ACUTE KINEMATIC, KINETIC, AND HORMONAL RESPONSES TO CLUSTER SETS IN

PARALLEL BACK SQUAT EXERCISE IN TRAINED AND UNTRAINED YOUNG MEN

UTILIZING HYPERTROPHIC INTENSITIES

by

Andreas Kreutzer

Bachelor of Arts, 2010
Boise State University
Boise, ID

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UTILIZING HYPERTROPHIC INTENSITIES

A Thesis for the Degree
Master of Science

by

Andreas Kreutzer

Thesis Approved by:

_____
Dr. Jonathan Oliver, Major Professor

_____
Dr. Melody Phillips, Committee Member

_____
Dr. Joel Mitchell, Committee Member

_____
Dr. Debbie Rhea, Associate Dean
Harris College of Nursing & Health Sciences

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Acute kinematic, kinetic, and hormonal responses to cluster sets

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CHAPTER I

Introduction

Background

Current American College of Sports Medicine (ACSM) guidelines suggest healthy adults perform resistance training 2-3 days per week for one to three sets per exercise at an intensity corresponding to 60-80% of one repetition maximum (1RM). These guidelines advise exercisers to complete 8-12 repetitions per exercise in a continuous fashion with 1-3 minutes rest between sets for improvements in strength and hypertrophy (4). The ACSM further suggests similar schemes for athletes in hypertrophic training cycles. Performing exercises in this fashion has been shown to produce a total volume load (TVL), the product of total repetitions and external load, that is beneficial for the development of lean body mass (34, 64) and muscular strength (64).

Muscular power is a major determinant of performance in activities such as jumping, throwing, and striking, as well as an important factor for the successful completion of activities of daily living (ADL). The greatest development in muscular power can be achieved by training at a load and velocity that maximizes mechanical power output during training (57). The greatest power output will be elicited at a load that optimizes both velocity and force, the so called optimal load (12, 39). Performing repetitions in a continuous fashion in accordance with ACSM guidelines results in a decrease in velocity of movement after ⅓ and ½ of repetitions performed during the bench press and back squat, respectively, leading to reduced total power output (35). One method to attenuate the reduction in velocity (24, 32) and power output (21, 32, 49) is the use of cluster sets (CLU). CLU incorporate short rest periods of 15-30 seconds between clusters of repetitions. The ability to maintain greater mechanical power output is purportedly facilitated by the ability of the phosphagen system to recover rapidly during the rest periods as supported by

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studies demonstrating lower blood lactate (BLa) concentrations (20, 23), as well as greater intra-muscular adenosine triphosphate (ATP) and phosphocreatine (PCr) levels following CLU when compared to traditional continuous configurations (TRD)..

While the beneficial results of CLU on velocity and power in the acute setting are une-quivocal, only some investigations have shown beneficial effects on long term power gains fol-lowing CLU training when compared with TRD. Favorable effects of CLU on muscular power have been reported when subjects trained at or near the optimal load for mechanical power out-put in the respective exercise (37, 59), while TRD elicited greater power gains than CLU (18) when training above the optimal load. Moreover, similar gains in muscle mass after hyper-trophic training with CLU when compared with TRD have been recorded (59). Finally, greater (59) and equal strength gains (19, 37) have been recorded following hypertrophic training at the optimal load with CLU when compared to TRD. Thus, incorporating CLU into hypertrophic training may provide benefits for power and strength development while eliciting similar gains in muscle mass as typically realized with TRD. The underlying mechanisms of this increased strength development and equal gains in lean body mass have not been investigated. Oliver et al. (59) found no difference in myosin heavy chain (MHC) alterations when comparing TRD and CLU. In that study, TVL was equated between conditions, thus rendering these variables non-factors. However, Oliver et al. did not compare hormonal responses to TRD and CLU. Thus, a comparison of endocrine responses to TRD and CLU is needed to determine whether hormonal response differs between conditions.

The endocrine system plays an important role in adaptations to resistance training. It fa-cilitates the remodeling or turnover of muscle protein, and thus is a key component in the break-down and subsequent repair of muscle tissue during resistance exercise (45). When muscle pro-

tein synthesis exceeds degradation an increase in muscle cross-sectional area results, which increases the muscles' ability to generate force (25). Resistance exercise produces acute changes in the hormonal environment, which facilitate protein turnover and muscle growth (16, 17, 40). The balance between anabolic hormones such as testosterone (T) and growth hormone (GH), and catabolic hormones such as cortisol (C) is important in the training process (45). While the mechanisms responsible for increases in muscle mass are without doubt multifactorial, acute resistance exercise transiently elevates circulating concentrations of anabolic and catabolic hormones, specifically T, GH, and C (36). This altered hormonal response has been shown to be connected to the overall magnitude of hypertrophy (46). In general, greater volume load (44, 63), shorter rest periods (7, 46), and higher intensity (27) have been shown to increase the hormonal response to resistance exercise. Further, the greater the metabolic stress induced by the exercise, the greater the hormonal response (23, 53). Another factor influencing hormonal response to resistance exercise is movement velocity and the resulting time under tension (TUT) with greater responses elicited by increased TUT (22).

Few studies have compared the hormonal response to CLU and TRD. Girman et al. (20) found no differences in the hormonal response to CLU and TRD when resistance-trained subjects performed a variety of exercises at varying intensities. Given this scarcity of research as well as conflicting results concerning training-status-dependent differences in hormonal response to exercise (2, 10, 43) , further investigations into the acute hormonal response to CLU and TRD are warranted. Ahtiainen et al. (2), whose subjects and exercise prescription most closely resembled those in the present study, found a greater total testosterone (TT), free testosterone (FT), and GH response in trained exercisers when compared with untrained (2), while there were no differences in C response based on training status.

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Purpose

The purpose of the present study was to examine the effect of cluster sets on the kinetic and kinematic profile (force, velocity, power) during the back squat in young trained and untrained men. Further, we sought to determine the pattern and time course of catabolic and anabolic hormones, as well as BLa concentration in response to CLU.

Hypotheses

We formulated the following hypotheses:

Kinematic and kinetic variables

Average velocity, force, and power output would be greater in later repetitions of each set during CLU when compared to TRD in both groups, with trained subjects producing greater values in all three of these variables when compared with untrained subjects. Concentric (CON), eccentric (ECC), and total (TOT) time under tension (TUT) would be greater during TRD when compared with CLU.

Hormonal and metabolic responses

TT, FT, GH, and C response would be greater following TRD when compared with CLU, with trained subjects experiencing a greater response in TT, FT, and GH and a similar C response when compared with untrained. BLa response would be greater during and after TRD when compared to CLU in all groups.

