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ORIGINAL ARTICLE

# Acute response to cluster sets in trained and untrained men

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**Abstract**
*Purpose* In traditional sets (TRD) repetitions are performed continuously, whereas cluster sets (CLU) allow a brief rest between groups of repetitions. We investigated the acute mechanical, metabolic, and hormonal response to CLU in men.
*Methods* Twelve resistance-trained (RT) and 11 untrained (UT) men performed TRD (4 × 10 repetitions with 2 min rest) and CLU [4 × (2 × 5) with 1.5 min rest between sets 30 s rest between clusters] at 70 % 1RM back squat in random order. Seven days separated trials. Average power and time under tension (TUT) were calculated. Blood was sampled pre, sets 1, 2, and 3; immediate post-exercise, 5, 15, 30, 60 min post-exercise for blood lactate, total testosterone (TT), free testosterone (FT), growth hormone (GH), and cortisol.
*Results* CLU produced greater average power at an increasing number of repetitions over each set with greater total volume load. TUT was shorter for RT and lower for CLU in repetitions 1, 6, 7, 8. Blood lactate was higher Set 2 through 30 min in TRD. RT had higher TT; however, the time course was similar between RT and UT. TT and FT increased immediate post-exercise and remained elevated 30 min in both conditions. GH was significantly greater during TRD with a similar pattern observed in both conditions. Cortisol was significantly lower at 30 min in CLU.
*Conclusion* CLU allowed greater total volume load, shorter TUT, greater average power, similar anabolic hormonal response, and less metabolic stress. The acute response was similar despite training status.

**Keywords** Resistance training · Power · Hormones · Metabolic · Mechanical

**Abbreviations**

| | |
|---|---|
| TRD | Traditional set |
| CLU | Cluster sets or clustering |
| ADP | Adenosine triphosphate |
| PCr | Phosphocreatine |
| 1RM | One-repetition maximum |
| RT | Resistance trained |
| UT | Untrained |
| TUT | Time under tension |
| TT | Total testosterone |
| FT | Free testosterone |
| GH | Growth hormone |
| CV | Coefficient of variation |
| RIA | Radioimmunoassay |
| ANOVA | Analysis of variance |

## Introduction

Performing repetitions in a continuous fashion in accordance with traditional set (TRD) configurations results in a decrease in force (Hardee et al. 2012b), velocity (Hardee et al. 2012b; Izquierdo et al. 2005), and power (Hardee et al. 2012b; Lawton et al. 2006) over a set. In many sports and activities of daily living, the ability to generate power

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is necessary making this type of training counterintuitive to the principle of specificity. One method to attenuate this reduction is the use of cluster sets (CLU) or clustering. CLU incorporate a short rest (typically 15–30 s) between individual repetitions (inter-repetition rest) or group of repetitions (intra-set rest) (Haff et al. 2008). The ability to maintain greater mechanical power output is facilitated by the ability of the phosphagen and glycolytic energy systems to recover during the added rest periods as evidenced by studies demonstrating lower blood lactate concentrations (Girman et al. 2014; Goto et al. 2005) following CLU when compared to TRD configurations, as well as greater intramuscular adenosine triphosphate (ATP) and phosphocreatine (PCr) concentrations (Gorostiago 2012).

While an argument could be made that the shorter (<15 s) or longer (>30 s) inter- and intra-set rest excludes specific studies, the manipulation of the set configuration and the desired training adaptation (greater power output) are in agreement with the theoretical basis of CLU (Haff et al. 2008), suggesting a comparison can be made. Thus, while the beneficial effects of CLU in the acute setting using both Olympic and traditional exercises (squat and bench press) are unequivocal, as evidenced by studies reporting greater force (Hardee et al. 2012b), velocity (Hardee et al. 2012b; Izquierdo et al. 2005), and power (Hardee et al. 2012b; Lawton et al. 2006), limited investigations have shown beneficial effects on long-term gains following CLU training when compared with TRD. Favorable effects of CLU on muscular power have been reported when participants incorporated CLU in training at or near the optimal load (the load at which the greatest power output is observed) (Kawamori and Haff 2004) for mechanical power output in the respective exercise (Izquierdo et al. 2006; Oliver et al. 2013; Zarezadeh-Mehrizi et al. 2013), while TRD elicited similar power gains (Lawton et al. 2004) when training above the optimal load.

Interestingly, the recommended intensity for the development of hypertrophy [67–85 % one-repetition maximum (1RM)] is most closely related with the intensities identified for the development of muscular power in trained subjects performing multi-joint exercises (Kawamori and Haff 2004). However, differing effects of CLU have been reported when utilizing hypertrophic intensities in trained and untrained males (Goto et al. 2005; Oliver et al. 2013). Oliver et al. (2013) recorded greater strength and power following a 12-week resistance training program incorporating hypertrophic intensities with CLU compared with TRD in a group of trained males. Further, the authors reported no differences in lean mass gains, suggesting that CLU were as effective as TRD for hypertrophic gains while augmenting power and strength development. This was in contrast to that observed by Goto et al. (Goto et al. 2005) in a population of untrained males performing a similar 12-week resistance training program in which CLU resulted in smaller gains in strength and lean mass; no measures of power were reported. The discrepancies between those studies may not be due to training status, but exercise type or muscle mass used (Folland et al. 2002; Rooney et al. 1994). Given the data regarding the beneficial effects of CLU (Izquierdo et al. 2006; Oliver et al. 2013; Zarezadeh-Mehrizi et al. 2013), the lower perception of effort and rate of fatigue associated with CLU (Hardee et al. 2012a), and that lower perception of effort may increase compliance in an untrained population; (Bibeau et al. 2010; Ekkekakis et al. 2008); an examination of differences due to training status using the same exercise type is warranted.

