significantly different from control group ( $p \leq 0.05$ ). (B) Effect sizes and 95% confidence intervals for displacement. (C) Peak power output percent change from baseline to after 8 weeks. \*, Significantly different from control group ( $p \leq 0.05$ ). †, Significantly different from traditional group ( $p \leq 0.05$ ).



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**Table 4.** Hormonal responses.

Hormone	TRT group	CRT group	CON group
Testosterone (nmol/L)			
Pre	2.53±0.69	2.23±0.70	2.20±0.48
Post	2.90±0.76* <sup>†</sup>	2.46±0.59* <sup>†,‡</sup>	2.18±0.48
% Change	14.6±5.7 <sup>†</sup>	10.6±4.7 <sup>†</sup>	-1.1±3.2
ES	0.49 (-0.40 to 1.38)b	0.34 (-0.54 to 1.22)b	-0.04 (-0.92 to 0.84)a
Cortisol (nmol/L)			
Pre	497.2±96.3	500.9±82.7	497.5±77.7
Post	427.9±83.5* <sup>†</sup>	413.4±101.7* <sup>†,‡</sup>	513.3±72.5
% Change	-13.4±6.8 <sup>†</sup>	-18.5±9.7 <sup>†,‡</sup>	3.4±6.2
ES	-0.74 (-1.64 to 0.17)c	-0.87 (-1.79 to 0.05)e	0.20 (-0.68 to 0.41)b
T/C × 10 <sup>-3</sup>			
Pre	4.6±1.0	4.1±1.0	4.3±1.0
Post	6.5±1.0* <sup>†</sup>	5.7±1.0* <sup>†</sup>	3.8±1.0*
% Change	40.8±5.3 <sup>†</sup>	39.7±7.5 <sup>†</sup>	-11.6±3.2
Effect Size	1.85 (0.99 to 2.70)f	1.56 (0.74 to 2.37)f	-0.49 (-1.21 to 0.24)d
IGF-1 (µg/L)			
Pre	394.1±113.9	507.1±82.7	392.1±96.2
Post	440.3±83.5* <sup>†</sup>	581.3±107.7* <sup>†,‡</sup>	388.8±94.2
% Change	15.5±19.7 <sup>†</sup>	16.6±12.1 <sup>†,‡</sup>	-0.75±0.82
ES	0.44 (-0.44 to 1.33)b	0.74 (-0.17 to 1.65)d	-0.03 (-0.91 to 0.83)a

**Note:** Values are means ± SD. ES presented with 95% confidence intervals. Lowercase letters represent the following: a, trivial nonsignificant increase; b, small significant increase; c, moderate significant increase; d, medium significant increase; e, large significant increase; f, very large significant increase. CON, control; CRT, cluster set; ES, effect size; IGF-1, insulin-like growth factor 1; Post, after training; Pre, before training; T/C, testosterone to cortisol ratio; TRT, traditional set.

\*Significant difference compared with pre training ( $p \leq 0.05$ ).

<sup>†</sup>Significant difference compared with control group ( $p \leq 0.05$ ).

<sup>‡</sup>Significant difference compared with traditional group ( $p \leq 0.05$ ).

CRT training interventions after the completion of the 8-week training period.

When examining the scientific literature it is well documented that resistance training has the ability to improve jumping performance and enhance the ability to express high power outputs during jumping movements (Arazi et al. 2014; Asadi and Ramirez-Campillo 2016; Kirksey et al. 1999; Kraemer et al. 2001). For example, after 6 weeks of resistance training Kirksey et al. (1999) reported a 2.3% increase in vertical jump displacement and a 3.1% increase in power output. Similarly, the TRT group in the present study resulted in a 5.6% increase in vertical jump performance and 8.2% increase in power output in response to the 8 weeks resistance training interventions. These greater increases in vertical jump performance and power outputs are likely due to the low levels of strength exhibited by the subjects in the present study and potentially the longer duration of training employed. Because the subjects in the present study had significantly less resistance training experience than the subjects in the paper by Kirksey et al. (1999), larger gains in performance as a result of improved neuromuscular control and increasing muscular strength would be expected and partially explain these findings. While it is clear that resistance training, which utilizes traditional set structures, can impact power-generating capacities and directly impact jumping performance, it has been suggested that modifications can be made to training structures, such as sets and loadings, to enhance the athlete's performance gains (Haff and Nimphius 2012).

In 2008, Haff et al. (2008a, 2008b) suggested that the use of cluster sets as part of a resistance training program would be ideally suited for targeting improvements in power-generating capacity. The rationale behind this recommendation centers on the ability of short periods of inter-repetition or intra-set rest intervals to allow for partial recovery of PCr stores (Haff et al. 2008a, 2008b; Iglesias-Soler et al. 2014) and the maintenance or enhancement of movement velocity across a training set (Tufano et al. 2016). In fact, Haff et al. (2003) have previously demonstrated that the use of cluster sets that employ a 30-s rest interval placed between repetitions resulted in significantly higher peak velocities during the acute

performance of clean pulls. Based upon these findings, Haff et al. (2008a, 2008b) have hypothesized that using cluster sets as part of a resistance training program will allow for a greater training specificity for power development, as a result of higher training velocities, and result in improved performance of high power movements.