Ratings of perceived exertion

RPE would be greater during TRD when compared with CLU in both groups.

CHAPTER II

Review of Literature

Cluster sets

Intra-set rest periods are thought to improve the quality of performance of each of the repetitions performed during a set. Haff et al. (24) theorized that CLU would allow the exerciser to recover between repetitions. This short-term recovery is multi-faceted. One of the main contributors to recovery of the phosphagen system is partial replenishment of intramuscular PCr concentration (33). PCr resynthesis occurs in an initial rapid phase, which has been shown to replenish intramuscular PCr concentrations to approximately 50% of resting levels following exhaustive dynamic exercise (33). Since CLU are designed to avoid exhaustion, this set configuration may facilitate recovery to an even greater percentage of resting levels. Haff et al. (24) developed a model in which the recovery facilitated by CLU would allow the exerciser to maintain V throughout a set of five repetitions of the power clean, when compared to a near-linear decrease in V during performance of the set in a traditional continuous fashion (TRD).

An operational definition of CLU has not been established, and a variety of different set configurations has been tested under the umbrella of inter-repetition rest, intra-set rest, and CLU. Researchers have investigated rest periods between each repetition as short as one second (9), and as long as 30 seconds (24). Moreover, traditional sets broken up in to shorter sets have been classified as CLU, as can be seen in Lawton et al. (48), who investigated the effects of eight sets of three repetitions with 120 seconds of rest between sets. We assume cluster sets as a scheme that breaks up traditional sets into a greater number of shortened sets. Individual repetitions separated by short rest periods are known as singles. Other CLU configurations include rest periods between groups of two (doubles), three (doubles) or more repetitions.

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Acute effects of cluster sets

Haff et al. (24) investigated the effects of CLU on peak power output, barbell velocity, and displacement during the power clean in trained young men (age: 23.4 ± 1.1 years). They applied a traditional set configuration (TRD), a CLU configuration and an undulating set (UND). TRD comprised one set of five repetitions in continuous fashion, without rest between repetitions. CLU incorporated 30 seconds of rest between repetitions, and UND manipulated the resistance during the set in a pyramid-type fashion. Subjects worked at 90% of 1RM and at 120% of 1RM, a much higher intensity than the optimal load for mechanical power output in the power clean, which has been found to be 80% 1RM (12). While barbell velocity declined significantly with over the five repetitions during TRD, it stayed consistent during CLU. During UND barbell velocity declined when resistance was increased, but recovered when resistance was decreased for the final two repetitions. Furthermore, CLU resulted in a significantly higher 5-repetition average barbell velocities in both the 90% and 120% trial when compared to TRD and UND. These findings suggest that CLU allowed for recovery between repetitions, facilitating greater conservation of V throughout the set. No significant differences were found in 5-repetition power averages between CLU, TRD, and UND with either resistance. This lack of difference in power averages may have been caused by the high load applied, making force the major contributor to power output and rendering movement velocity less important.

Lawton et al. (49) examined mechanical power output in four different set configurations during the bench press in 26 trained young athletes (age: 18.0 ± 0.3 years). They compared a TRD configuration of 6 continuous repetitions to a cluster set of six single repetitions with 20 seconds between each repetition, a cluster of six repetitions performed as three pairs of doubles with 50 seconds rest between each pair, and a cluster of six repetitions performed as two triples

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with 100 seconds rest between triples. All repetitions were performed at 85% of 1RM, a significantly greater intensity than the optimal load for bench press, which has been shown to range from 40-70% of 1RM (12). The traditional set resulted in a linear loss of power output across the set, whereas all cluster sets resulted in greater individual repetition power as well as total power output. Total power output was significantly greater in singles (21.6%), doubles (22.7%), and triples (25.1%) when compared with TRD. This finding suggests that a variety of CLU configurations ranging from 20 seconds of rest between individual repetitions to 100 seconds of rest between triples will allow exercisers to recover sufficiently to maintain a greater movement velocity and mechanical power during a set of bench press when compared to TRD.

Denton and Cronin (15) compared the effect of set configurations of 24 bench press repetitions in ten trained young healthy men (age: 25.2 ± 4.5 years) . Their traditional scheme (TRD) consisted of four sets of six repetitions with five minute rest between sets. CLU comprised eight sets of three repetitions with 130 second rest between triples. Subjects worked at 85% of 1RM, significantly above the ideal load for the bench press exercise. The researchers found no significant difference in power output between CLU and TRD, suggesting that when working at a load above the optimal load, CLU may not provide any benefits for power production. This may be due to the fact that the high external load might prevent exercisers from performing repetitions at a sufficiently high velocity. Blood lactate concentration was greater in TRD than in CLU five minutes after cessation of exercise (P5), but did not differ between conditions immediately following exercise, 15 minutes after exercise, or 30 minutes after exercise. LA concentration during CLU was elevated above resting levels only immediately following exercise, returning to baseline levels by P5. While the lack of LA measurements during the bout does not allow for inference of intra-set recovery, the overall metabolic stress appears to have been lower in CLU when compared to TRD.

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Hardee et al. (32) examined the effect of inter-repetition rest on the power output during three sets of six repetitions of power cleans at 80% of 1RM (optimal load) with either 0 seconds (P0), 20 seconds (P20) or 40 seconds (P40) of rest between repetitions. Their subject population comprised ten male recreational weightlifters aged 23.6 ± 0.4 years. The investigators found that peak power significantly decreased by 15.7% from repetition 1 to repetition 6 during P0. During P20 (5.5%) and P40 (3.3%) decreases in power from repetition 1 to repetition 6 were significantly lower during the continuous protocol. Peak force declined significantly from repetition 1 to repetition 6 during P0 (7.3%), decreased less during P20 (2.7%), and remained constant (+0.4%) during P40. Peak velocity significantly decreased during P0 (10.2%), and declined slightly during P20 (3.8%) and P40 (1.7%). There were no significant differences between CLU conditions, suggesting that rest periods of 20-40 seconds between repetitions provide ample time for recovery leading to attenuated loss of power output when compared to TRD. Furthermore, Hardee et al. found that peak velocity declined immediately (repetition 2) in P0, whereas it did not decline significantly until repetition 4 in P20 and until repetition 5 in P40. A similar pattern could be seen in peak force, which started to decrease significantly at repetition 3, while it remained constant until repetition 5 in P20 and throughout the entire set in P40. Peak power decreased immediately in P0, while it did not decrease significantly until repetition 5 in either CLU condition. This suggests that rest times of 20-40 seconds between repetitions allows for extended maintenance of velocity, force, and power output when compared to TRD, with possibly greater benefits with longer recovery times.