Outside of kinetic and kinematic differences between CLU and TRD, few data exist on the acute response of those factors, mechanical, metabolic, hormonal; that have been suggested to contribute to long-term adaptations observed following resistance training. A preponderance of evidence exists indicating that mechanical stress is the primary factor responsible for adaptations in strength and power (Crewther et al. 2005). Further, mechanical stress has been shown to directly stimulate cellular process responsible for hypertrophy (Miyazaki et al. 2011; Vandenburgh and Kaufman 1979). The hypertrophic response has also been attributed to metabolic factors, given that blood flow restriction exercise at low intensities results in significant hypertrophy (Suga et al. 2009). Takada et al. (Takada et al. 2012) also showed that both muscle cross-sectional area and strength were correlated with metabolic stress after a 4-week intervention. Further, while the debate on whether or not the acute post-resistance increases in hormones are necessary for adaptation, specifically hypertrophy, the role of lactate in stimulating testosterone release is well established (Lu et al. 1997). Metabolic byproducts have also been reported to be a potent stimulator of growth hormone secretion (Gordon et al. 1994), which is supported by observations of larger growth hormone responses in the presence of elevated metabolic stress following ischemic exercise (Takarada et al. 2000). Significant correlations have also been reported between blood lactate and cortisol (Raastad et al. 2000). These hormones have also been extensively examined in relation to strength, power (Crewther et al. 2006), and hypertrophic adaptations (Kraemer and Ratamess 2005). To date, no studies have examined the differences in the acute mechanical, metabolic, and hormonal factors, which have been identified as contributing to long-term adaptations between TRD and CLU.

Therefore, this study expands on our recent study examination of the kinetic and kinematic differences between TRD and CLU in RT and UT men (Oliver et al. 2015) by examining the differences in those factors, mechanical, metabolic, and hormonal; that have been identified as potential contributors to the mechanism(s) responsible for

**Table 1** Baseline demographics of subjects

| | Untrained ($n = 11$) | Resistance trained ($n = 12$) | Cohen's $d$ |
|---|---|---|---|
| Age (years) | 25 ± 1 | 25 ± 1 | 0.0 |
| Height (cm) | 179.9 ± 2.0 | 179.1 ± 2.2 | 0.1 |
| Body mass (kg) | 83.3 ± 3.5 | 84.6 ± 2.1 | 0.1 |
| Body fat (%) | 27.6 ± 2.2 | 15.8 ± 1.3* | 0.6 |
| Lean mass (kg) | 56.6 ± 1.6 | 67.7 ± 1.6* | 2.0 |
| Bone mineral content (kg) | 3.1 ± 0.4 | 3.6 ± 0.3* | 0.4 |
| 1RM back squat (kg) | 86.8 ± 5.1 | 146.9 ± 4.9* | 3.5 |
| 1RM back squat:body mass | 1.07 ± 0.08 | 1.75 ± 0.07* | 3.0 |

Values are mean ± SE

*1RM* one-repetition maximum

* Significant difference between groups

differing adaptations observed between TRD and CLU. In following with our recent report (Oliver et al. 2015), a secondary purpose was to examine if differences exist between trained and untrained males. With TRD, we hypothesized greater metabolic stress with a resultant larger hormonal response; whereas, CLU would attenuate the decline in power attributed to TRD. Further, we hypothesized a similar, albeit lower, response in all variables of interest in those with no previous training history.

## Methods

### Subjects

Twelve resistance-trained (RT) and 11 untrained (UT) men completed the study. RT subjects were currently participating in a structured resistance training program that included the back squat exercise. Further, RT had ≥3 years experience performing the back squat. No RT subject reported participating in a weight class event or physique competition. UT males had no previous experience with resistance training, specifically the back squat nor did any report following caloric restriction. Selection criteria included: (1) males between 20 and 35 years of age; (2) with no previous history of smoking and/or tobacco use (6 months); (3) not taking thyroid, androgenic, or other medications known to affect endocrine function, and (4) reportedly not consuming any ergogenic levels of nutritional supplements known to affect muscle mass, insulin-like substances, or anabolic/catabolic pro-hormones or hormones within the previous 6 months leading up to the study. Subject demographics are presented in Table 1. While both groups were similar in age, height and body mass; UT subjects had significantly higher body fatness as determined by dual X-ray absorptiometry. 1RM back squat and 1RM parallel back squat to body mass ratio were significantly greater in RT subjects.

This study was conducted according to the Declaration of Helsinki guidelines. All procedures involving human subjects were approved by the Institutional Review Board of Texas Christian University for use of human subjects in research (protocol no. SUM 13-17-1401 AM). Written consent was obtained from all subjects.

### Experimental design

The study was conducted in a repeated-measures, counterbalanced, randomized design in which all subjects served as their own controls completing both experimental conditions. Following determination of height, weight, and body composition, subjects completed a familiarization session. Forty-eight hours later, subjects returned to the laboratory for determination of 1RM in the back squat exercise. Subjects then performed 4 sets of 10 repetitions of the back squat exercise with a load corresponding to 70 % 1RM using either TRD (4 × 10 with 120 s inter-set rest) or CLU [4 × (2 × 5) with 90 s inter-set rest and 30 s intra-set rest] set configurations. This intensity was selected as others have shown beneficial effects of CLU at these intensities following a period of training (Izquierdo et al. 2006; Oliver et al. 2013). Further, the total rest time was selected to equate rest between conditions (Hansen et al. 2011). Seven days separated the trials. The experimental design, set configurations performed for the TRD and CLU experimental trials, and timing of blood sampling are presented in Fig. 1a–c.