The present study supports this recommendation in that after 8 weeks of training the CRT group demonstrated a significantly greater improvement in both power output and vertical displacement during the vertical jump assessments when compared with the TRT group. In fact, the CRT group demonstrated a small but significant 12.4% increase in power output during the vertical jump test, which was significantly greater than the trivial 8.2% increase noted in the TRT group. Additionally, the CRT group in the present study demonstrated a small but significant 7.1% increase in vertical jump displacement after the training period. Interestingly, the findings of the present study are very similar to those reported by Asadi and Ramirez-Campillo (2016), where 6 weeks of plyometric training with cluster sets resulted in a 10.1% increase in vertical jump performance. Based upon these findings and the current body of scientific knowledge it appears that using cluster sets as part of a periodized training program can significantly improve markers of power output when compared with traditional set structures.

While it is commonly recommended that cluster sets are useful for power development it is generally suggested that traditional sets may be better suited for increasing maximal strength and hypertrophy (Haff et al. 2008a, 2008b). Support for this recommendation is generally suggested based upon the work of Lawton et al. (2004), who report significantly greater increases in bench press strength with traditional sets when compared with cluster sets when performed with the same percentage load of 6RM. In fact, in this study the traditional set structure resulted in a 9.7% increase in 1RM, whilst the cluster sets only resulted in a 4.9% increase. These results are very similar to the very large 8.7% increase in bench press 1RM seen in the TRT group in the present study. However, in contrast to the study by Lawton et al. (2004) a very

large 8.3% increase in bench press strength was seen in the CRT group after the 8 weeks of training. Interestingly, the CRT group exhibited a large 8.4% increase in 1RM back squat, while the TRT group displayed a very large 7.6% increase in 1RM back squat. Couple these findings with the very large 5.7% increase in military press 1RM and the very large 8.3% increase in deadlift 1RM as a result of the cluster set intervention it is clear that cluster sets can in fact result in significant improvements in maximal strength if programmed as part of a periodized training program. While traditionally not recommended as a tool for the maximization of muscular strength, cluster sets may actually be useful because they can result in increases in maximal strength, whilst resulting in greater gains in power output. Support for this contention can be seen in the work of [Oliver et al. \(2013\)](#) who suggest that the use of cluster sets can result in significant improvements in both muscular strength and power output in response to resistance training performed for 8 or 12 weeks in duration. Whilst the present study does suggest that cluster sets can result in improvements in maximal strength, these improvements appear comparable with those demonstrated with traditional set structures.

While maximal strength and power-generating capacity are often examined as part of performance testing batteries, it is important to see how these factors can translate to other markers that are related to sports performance, such as sprinting speed and change of direction ability. It is well documented that there is a significant correlation between vertical jump, sprint, and change of direction performances ([Hori et al. 2008](#)). Based upon these relationships it would be expected that training interventions that result in improvements in jumping performance should translate to improvements in sprint and change of direction performances. While the rationale behind this possibility is sound the results of the present study suggest that equal sprint and change of direction performance gains can be achieved with resistance training programs that either use traditional or cluster set structures. One possible reason for the present findings may be related to the fact that similar gains in lower body strength were achieved with in the CRT ( $\uparrow$  8.4%) and TRT ( $\uparrow$  7.6%) groups. Recent work by [Seitz et al. \(2014a\)](#) suggests that lower body strength has a significant relationship to sprinting performance, especially in short distance sprints such as the 20-m sprint used in the present study. Additionally, it has been documented that increases in lower body strength can result in improvements in change of direction performance ([Speirs et al. 2016](#); [Suchomel et al. 2016](#)). Therefore, it is plausible that the lack of difference in lower body strength gains seen with the CRT and TRT groups may partially explain why no significant differences were seen in sprint and change of direction performance in the present study.

While there is a lot of literature that has explored the acute kinematic and kinetic performance responses to cluster sets there is very little research that has explored the acute and chronic hormonal responses to utilizing these types of sets. In one of the few studies to look at hormonal responses, [Oliver et al. \(2015\)](#) reported that traditional sets result in significantly greater metabolic stress as indicated by lactate responses and greater postexercise growth hormone, cortisol, free testosterone, and total testosterone levels when compared with cluster sets. [Kraemer and Ratamess \(2005\)](#) suggest that resistance training protocols that create greater metabolic stress through the use of high training volumes, moderate to high intensities, shorter rest intervals, and large muscle mass exercises produce the greatest acute hormonal responses. While acute hormonal responses shed light on the overall metabolic and hormonal responses associated with various resistance training interventions, another important consideration is the impact of longitudinal training on resting hormonal concentrations.