In a related study Hardee et al. (30) found that a significant increase in ratings of perceived exertion (RPE) was associated with the aforementioned decrease in power output, suggesting that RPE may be a valid indication of the level of fatigue induced by resistance exercise. The investigators found significantly smaller increases in RPE in P40 when compared to P20 and

P0, suggesting that increased rest time between repetitions provided greater attenuation of fatigue when compared to shorter rest periods or TRD.

Joy et al. (38) were the first to examine the kinematic and kinetic effects of CLU during hypertrophic resistance exercise. They compared a TRD configuration of four sets of 10 repetitions of the back squat with two minutes of rest between sets to a CLU configuration of eight sets of five repetitions with one minute rest periods between sets. Subjects (ten trained men; age: 23 $\pm$ 2.4 years) performed all repetitions at 75% of 1RM, a load close to the optimal load for the back squat exercise (40-70% 1RM). Mean power output decreased similarly from repetition 1 to repetition 5 in CLU and TRD. However, mean power output from repetition 6 to repetition 10 was significantly greater in CLU than in TRD, suggesting that the 60 second rest period in CLU allowed for sufficient recovery to improve subsequent power production capacity.

Along with these attenuated power decreases during CLU when compared to TRD, cluster sets have been shown to produce attenuated metabolic responses. Goto et al. (23) found an attenuated lactate response to 3-5 sets of 10 repetitions at 75% 1 RM in CLU when compared to TRD. Subjects (26 healthy, non-resistance trained men, age 22.7 $\pm$ 0.5 years) performed lat pull-down, shoulder press, and bilateral knee extension either continuously (TRD) or with one minute rest after fiver repetitions (CLU). Girman et al. (20) used TRD and CLU during clean and pull, back squat, and bench press to determine the effects of CLU on metabolic stress in trained young men. TRD comprised a single set of 4-10 repetitions at 50-75% 1RM depending on the exercise. During CLU, subjects performed doubles for 2-5 sets depending on the exercise performed; intensities were matched with TRD. The researchers found lower blood lactate concentration after CLU when compared to TRD, suggesting that the CLU configuration attenuated metabolic stress during a variety of exercises at differing intensities. Gorostiaga et al. (21) found greater adenosine triphosphate (ATP) and PCr concentrations, as well as an attenuated LA response, following

the first and last set of CLU during bilateral knee extensions when compared to TRD. These findings suggest lower metabolic stress and greater short-term recovery during CLU when compared to TRD.

In summary, CLU elicit beneficial effects on the acute kinematic and kinetic response to resistance exercise, allowing for greater maintenance of power throughout the exercise when intensity is at or near optimal load for mechanical power production . No beneficial results have been found in most studies working at an intensity greater than the optimal intensity, with one study (49) showing positive effects despite the high intensity. Thus, load may play an important role in the effectiveness of CLU, but further research is warranted to confirm the significance of working at or near optimal load. Acute metabolic responses to CLU confirm Haff's theoretical model (24) of intra-set recovery provided by CLU in trained and untrained subjects at a variety of exercise intensities.

Long-term responses to cluster sets

Several studies have investigated the long-term adaptations to CLU when compared to TRD. Drinkwater et al. (18) found greater power gains in the bench throw after six weeks of TRD training when compared to CLU training. Subjects (26 trained men; age: 18.6 ± 0.3 years) participated in three training sessions per week, performing 24 repetitions of bench press either in a TRD or CLU configuration. They worked at 80-105% of 6RM, an intensity greater than the optimal load of 40-70% of 1RM for maximal power output in the bench press (12). In a study by Folland et al. (19), 23 healthy adults between the ages of 18 and 29 completed three training sessions per week for nine weeks. They were assigned to either a CLU or TRD protocol of 40 repetitions of bilateral knee extensions at 73% of 1RM, an intensity close to the optimal load for this exercise. After nine weeks, there was a tendency towards greater high velocity strength gains in CLU when compared to TRD, but no significant differences were found between conditions. In a

periodized training study, Izquierdo et al. (37) subjected subjects to either a CLU or TRD protocol in the bench press and back squat. Subjects trained twice per week for 16 weeks. During the initial six weeks, repetitions were performed at 65-75% of 1RM in a hypertrophic training setting. During the following five weeks, subjects trained for strength at 80-85% of 1RM. In the final phase, all subjects underwent the same power training protocol at 40-90% of 1RM with no differences in rest or any other variables between groups. In the parallel squat, similar power gains were achieved in both groups after the first and second training phases. Greater gains in power manifested in the CLU group after the final phase when compared to TRD. A difference in power gains may not have realized during the initial training phase due its short duration (6 weeks), but the adaptations for the delayed realization of greater power gains in CLU may have taken place during this phase in which subjects were working near the optimal load for maximal power output during the parallel squat.

Hansen et al. (29) investigated the effects of eight weeks of CLU or TRD training with the parallel squat and the clean on peak force, velocity, and power of ballistic jump squats with an external load of 0, 20, 40, and 60 kg. Subjects in this study (trained men; age: 19.7 ± 1.9 years) performed training repetitions at 80-90% of 1RM, an intensity greater than the optimal load. Hansen et al. found possibly negative effects of CLU on power gains during jump squat testing with a 20 kg load, and likely positive effects of CLU on power gains during jump squat testing with a 40 kg load. Oliver et al. (59) reported greater power gains in bench press, back squat and vertical jump after training for 12 weeks at 65-75% of 1RM with a CLU configuration when compared to TRD. Moreover, the investigators found no difference in lean body mass gains between the two groups.

In summary, long-term effects of CLU further research is needed to investigate the training effects of CLU when compared to TRD. Present research indicates no beneficial effects of

CLU if training above the optimal load, and beneficial effects if training at or near the optimal load (Table 2). The influence of training status and age on the effectiveness of CLU in long-term adaptations is currently unknown and warrants further research.

While further research is warranted, previous studies indicate that CLU can provide acute benefits on mechanical power output during resistance exercise if performed at or near the optimal load for maximal power development (32, 49). This enhanced ability to maintain velocity and power throughout a set is facilitated by recovery during intra-set rest periods of 20-40 seconds between clusters of repetitions (32), as evidenced by data suggesting attenuated metabolic stress (20, 21, 23) and lower RPE (30) during CLU when compared to TRD. Some studies have shown beneficial effects on long term power gains following CLU training when compared with TRD training (37, 59). Moreover, similar gains in muscle mass after hypertrophic training with CLU when compared with TRD have been recorded (59). Finally, greater (59) and equal strength gains (19, 37) have been recorded following hypertrophic training at the optimal load with CLU when compared to TRD. Thus, incorporating CLU into hypertrophic training may provide benefits for power development while maintaining or improving gains in muscle mass and strength typically realized with TRD. The intensity recommended in the current ACSM guidelines (4) for resistance training in healthy subjects (60-80% of 1RM) coincides with the optimal load for major lifts such as the parallel squat (45-75% of 1RM) and the bench press (40-70% or 1RM). Thus, incorporating CLU into resistance exercise may provide a valuable tool to increase muscular power gains, while maintaining gains in muscle mass and strength.