### Familiarization session

Prior to familiarization, subjects' height and body mass were determined to the nearest 0.1 cm and 0.1 kg, respectively; using a stadiometer (Seca; Chino, CA) and self-calibrating digital scale (Seca; Chino, CA) with subjects in socks or bare feet. Subjects then underwent body composition determination via dual X-ray absorptiometry (GE

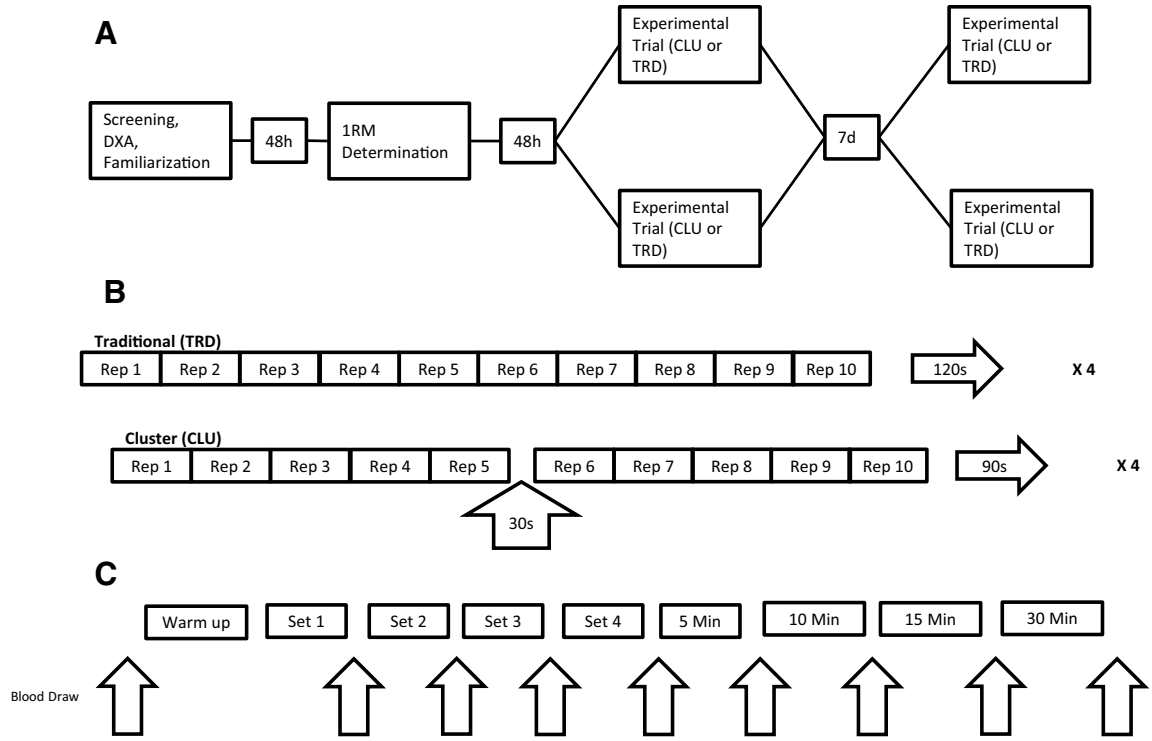


**Fig. 1** Schematic of experimental design (**a**); traditional (TRD) and cluster (CLU) set configurations (**b**); timing of blood sampling (**c**)

Healthcare; Little Chalfont, United Kingdom) calibrated according to manufacturer's guidelines and performed by a trained technician.

Following demonstration of appropriate back squat technique, all subjects, regardless of training status, were required to perform the exercise until demonstrating proficiency using only the weight of the bar (20.4 kg). Those unable to perform using proper technique as determined by research personnel were excluded from further testing ($n = 1$).

### One-repetition maximum testing

Subjects returned to the laboratory at least 48 h after familiarization having refrained from any physical activity outside of daily living for determination of 1RM in the back squat exercise. Following a supervised, dynamic warm-up (8–10 min), subjects performed two sets of five repetitions at 40–60 % of their estimated 1RM with 2 min rest between sets. After a 3-min rest, subjects performed 1–2 sets of 2–3 repetitions at a load corresponding to 60–80 % 1RM. Subjects then began performing sets of 1 repetition of increasing weight for 1RM determination. Three to 5 min rest was provided between each successive attempt. All 1RM determinations were made within 3–5 attempts. For an attempt to be considered successful, subjects were required to reach a depth of the squat at which the top of the thigh was parallel to the floor as observed by the same trained, research personnel. A verbal "up" command was provided during 1RM determination. 1RM was defined as the point at which the subject could no longer increase the weight and complete a full repetition while maintaining proper form. For all 1RM testing, safety bars were put in place to prevent injury. This method has been shown to have an intra-class coefficient of 0.99 and a corresponding Pearson product-moment coefficient of 0.99 (Oliver et al. 2013). At the end of the final repetition, placement of both feet was measured and recorded. During a subsequent repetition using only the bar (20.4 kg) subjects were asked to pause at the bottom of the repetition to mark parallel depth. Foot placement as obtained during final successful 1RM was maintained over the course of subsequent trials by taping, while parallel depth as obtained during the subsequent repetition using only the bar was maintained by placing a stretch cord at the appropriate depth for participants to reach on the eccentric phase in all subsequent testing. All testing was performed on an Optima Smith Machine (LifeFitness; Schiller Park, IL).

### Experimental testing

On the day of experimental testing, subjects arrived having refrained from lower body training for at least 72 h and any activities outside of daily living for the previous 48 h.

Subjects were immediately seated quietly in a phlebotomy chair for 5 min prior to catheter insertion. Following the supervised dynamic warm-up (8–10 min), identical to that performed for 1RM determination, subjects performed two sets of five repetitions of the parallel back squat exercise with a load equivalent to 40 and 60 % of 1RM. After 2 min rest, subjects performed the back squat using either TRD or CLU using 70 % 1RM. Subjects were instructed to perform the concentric (upward) portion of each repetition "as explosively as possible". If subjects paused for more than 2 s in the extended position, or were unable to complete a repetition, resistance was lowered by 13.6 kg. Verbal encouragement was provided throughout all experimental testing conditions for all subjects. Both experimental conditions (TRD and CLU) were performed at the same time of day to reduce the potential for diurnal variation in hormones measured.