Generally, changes in resting testosterone concentrations are inconsistent or nonexistent in women ([Häkkinen et al. 1992](#); [Kraemer and Ratamess 2005](#)). For example, [Häkkinen et al. \(1992\)](#)

report that after 3 weeks of intensive resistance training women display no systematic changes in resting serum or free testosterone. Conversely, [Staron et al. \(1994\)](#) have reported that after an 8-week progressive resistance training program serum testosterone levels are elevated in women. Similarly, the women in the present study also demonstrated increases in resting testosterone levels when compared with the CON group. While not statistically different, the TRT group displayed a 14.6% increase, whilst the CRT group only increased by 10.6%. Alterations in resting testosterone levels are often related to changes in resistance training volume and intensity ([Haff et al. 2008c](#); [Kraemer and Ratamess 2005](#)). When resting testosterone levels are elevated in women they tend to also display increases in both strength and power in comparison to women with lower resting testosterone ([Häkkinen et al. 1992](#)). Interestingly, in the present study the TRT group exhibited higher resting testosterone levels and maximal strength posttraining when compared with the CRT group. Conversely, the CRT group displayed greater increases in power production, but this occurred with slightly lower resting testosterone levels. Taken collectively it appears that the training methods used in the present study created positive elevations in resting testosterone levels in women.

Resting cortisol levels also appear to be reflective of long-term training stress ([Kraemer and Ratamess 2005](#)) or alterations in training stressors ([Haff et al. 2008c](#)). For example, [Haff et al. \(2008c\)](#) report that when training volume load is increased there is a significant increase in resting cortisol (+48.4%) in women weightlifters. When training load is reduced resting cortisol levels are reduced and often return to baseline ([Haff et al. 2008c](#)). While both training groups in the present study demonstrated decreases in resting cortisol, the CRT group resulted in a larger decrease in response to training. Based upon previous research this might suggest that the use of cluster sets creates a favorable environment for performance gain without the metabolic stress associated with traditional resistance training sets. While these findings are interesting a better understanding of training stress can be found by examining the relationship of testosterone to cortisol.

Typically, when elevations in resting testosterone concentrations are coupled with reductions in resting cortisol concentrations it is believed that an enhanced anabolic environment ([Staron et al. 1994](#)) and increased performance capacity exists ([Haff et al. 2008c](#)). Additionally, it is also suggested that the use of the resting T/C ratio may in fact be an indicator an athlete's performance preparedness ([Haff et al. 2008c](#); [Häkkinen et al. 1985](#)). In the present study it was noted that both the CRT and TRT groups displayed increases in both maximal strength and power production capacity in the selected tests. As expected both of these groups also demonstrated significant very large increases in the T/C ratio when compared with the CON group. Collectively this hormonal data suggests that both training groups created a favorable resting hormonal profile and that using either traditional or cluster sets as part of a resistance training program can result in their volume and intensity being manipulated to create a hormonal environment that is favorable when attempting to maximize strength and power performances.

Another hormone that can be impacted by manipulations of volume and intensity during resistance training is IGF-1. Long-term resistance training studies suggest that higher volume resistance training programs can result in elevations in IGF-1 concentrations in women ([Borst et al. 2001](#); [Kraemer and Ratamess 2005](#); [Marx et al. 2001](#)). In the present study both the TRT and CRT groups demonstrated increases in resting IGF-1 concentrations when compared with the CON group. Interestingly, the CRT group displayed a significantly greater medium increase in IGF-1 concentrations after the 8-week training intervention. These findings were not completely unexpected as [Borst et al. \(2001\)](#) and [Marx et al. \(2001\)](#) both suggest that following 13 to 24 weeks of resistance training, women can express increases in IGF-1. While only 8 weeks in

duration, the present study seems to add evidence to the literature that suggests resistance training with appropriately periodized volumes and intensities can result in increases in resting IGF-1 concentrations.

In summary, the data collected in the present study support the hypothesis that implementing cluster sets into a periodized resistance training program can result in improvements in power generating capacity. Additionally, the present study expands upon this recommendation to suggest that cluster sets have the ability to create similar strength gains. Specifically, it may be recommended that strength and conditioning professionals integrate cluster sets into their periodized training programs to improve vertical jumping performances, which is particularly important for volleyball players. The use of cluster sets as part of the periodized training plan does not hinder strength development and therefore can be used as part of a well-rounded resistance training program. This being said if maximal strength development is the targeted capacity then the strength and conditioning professional should consider using traditional sets as part of the athletes' training plan. Based upon these findings it may be warranted for strength and conditioning professionals to use mixed training models that utilize both traditional and cluster sets in their resistance training programs.

### Conflict of interest statement

The authors express that there are no conflicts of interest to report.

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