Hormonal and metabolic responses to resistance exercise
Overview

The endocrine system plays an important role in adaptations to resistance training. It facilitates the remodeling or turnover of muscle protein, and thus is a key component in the breakdown and subsequent repair of muscle tissue during resistance exercise (45). When muscle protein synthesis exceeds degradation and increase in muscle cross-sectional area results, which increases the muscles' ability to generate force. Resistance exercise produces acute changes in the hormonal environment, which facilitate protein turnover and muscle growth (16, 17, 40). The balance between anabolic hormones such as testosterone (T) and growth hormone (GH), and catabolic hormones such as cortisol (C) is important in the training process (45). The effect of different modalities of resistance training on these hormones is examined in the following section.

Anabolic hormones

Testosterone

Testosterone (T) has a major anabolic effect on muscle tissue (16, 17). It is synthesized and secreted from the Leydig cells of the testes, and contributes to muscle growth by increasing protein synthesis and decreasing protein degradation. The majority of T is bound to albumin (~38%) and sex hormone-binding globulin (~55-60%) with the remaining T unbound, i.e. free testosterone (FT) (51). FT is immediately available to the tissues, and albumin-bound T can be made available to tissues quickly. Therefore, the amount of total testosterone (TT) and FT are of the greatest interest in the resistance exercise research setting.

There seems to be a relative intensity and volume threshold that has to be reached to induce a testosterone response. Yarrow et al. (73) found no increase in TT after four sets of six repetitions at 50% of 1RM, nor after three sets of six repetitions at 40% of 1RM during concentric actions, and 100% of 1RM during the eccentric portion of the movement. This suggests that neither protocol elicited a work load great enough to produce a TT response. On the other hand,

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Kraemer et al. (44) found that TT was increased as a result of heavy resistance training, with greater responses to shorter rest periods of one minute when compared to three minutes, and greater load of 5RM when compared with 10RM. Ratamess et al. (63) showed that six sets of ten repetitions at 80-85% 1RM, but not one set of ten repetitions at the same intensity increased TT, suggesting a threshold of volume must be reached to elicit a TT response. Slower lifting velocities, and thus increased time under tension (TUT) have been shown to elicit greater FT responses than faster velocities and thus shorter TUT (22). Furthermore, a certain metabolic demand must be placed on the system to raise TT levels, as shown by Hakkinen and Pakarinen (26). In their study, 20 sets of 1RM, which elicited a lactate response of ~4mmol/L, resulted in no change in TT. On the other hand, ten sets of ten repetitions at 70% 1RM, which elicited a lactate response of ~15mmol/L, induced a significant increase in TT and FT.

Resistance training status or experience seems to play an important role in regulating the hormonal response to resistance exercise. In general, strength-trained athletes have greater TT and FT responses than untrained subjects (1, 2, 10, 20, 43, 68).

Growth hormone
Growth hormone (GH) is another anabolic hormone influencing muscle tissue growth. It is synthesized and released from the somatotrope cells, located within the pituitary gland (5). GH contributes to protein metabolism by increasing protein synthesis and reducing the degradation of muscle protein (45, 71). Resistance exercise, particularly hypertrophic schemes, elicits an increased GH response (40). Kraemer et al. (44) showed that a neuronal scheme produced a 3-fold increase in circulating GH, while a hypertrophy scheme elicited an 11-fold increase in resistance trained men. Zafiridis et al. (74) found similar responses in their study of resistance trained men, in which a hypertrophic scheme elicited a 13-fold increase, and a neuronal scheme produced a 4-fold rise in GH. Slower lifting velocities, and thus increased time under tension (TUT) have been

shown to elicit greater GH responses than faster velocities and thus shorter TUT (22). There are conflicting results in the examination of the effect of training status on GH secretion following resistance exercise. Some studies have found greater responses in untrained than in trained (54), others found no difference between the two groups (2), while still others found a greater response in trained than in untrained individuals (65, 67). Thus, training status has not been established as a major determinant of GH response to resistance exercise.

Catabolic hormones

Cortisol

Cortisol (C) is considered the primary catabolic hormone. It is synthesized and secreted from the adrenal cortex, and plays a major role in decreasing protein synthesis and increasing protein degradation (46). Furthermore, it is one of the primary stress hormones (8); elevated levels of C have been shown to be caused, among others, by depression, trauma, and overtraining (69).

Resistance exercise can produce elevated levels of C. A greater response occurs as a result of hypertrophy schemes when compared with neuronal training schemes (42). Power training has also been shown to increase C levels, but their magnitude is less than that elicited by hypertrophic exercise (55). Slower lifting velocities, and thus increased TUT have been shown to elicit greater C responses than faster velocities and thus shorter TUT (22). Examination of the effect of training status on C response has produced conflicting results. Some studies found a greater C response in untrained than in trained men (54), others found no difference between the two groups (2, 43, 68).

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CHAPTER III

Methods

Subjects

Twelve resistance trained (RT; n = 12) men with at least 3 years' experience performing the parallel back squat exercise and twelve untrained (UT; n = 12) men completed the study. Selection criteria included 1) males between the ages of 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 affect muscle mass, insulin-like substances, or ana-bolic/catabolic pro-hormones or hormones within the previous six months leading up to the study. This study was conducted according to the Declaration of Helsinki guidelines. All proce-dures 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 followed a repeated-measures, counterbalanced, randomized design in which all subjects served as their own controls completing both experimental conditions. After determi-nation of height, weight, and body composition, subjects completed a familiarization session. At least 48 hours after the familiarization, subjects reported to the laboratory for determination of one repetition maximum (1RM). A minimum of 72 hours following 1RM determination, subjects underwent the same experimental testing procedures under two conditions, randomly assigned – TRD and CLU. At least 7 days separated experimental conditions (Figure 1).