### Average power determination

Subjects performed all experimental testing on a portable force platform (Accupower, AMTI; Watertown, MA) with the right side of the barbell attached to two linear position transducers (PA-80-HG, Unimeasure; Corvallis, OR). The linear position transducers were mounted anteriorly and posteriorly to the subject forming a triangle when attached to the barbell, allowing for measurement of horizontal and vertical bar displacement using previously accepted procedures (Cormie et al. 2007). The linear position transducers produced a voltage signal that represented the degree at which the LPTs were extended, allowing for the calculation of displacement–time data. From this displacement–time data, instantaneous velocity and time under tension (TUT) were calculated throughout the movement. Ground reaction force was collected via force plate and displacement data were sampled at 1000 Hz via an analog-to-digital converter (Sewell Direct; Provo, UT). Signals from the force plate and two linear position transducers were filtered using a second-order Butterworth low-pass filter with a cut-off frequency of 20 Hz and collected by a laptop computer using custom-built data acquisition and analysis software (Treadmetrix; Park City, UT). Average power was calculated as the product of average force and velocity for each repetition over all sets. The reliability of the equipment and software was assessed through comparison of average power between two trials over two repetitions. The intra-class correlation coefficient for this comparison was 0.97 ($p = 0.001$). The data presented herein represent a subset of those in which kinetic and kinematic data were collected. These data are those in which blood samples were able to be obtained. Data associated with the larger sample examining differences in the kinetics and kinematics of CLU and TRD is published elsewhere (Oliver et al. 2015).

### Blood sampling and analyses

Upon arrival to the laboratory for experimental testing subjects were seated in a phlebotomy chair for catheter insertion. The area was sterilized using standard sterile phlebotomy procedures and an indwelling catheter (BD Biosciences; San Jose, CA) was inserted into an antecubital vein and capped to allow for multiple blood draws. The catheter was kept patent by flushing with 2–3 ml of 0.9 % sodium chloride (G-Biosciences; St. Louis, MO) injected into the portal site. Prior to each blood sampling from the catheter, a 3-ml vacutainer (BD Biosciences; San Jose, CA) was used to withdraw a waste sample. Blood for the analysis of serum total testosterone (TT), free testosterone (FT), cortisol, and growth hormone (GH) was drawn into 5-ml vacutainer tubes that contained no additive (BD Biosciences, San Jose, CA) prior to the dynamic warm-up, immediately post-exercise, as well as 5, 15, 30, and 60 min post-exercise (Fig. 1c). Samples were allowed to coagulate in cooling beads for at least 30 min, and subsequently centrifuged at 2500 rcf for 10 min (Beckman Coulter Allegra X-12, Beckman Coulter; Brea, CA). After centrifugation, serum was stored in aliquots at −80 °C for later analysis. A second 3-ml vacutainer tube containing the anti-coagulant ethylenediaminetetraacetic acid (EDTA) was collected prior to dynamic warm-up, at the conclusion of each set (Set 1, Set 2, Set 3), immediately post-exercise, as well as 5, 15, 30, and 60 min post-exercise. Immediately after collection, 0.5 ml of whole blood was pipetted into 1 ml of cold 8 % perchloric acid to stabilize blood lactate (Lowry and Passonneau 1972). Samples were then centrifuged at 3000 rpm for 10 min in a microcentrifuge (Eppendorf; Hauppauge, NY). The resultant supernatant was stored at −80 °C for later analysis.

TT, FT, and cortisol were analyzed via radioimmunoassay (RIA; Siemens, Washington, DC). All samples were run in duplicate on an ISO Data 100 gamma counter (Titertek; Pforzheim, Germany). The inter-assay coefficient of variation (CV) was 5.06, 4.91, and 7.61 % for TT, FT, and cortisol, respectively. The intra-assay CV was 2.98, 2.33, and 2.90 % for TT, FT, and cortisol, respectively. GH concentrations were determined in duplicate using ImmuChem™ Double Antibody hGH RIA (MP Biomedicals; Orangeburg, NY) Inter-assay and intra-assay CV for GH were 7.57 and 2.62 %, respectively. Blood lactate concentrations were determined via spectrophotometric assay (Passonneau and Lowry 1993) in triplicate. Absorbances were read at 340 nm using a Thermo Scientific spectrophotometer (Thermo Scientific; Waltham, MA). All blood lactate samples were analyzed in triplicate. Inter-assay and intra-assay CV were 3.11 and 1.73 %, respectively. It has been previously demonstrated that receptors in target tissues are exposed to serum levels of hormone and thus we

did not adjust specific hormone concentrations to changes in plasma volume (Rubin et al. 2005).

### Statistical analyses

A priori power analysis was conducted using G*Power version 3.1.9 to determine the minimum sample size required to find significance with a desired level of power set at 0.80, an α-level at 0.05, and a standardized effect size calculated from previous studies (Goto et al. 2005). It was determined that a minimum of 8 subjects were needed to ensure adequate power.

Baseline demographics were evaluated by independent sample *t* test. Mechanical data were assessed by repeated measures analysis of variance (ANOVA) with the following factors: training status (2 levels), condition (2 levels), set (4 levels), repetition (10 levels). All other variables of interest (blood lactate, TT, FT, GH, and cortisol) were also analyzed by repeated measures ANOVA with the following factors: training status (2 levels), condition (2 levels), time (multiple levels depending on variable of interest). All data were normally distributed as determined by the Kolmogorov–Smirnov test of normality. Bonferroni post hoc analysis was performed when a significant finding ($p \leq 0.05$) was identified. Data are presented as mean ± standard error, unless otherwise noted. All analyses were performed using SPSS V.22 (IBM Corporation; Armonk, NY).