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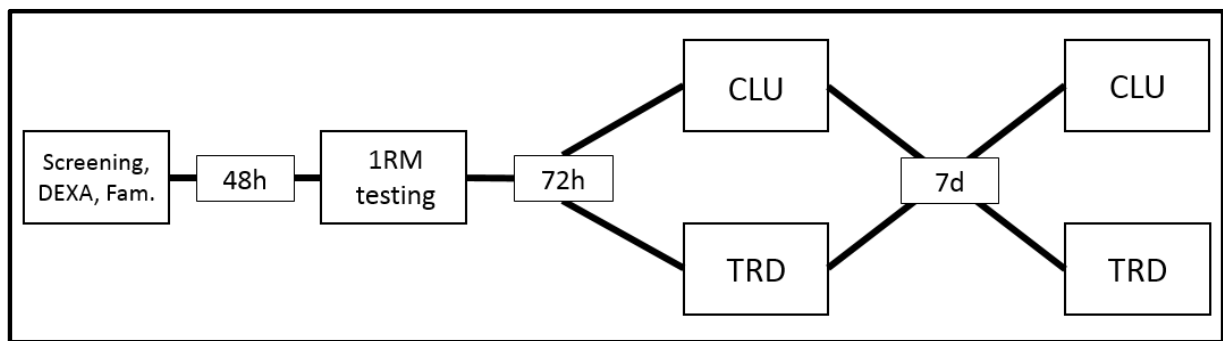
FIGURE 1 – Experimental design.

Familiarization Session

Prior to familiarization, subjects' height and body mass were determined to the nearest

0.5 cm and 0.2 kg, respectively, using a stadiometer (Seca, Chino, CA) and self-calibrating digi-

tal scale (Seca, Chino, CA) with subjects in socks or bare feet. Subjects then underwent body

composition determination via dual x-ray absorptiometry (DXA; GE Healthcare, Little Chalfont,

United Kingdom) calibrated according to manufacturer's guidelines, and performed by a trained

technician. All subjects, regardless of training status, participated in a familiarization session af-

ter research personnel demonstrated proper form for the parallel back squat exercise. Subjects

were required to perform the exercise until demonstrating proficiency. Only the weight of the bar

(20.4 kg) was used during familiarization. Those unable to perform using proper form were ex-

cluded from further testing (n = 1).

One Repetition Maximum Testing

At least 48 hours after familiarization, subjects returned to the laboratory having re-

frained from any physical activity outside of daily living for the previous 48 hours for determina-

tion of 1RM in the parallel back squat exercise. Following a dynamic warm-up (8-10 minutes)

subjects performed two sets of five repetitions at 40-60% of their estimated 1RM with two

minutes rest between sets. After a three minute rest, subjects performed one to two sets of 2-3

repetitions at a load corresponding to 60-80% 1RM. Subjects then began performing sets of 1

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repetition of increasing weight for 1RM determination. Three to five minutes rest was provided

between each successive attempt. All 1RM determinations were made within three to five at-

tempts. For an attempt to be considered successful, subjects were required to reach a depth of the

squat at which the top of the thighs was parallel to the floor as determined by research personnel.

A verbal "up" command was provided. 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 of 1RM determina-

tion has been shown to have an intra-class coefficient of 0.99 and a corresponding Pearson prod-

uct-moment coefficient of 0.001 (59). 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 and

parallel depth were used in all subsequent testing. All testing was performed on an Optima Smith

Machine (LifeFitness, Schiller Park, IL).

Experimental testing
　　　Subjects reported to the laboratory having refrained from any lower body training for at

least 72 hours and any activities outside of daily living for at least 48 hours. Prior to warm-up,

subjects remained seated quietly in a phlebotomy chair for five minutes for catheter insertion.

After a dynamic warm-up (8-10 minutes), subjects performed two sets of five repetitions of the

back squat exercise with a load equivalent to 40 and 60% of 1RM. After two minutes rest, sub-

jects performed the back squat using either TRD or CLU with a load equivalent to 70% of 1RM.

The set configurations (Fig. 2) were as follows: a) TRD consisted of four sets of ten repetitions

(4x10) with 120 seconds rest between sets, and b) CLU consisted of four sets of two times five

repetitions (4x(2x5)) with 30 seconds rest between clusters of five repetitions and 90 seconds rest

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between sets. Subjects were instructed to perform the concentric (upward) portion of each repetition "as explosively as possible". If subjects paused for more than two seconds in the extended position, or were unable to complete a repetition, resistance was lowered by 13.6 kg.
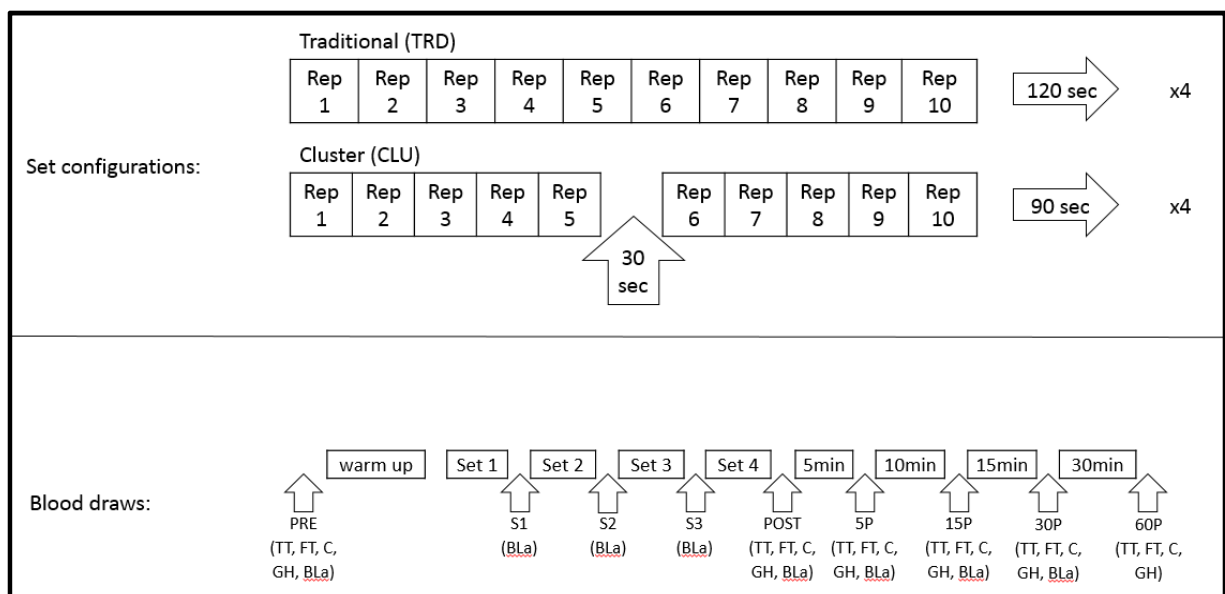
FIGURE 2 – Set configurations for traditional (TRD) and cluster (CLU) sets. Blood draw points during experimental trials. Blood samples will be obtained prior to a dynamic warm up (PRE), at the conclusion of each set (S1, S2, S3), immediately post exercise (POST), five minutes (5P), 15 minutes (15P), 30 minutes (30P), and 60 minutes (60P) post exercise. TT = total testosterone; FT = free testosterone; C = cortisol; GH = growth hormone; BLa = blood lactate. Measures of time denote time passed since last blood draw.

Force plate and linear position transducers

Subjects performed all exercise bouts on an AccuPower portable force platform (FP; AMTI, Watertown, MA) with the right side of the barbell attached to two linear position transducers (LPT; Treadmetrix, Park City, UT). The LPTs were mounted below and anterior (LPTa), and below and posterior (LPTp) to the subject, forming a triangle when attached to the barbell, thus allowing for measurement of horizontal and vertical bar displacement. The LPTs produced a voltage signal that represented the degree at which the LPTs were extended, allowing for the calculation of displacement-time data (11). From this displacement-time data, instantaneous velocity was calculated throughout the movement. Ground reaction force (GRF) was collected via force plate and displacement data were sampled at 1000 Hz via an analog-to-digital converter

Acute kinematic, kinetic, and hormonal responses to cluster sets

(Sewell Direct, Provo, UT) and collected by a laptop computer using custom-built data acquisition and analysis software (Treadmetrix, Park City, UT). Peak and average values for each individual repetition as well as for each set were determined for force, velocity and power. The custom software also recorded concentric and eccentric time under tension (TUT) for each individual repetition.

Blood sampling and analysis

At the beginning of each of the experimental testing sessions (TRD and CLU), subjects were seated quietly in a phlebotomy chair. Following sterilization of the area, 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 samples were obtained prior to a dynamic warm up (PRE), at the conclusion of each set (S1, S2, S3), immediately post exercise (POST), as well as five (5P), 15 (15P), 30 (30P), and 60 minutes (60P) post exercise (Fig. 2). Blood for the analysis of serum TT, FT, C, and GH was drawn into vacutainers containing no additive (BD Biosciences, San Jose, CA) at time points PRE, POST, 5P, 15P, 30P and 60P. Samples were allowed to coagulate in cooling beads for at least 30 minutes, and subsequently centrifuged at 2,500rpm for 10 minutes (Beckman Coulter Allegra X-12; Beckman Coulter, Brea, CA). After centrifugation, serum was aspirated and stored in aliquots at -80°C for later analysis. A second vacutainer containing the anticoagulant ethylenediaminetetraacetic acid (EDTA) was collected at time points PRE, S1, S2, S3, POST, 5P, 15P, and 30P. Immediately after collection, 0.5 mL of whole blood was pipetted into 1 mL of cold 8% perchloric acid to stabilize BLa (52). Samples were then centrifuged at

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3,000rpm for 10 minutes in a microcentrifuge (Eppendorf, Hauppauge, NY). Supernatant was

aspirated and stored at -80°C for later analysis.

Total testosterone (TT), free testosterone (FT), and Cortisol (C) were analyzed via radio-

immunoassay (RIA; Siemens, Washington, D.C.). All samples were run in duplicate on an ISO

Data 100 gamma counter (Titertek, Pforzheim, Germany). The inter-assay coefficient of varia-

tion (CV) was 5.06%, 4.91%, and 7.61% for TT, FT, and C respectively. The intra-assay CV was

2.98%, 2.33%, and 2.90% for TT, FT, and C respectively. GH concentrations were determined in

duplicate using ImmuChem™ Double Antibody hGH RIA (MP Biomedicals, Orangeburg, NY;

inter-assay CV: 7.57%; intra-assay CV: 2.62%;). Blood lactate concentrations (BLa) were deter-

mined via spectrophotometric assay (52) in triplicate. Absorbances were read at 340nm using a

Thermo Scientific spectrophotometer (Thermo Scientific, Waltham, MA). All BLa sample were

analyzed in triplicate. Inter-assay and intra-assay CV were 3.11% and 1.73%, respectively.

Ratings of Perceived Exertion

Prior to the beginning of each exercise protocol and immediately following each set, sub-

jects rated their perceived exertion on a standard Borg's scale from 6-20 (6). Subjects were in-

structed by research personnel on the use of the scale prior to and during warm-up. Subjects were

asked to rate their perceived exertion relating to the complete set of exercise during TRD and

CLU. The Borg's scale is a widely used tool, and its ratings correlate highly with heart rate and

other physiological variables (6). The scale consists of numbers 6-20, with each rating corre-

sponding to feeling of exertion. A rating of 7 corresponds to "very, very light" exertion, whereas

a rating of 19 corresponds to "very, very hard" exercise.

Statistical analysis

All analyses were performed using Statistical Package for the Social Sciences (SPSS)

V.22 (IBM Corporation, Armonk, NY). A multifactorial analysis of variance (ANOVA) with

repeated measures was used to determine the statistical significance of our findings. The factors included training status (two levels), condition (two levels), and time (multiple levels depending on the variable in question). Bonferroni post hoc analysis was performed when a significant finding ($p < 0.05$) or trend ($p \leq 0.10$) was identified. Dependent measures were force, velocity, and power output, BLa, TT, FT, GH, and C concentration, as well as CON, ECC, and TOT TUT, RPE, load and total volume load (TVL). Data are presented as mean ± standard error, unless otherwise noted.

CHAPTER IV

Results

Subject Demographics

Baseline demographics are presented in Table 1. RT subjects had 6.1±2.1 years training experience. While both groups were similar in age, height and body mass, UT subjects had significantly high body fatness as determined by DXA. As expected, 1RM parallel back squat and 1RM parallel back squat to body weight ratio was significantly different between groups.

TABLE 1 – Subject characteristics (mean±SD). BS1RM = Back squat one-repetition maximum; BS1RM:BW = ratio of back squat one-repetition maximum to body weight. $ = significantly different from untrained; Student's t-test; p<0.05.