## Results

### Load and total volume load

A condition × set × rep interaction ($p < 0.001$) was observed. Though no difference was observed between TRD and CLU in load in Sets 1 through 3; in Set 4 subjects moved a greater load during CLU for repetitions 6 ($p = 0.038$), 7 ($p = 0.013$), 8 ($p = 0.001$), 9 ($p < 0.001$), and 10 ($p < 0.001$). The reduction in load during Set 4 of TRD resulted in a greater total volume load (sets × repetitions × load) during CLU (3266.6 ± 100.7 kg) when compared with TRD (3237.6 ± 100.3 kg; $p = 0.001$). A main effect for training status ($p < 0.001$) was observed for load. RT subjects moved a greater load (102.9 ± 3.5 kg) when compared with UT subjects (59.7 ± 3.6 kg), which contributed to trained subjects completing a significantly greater total volume load (4115.2 ± 138.9 kg) when compared with untrained subjects (2389.0 ± 145.1 kg; $p < 0.001$).

### Average power output

A condition × set × rep interaction ($p = 0.039$) was observed for average power. CLU produced greater average power at an increasing number of repetitions from Set 1 through Set 4. Average power was greater during CLU for five repetitions in Set 1 (Fig. 2a), six repetitions in Sets 2 (Fig. 2b) and 3 (Fig. 2c), and eight repetitions in Set 4 (Fig. 2d). A training x rep ($p = 0.001$) interaction was also observed. Similar to results observed in load, RT subjects produced significantly greater average power in both conditions at all repetitions ($p < 0.001$).

### Time under tension

The condition × set interaction approached significance ($p = 0.075$) in which post hoc analysis showed the average time to complete a repetition increased in both TRD and CLU. However, the increase was attenuated in CLU resulting in significantly shorter TUT in Set 3 (TRD, 2.3 ± 0.1 s; CLU, 2.1 ± 0.1 s; $p = 0.028$) and Set 4 (TRD, 2.4 ± 0.1 s; CLU, 2.3 ± 0.1 s; $p = 0.081$; Fig. 3a). A condition × rep interaction was observed ($p < 0.001$). When collapsed across all sets the average TUT was lower for CLU in repetitions 1 ($p = 0.028$), 6 ($p = 0.037$), 7 ($p = 0.006$), and 8 ($p = 0.006$) compared to TRD (Table 2). The average time to complete a repetition was significantly shorter for RT subjects (2.1 ± 0.1 s) compared to UT subjects (2.3 ± 0.1 s) as evidenced by a main effect of training status ($p = 0.045$).

### Blood lactate

A significant condition × time interaction ($p < 0.001$) was observed for blood lactate. Blood lactate increased above baseline values at the conclusion of Set 1 and remained elevated at 30 min in both TRD and CLU. However, blood lactate was significantly higher following Set 2 ($p = 0.006$), Set 3 ($p < 0.001$), immediate post-exercise ($p < 0.001$), 5 ($p < 0.001$), 15 ($p < 0.001$), and 30 ($p < 0.001$) min post in TRD compared to CLU.

### Total testosterone and free testosterone

While a main effect of time was observed ($p < 0.001$), the condition × time interaction approached significance ($p = 0.095$) with post hoc analysis revealing no significant differences at any time point between TRD and CLU. However, TT returned to baseline concentrations by 30 min post-exercise in CLU, while TT did not return to baseline concentrations until 60 min in TRD (Fig. 3a). A main effect of training status was observed in TT ($p = 0.034$). RT subjects had higher overall concentrations of TT (662.0 ± 34.7 ng $dl^{-1}$) compared to UT subjects (548.1 ± 36.3 ng $dl^{-1}$).

A main effect for time was also observed in FT ($p < 0.001$). In contrast to TT, no significant training status