Group	n	Age (years)	Height (cm)	Body mass (kg)	Body fat (%)	BS1RM (kg)	BS1RM:BW ratio	Training years
Trained	12	24.7±4.1	179.1±7.8	84.6±7.4	15.8±4.6$^{\$}$	146.9±17.1$^{\$}$	1.75±0.24$^{\$}$	6.1±2.1$^{\$}$
Untrained	12	25.0±3.1	180.1±6.3	85.4±13.3	28.3±7.4	90.0±19.6	1.07±0.24	-
p-value		0.823	0.717	0.856	< 0.001	< 0.001	< 0.001	-

Kinematic and Kinetic variables

Velocity

The greatest average velocity was recorded at repetition 2 in both CLU and TRD. RT subjects produced significantly higher (0.751 ± 0.24 m·s^{-1}) velocities than UT (0.661 ± 0.24 m·s^{-}

Acute kinematic, kinetic, and hormonal responses to cluster sets

[1]; p = 0.015). However, similar patterns of decline were observed in RT and UT subjects in each condition as evidenced by a significant condition x rep ($p < 0.001$) interaction. CLU resulted in significantly higher average velocities in repetitions 1, 6, 7, 8, 9, and 10 compared to TRD. A condition x set ($p < 0.001$) interaction was also observed. Average velocities during CLU and TRD collapsed by training status and set are shown in figure 3.
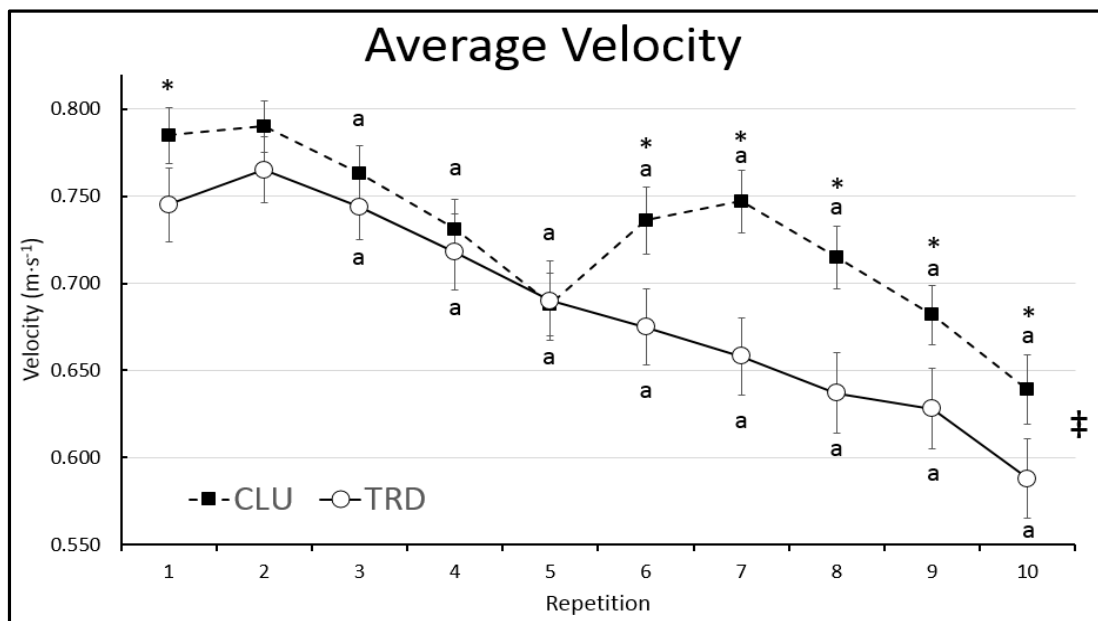
FIGURE 3 – Average velocity ($m \cdot s^{-1}$) by repetition during exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. * = sig. diff. from TRD; a = sig. diff. from peak value within same condition; ‡ = main effect for training status $p < 0.05$

Average velocity declined from set 1 to set 4 in both conditions; however, the decline was attenuated in the CLU condition resulting in greater average velocities compared with TRD (Fig. 4) in sets 2 ($p = 0.041$), 3 ($p = 0.014$), and 4 ($p = 0.003$).

Acute kinematic, kinetic, and hormonal responses to cluster sets
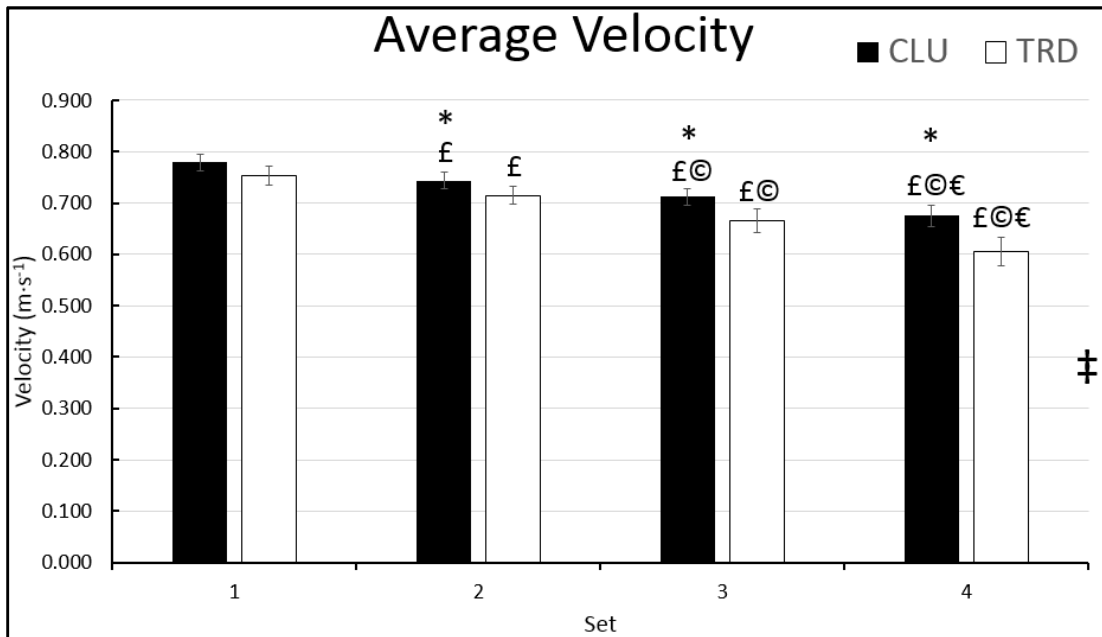
FIGURE 5 – Average velocity (m·s^{-1}) by set during exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. * = sig. diff. from TRD; £ = sig. diff. from set 1; © = sig. diff. from set 2; € = sig. diff. from set 3 ‡ = main effect for training status $p < 0.05$.

Force

RT subjects produced significantly greater force (1860.3 ± 49.6 N) in both conditions when compared with UT (1462.7 ± 49.6 N). However, similar patterns were again observed in both RT and UT. The CLU condition resulted in significantly greater average force during iso-lated reps in Sets 1 – 3, with a pattern emerging in Set 4 in which average force was greater in all later repetitions (7- 10) compared to TRD (Fig. 5).