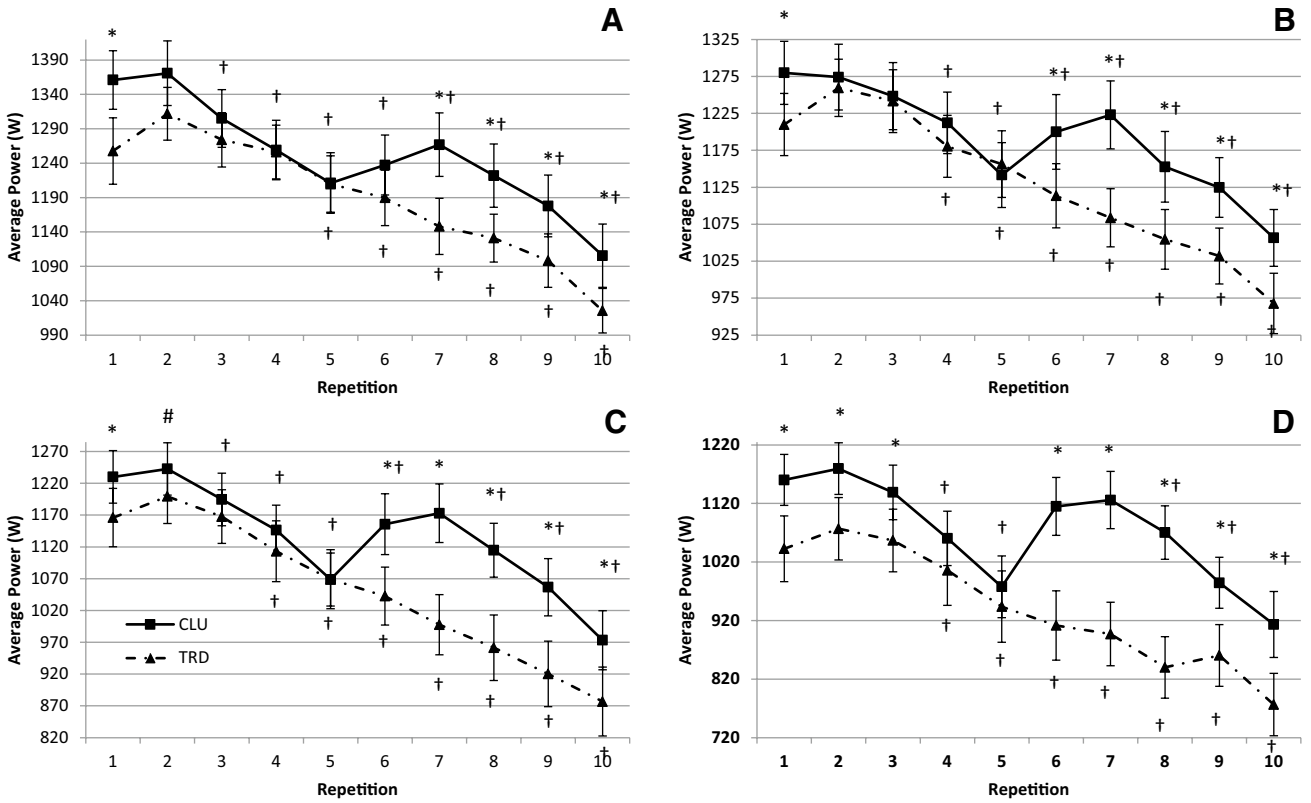


**Fig. 2** Average power per repetition for Set 1 (**a**), Set 2 (**b**), Set 3 (**c**), Set 4 (**d**). †Significant difference from peak value during respective set ($p < 0.05$); *significant difference between conditions ($p < 0.05$); #significant difference between conditions ($p < 0.10$)

or condition × time interaction was observed. FT increased immediate post-exercise and remained elevated above baseline concentrations up to 30 min before dropping below baseline concentrations at 60 min (Fig. 3b).

### Growth hormone

Main effects for time ($p < 0.001$) and condition ($p = 0.040$) were observed for growth hormone. Growth hormone concentrations were significantly greater during TRD (15.5 ± 3.0 ng ml$^{-1}$) when compared with CLU (10.1 ± 2.0 ng ml$^{-1}$) when averaged across all time points. GH collapsed across condition and time is presented in Fig. 3c. Growth hormone concentration increased immediate post-exercise reaching a peak value of 19.6 ± 3.2 ng ml$^{-1}$ at 15 min with a continued elevation above baseline concentrations at 60 min (8.3 ± 2.6 ng ml$^{-1}$, $p = 0.015$). There were no differences between RT and UT subjects ($p = 0.159$).

### Cortisol

A significant condition × time interaction ($p = 0.018$) was detected for cortisol. Cortisol was significantly lower at 30 min in CLU compared with TRD ($p = 0.021$). While cortisol was only significantly different at one time point, the time course of cortisol concentrations were significantly different between TRD and CLU. Cortisol increased in a stepwise fashion in both TRD and CLU; however, peak values were observed at 30 min in TRD while CLU cortisol concentrations were not significantly different than baseline values at the same time point ($p = 0.421$, Fig. 3d). There was no difference between RT and UT subjects ($p = 0.785$).

## Discussion

The major findings in this study were that CLU resulted in greater average power while concomitantly allowing for a larger total volume load, highlighting a greater mechanical stress in the form of high forces. However, TUT was lower in CLU demonstrating that the mechanical stress as depicted by TUT was greater in TRD. CLU produced less metabolic stress, but produced a similar anabolic hormone response as measured by TT and FT. Further, despite lower TT in UT, similar responses were observed in all other variables of interest across subjects.

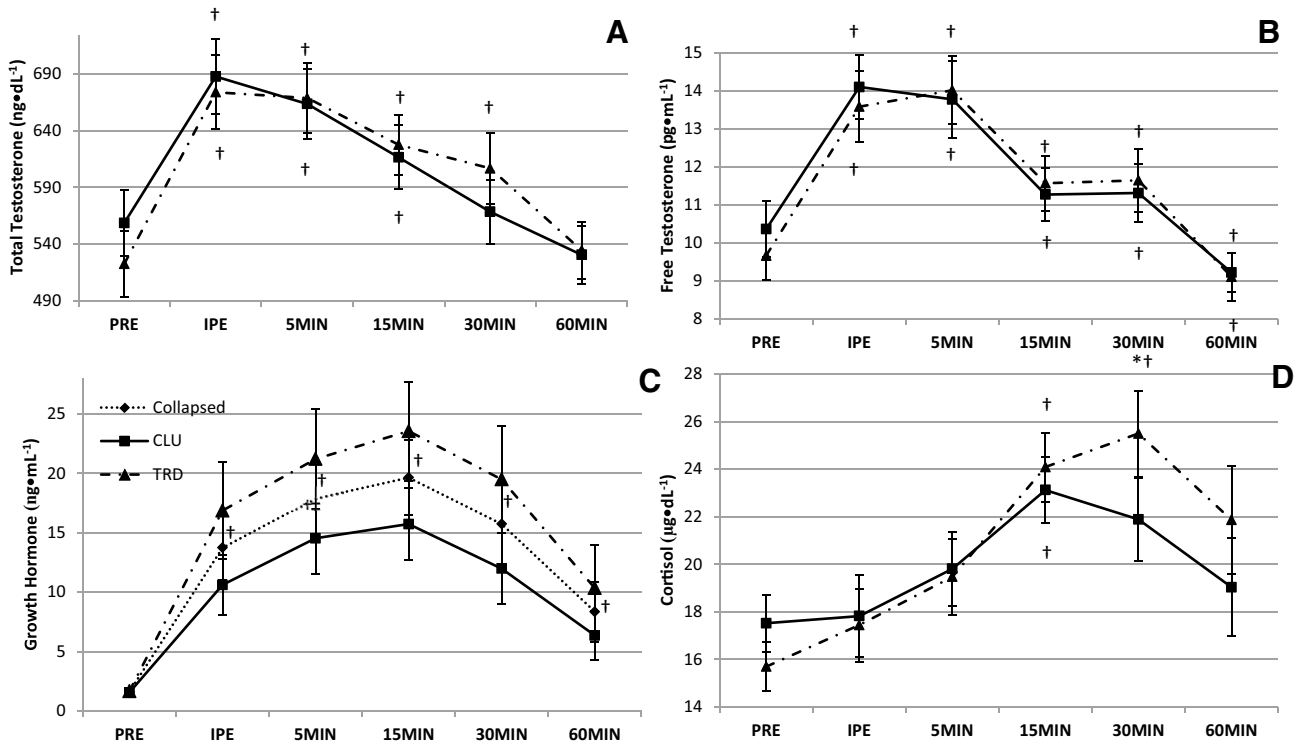


**Fig. 3** Serum total testosterone (**a**), free testosterone (**b**) growth hormone ng $dl^{-1}$(**c**) and cortisol (**d**) collapsed by training status before (*PRE*), immediately post-exercise (*IPE*), 5 (*5MIN*), 15 (*15MIN*), 30 (*30MIN*), and 60 (*60MIN*) min post-exercise in traditional (*TRD*) and cluster (*CLU*) set configurations. †Significant difference from *PRE*; *significant difference between conditions ($p < 0.05$)

**Table 2** Time under tension (seconds) collapsed by repetition and training status

| Repetition | TRD | CLU |
|---|---|---|
| 1 | 2.2 ± 0.1 | 2.1 ± 0.1* |
| 2 | 2.1 ± 0.1 | 2.0 ± 0.1 |
| 3 | 2.1 ± 0.1 | 2.0 ± 0.1 |
| 4 | 2.2 ± 0.1 | 2.1 ± 0.1 |
| 5 | 2.2 ± 0.1 | 2.3 ± 0.1 |
| 6 | 2.3 ± 0.1 | 2.1 ± 0.1* |
| 7 | 2.3 ± 0.1 | 2.1 ± 0.1* |
| 8 | 2.4 ± 0.1 | 2.1 ± 0.1* |
| 9 | 2.4 ± 0.1 | 2.2 ± 0.1 |
| 10 | 2.5 ± 0.1 | 2.4 ± 0.1 |

Values are mean ± SE

*TRD* traditional, *CLU* cluster

* Significant difference between conditions

Significantly greater power output in CLU was not an unexpected outcome as others have reported similar findings (Hansen et al. 2011; Hardee et al. 2012b; Joy et al. 2013); however, in those studies, total volume load was equated between conditions. CLU resulted in greater average power while allowing for a greater total volume load in both RT and UT subjects, which is a novel aspect of the current study. In fact, a similar number of RT and UT subjects required a reduction in load in later repetitions of Set 4 during the TRD protocol. Lower loads require less force and allow for a higher velocity of movement while higher loads are associated with lower velocities and result in greater time under tension; thus, it would be assumed that average power during later repetitions would remain constant in the TRD condition and decrease in CLU. Instead, a decline in average power was observed in the TRD condition suggesting a decrease in the amount of force and velocity, also evidenced as longer total time under tension; while CLU resulted in greater average power output and a lesser time under tension at higher forces. Thus, the mechanical stress in the form of high force was greater in CLU, while the mechanical stress was greater in TRD when examining TUT. These data suggest that long-term adaptations would likely differ based upon differences in mechanical stress.

The greater mechanical stress in the form of longer TUT raises an interesting question as Burd et al. (2012) showed that greater TUT increased protein synthesis acutely following resistance exercise. However, those same authors reported that the increased TUT delayed protein synthesis 24–30 h post-resistance exercise. Therefore, it is possible that TUT may be less of a factor in hypertrophic

adaptations when the intensity and volume are equated, similar to that observed in the study by Oliver et al. (2013). Further interpretation is not possible given the fact that the only study in which a similar CLU and TRD configuration was utilized equated total volume load and intensity, making the higher forces observed in this study a non-factor (Oliver et al. 2013).

In agreement with our original hypothesis, greater metabolic stress as measured by lactate was observed in the TRD condition. Recognizing that fatigue can result from a decrease in a muscle's force generating capacity or contraction velocity, the definition of fatigue includes a decrease in the expected or required power output (Fitts 1994). While the causes of fatigue are not fully understood (Fitts 1994), the original CLU model by Haff et al. (2003) was based upon the assumption that short intra-set rest periods would provide sufficient time for partial replenishment of PCr allowing for the ability to produce greater power in subsequent repetitions. In support, Gorostiaga et al. (Gorostiago 2012) reported a near-complete depletion of PCr stores when performing leg press using TRD and suggested increases in lactate and byproducts of metabolism may contribute to fatigue. However, in the current study, a similar protocol to that of (Gorostiago 2012) attenuated the decline (~15 vs. 80 %). Greater average power was achieved in CLU sets [Set 2 (TRD, 1130 ± 39 W; CLU, 1191 ± 42 W; $p = 0.010$), Set 3 (1051 ± 46 W; CLU, 1136 ± 41 W; $p = 0.003$), Set 4 (TRD, 941 ± 53 W; CLU, 1073 ± 46 W; $p = 0.001$)] in which lower lactate values were observed. This, not surprisingly, corresponded to the reduced TUT observed in CLU in later sets (Set 3 and Set 4).

Given the greater TUT and metabolic stress, we hypothesized a larger hormonal response following TRD. However, these data support our original hypothesis in part. In contrast to our original hypothesis and the work of others (Goto et al. 2009), we observed a similar response in TT and FT for both conditions. Goto et al. (2005) reported neither the TRD nor CLU condition produced significant elevations in TT with reported peak blood lactate levels of ~6 and ~4 mmol $l^{-1}$ in TRD and CLU, respectively. In the current study, we observed peak values of 9.3 ± 0.5 and 12.7 mmol $l^{-1}$ in CLU and TRD, respectively. Given that Goto et al. (Goto et al. 2005) reported a difference in growth hormone and cortisol between the two conditions, differences in training status and/or exercise type may also have contributed to these divergent findings. To the authors' knowledge, no previous studies have examined the differences in hormonal response due to training status in TRD and CLU. This population was included due to conflicting results concerning training status dependent differences in hormonal response to exercise (Ahtiainen et al. 2004; Kraemer 1999). While we observed a main effect of training status in TT, no significant interaction with training status was reported. Further, no effect of training status was observed in other hormones of interest. In fact, a comparable hormonal response was observed in TRD and CLU in UT and RT subjects. A similar observation was made by Ahtiainen et al. (2004) in strength-trained and non-strength-trained subjects performing the back squat exercise for maximum number of repetitions and forced repetitions. Therefore, the differences between the current study and that of Goto et al. (2005) may in fact be attributable to exercise type. Exercises involving larger muscle mass (i.e., back squat) produce larger elevations in hormones than those exercises involving smaller muscle mass (Ratamess et al. 2005), such as those performed in the study by Goto et al. (2005).

Still, the lack of a significant difference in TT and FT between the conditions is intriguing. A novel yet confounding factor in the current study, was the reduction in load when a subject approached failure, thus allowing a greater total volume load to be achieved in the CLU condition. The greater total volume load performed during the CLU condition may have been sufficient to produce a similar TT and FT response in the absence of higher lactate values, as greater total volume load has been shown to result in a larger TT response (Raastad et al. 2000). However, Häkkinen and Pakarinen (1993) showed that the performance of 10 sets of 10 repetitions resulted in a larger TT and FT response than the performance of 20 sets of 1 repetition at the same intensity, suggesting total volume load alone is not sufficient to induce a large TT and FT response. Thus, there likely exists a threshold total volume load and lactate value that results in similar TT and FT response. These data do not allow for determination of this hypothetical threshold.

The similar, albeit smaller, pattern of growth hormone response in the CLU condition supports our original hypothesis. Goto et al. (2005) reported no elevation in growth hormone post-CLU; however, it is again likely the failure of that exercise program to induce significant elevations in blood lactate was responsible for the lack of response, as there appeared to be a similar pattern in the CLU condition although not statistically significant. On the contrary, Girman et al. (Girman et al. 2014) found no difference in growth hormone between CLU and TRD conditions in a group of trained males. In an effort to mimic a typical hypertrophy off-season training day, subjects in that study performed two exercises (clean pull and back squat) using TRD and CLU followed by two circuits in which the set and rep configurations did not differ between conditions. While significantly lower lactate values were observed immediately following CLU performance, higher lactate values than those reported herein were reported immediately following performance of a final circuit (14.6 ± 0.4 mmol $l^{-1}$, TRD; 14.3 ± 0.4 mmol $l^{-1}$, CLU), and these did not differ between conditions. Thus,

the similar lactate values could have contributed to the similar growth hormone response; however, differences in TUT may, too, have influenced the results by Girman et al. (2014). Growth hormone has been shown to be elevated to a greater degree following slow movement exercise compared to normal movement (Goto et al. 2009). TUT was not controlled during the current study, but TUT in Set 4 was 2.43 ± 0.09 and 2.26 ± 0.09 s in the TRD and CLU condition, respectively. In the study conducted by Girman et al. (2014), TUT was controlled in a 2-0-2 tempo, providing for more than 1.5 s longer TUT than that reported in the current study. Further studies are necessary to examine the potential differences in effect of TUT and lactate on the growth hormone response following exercise.

Programs that elicit the largest growth hormone response have been suggested to induce the largest cortisol response (Kraemer and Ratamess 2005); likely due to the correlation between lactate and cortisol (Raastad et al. 2000). This is highlighted by the fact that traditional strength protocols fail to elicit significant elevations in cortisol, while hypertrophy and endurance protocols induce elevations up through 30 min post-exercise (Smilios et al. 2003). In the current study, cortisol increased in a linear fashion in the TRD condition, remaining elevated 30 min post-exercise, while a lesser slope of increase was observed in CLU achieving only one value (15 min) above baseline values. This is in disagreement with Girman et al. (2014) in which the authors reported a similar cortisol response for both CLU and TRD conditions. The similar high lactate values and accompanying pattern of growth hormone observed immediate post-exercise in that study likely contributed to the divergent findings.

The fact no significant interaction with training status was observed in the current study suggests similar long-term adaptations in both RT and UT men. However, differing observations have been made when a similar training program was utilized. These current data suggest that the difference between the investigations of Oliver et al. (2013) and Goto et al. (2005) may not be related to training status, but may be due to difference in exercise type. However, it must be noted that total volume load was equated in the study by Oliver et al. (2013); whereas, total volume load differed in the current study. While greater total volume load may have been sufficient to produce a similar hormonal response (Raastad et al. 2000), others have shown that total volume load alone is not sufficient to induce a large TT and FT response (Häkkinen and Pakarinen 1993).

## Conclusion

Notably, this is the first study to examine fully mechanical, metabolic, and hormonal factors, which are identified as potential contributors to the long-term adaptations observed following resistance training. Particular findings of interest were that CLU allowed for greater power output over the course of the sets, while concomitantly allowing subjects to lift a greater total volume load. Thus, while higher forces were achieved in CLU indicating a greater mechanical stress, the longer TUT in TRD demonstrates significant difference in the mechanical stress experienced in these two conditions. Further, while TRD resulted in greater metabolic stress, this did not have an impact on the hormonal response as CLU produced a similar anabolic hormonal response. While slightly lower, the pattern and time course did not differ between RT and UT subjects in any of the measured variables. Our data provide support for further research examining the longitudinal training adaptations in CLU and in UT subjects incorporating this novel training method.

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