Acute kinematic, kinetic, and hormonal responses to cluster sets
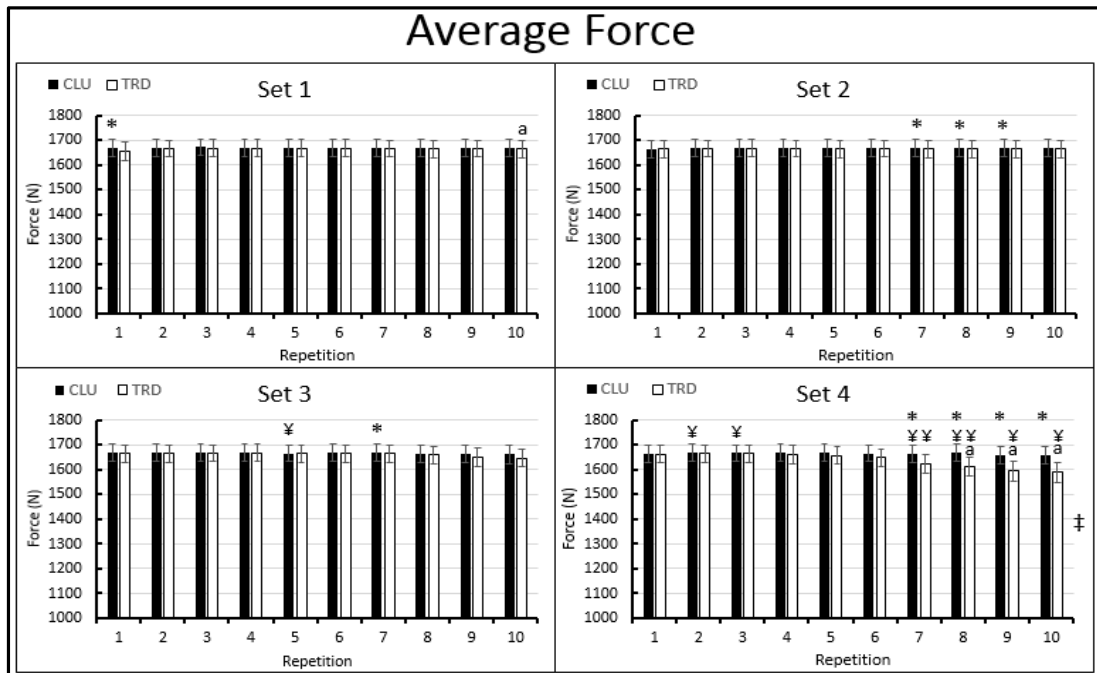
FIGURE 5 – Average force output (N) during all four sets using cluster sets (CLU) and traditional sets (TRD) collapsed by training status. * = sig. diff. from TRD; ¥ = sig, diff. from same repetition in set 1; ‡ = main effect for training status; p < 0.05.

Power

Average power output was greatest at repetition 2 in all sets during both conditions, with the exception of Set 2, in which peak power levels were reached at repetition 1 during CLU, and at repetition 2 during TRD. A condition x set x rep (p = 0.033) interaction 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, six repetitions in Sets 2 and 3, and eight repetitions in Set 4 (Fig. 6). A training status x rep (p = 0.001) interaction was also observed. Similar to results observed in force and velocity, RT subjects produced significantly greater power in both conditions at all repetitions (all p < 0.002). However, a different pattern of decline was observed in which the decline in power output was observed later (repetition 5) in RT subjects compared to UT subjects (repetition 4).

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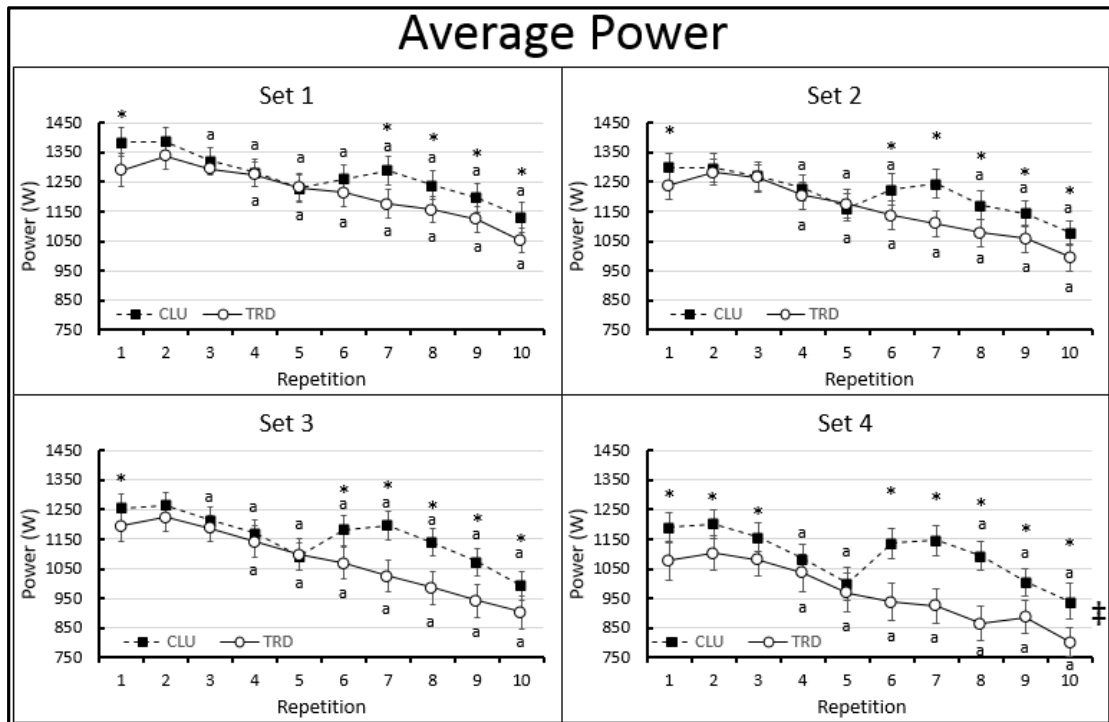Acute kinematic, kinetic, and hormonal responses to cluster sets

FIGURE 6 – Average power output (W) during all four sets using cluster sets (CLU) and traditional sets (TRD) collapsed by training status. * = sig. diff. from TRD; a = sig. diff from peak value within same set and condition; ‡ = main effect for training status; p < 0.05.

Time Under Tension

Concentric time under tension

In evaluating CON TUT, a condition x rep (p < 0.001) interaction (Fig. 7) and a main effect for set (p < 0.001) were observed. When collapsed over sets, average CON TUT was greater during TRD at repetitions 6 (p < 0.001), 7 (p < 0.001), 8 (p < 0.001), and 9 (p = 0.032). A pattern was observed in which CON TUT increased linearly beginning at repetition 3 in TRD; whereas, a similar increase was observed in each cluster in the CLU condition (Fig. 7). Average CON TUT increased progressively from set to set (all p < 0.001) in both conditions, with no differences between CLU and TRD.

Acute kinematic, kinetic, and hormonal responses to cluster sets
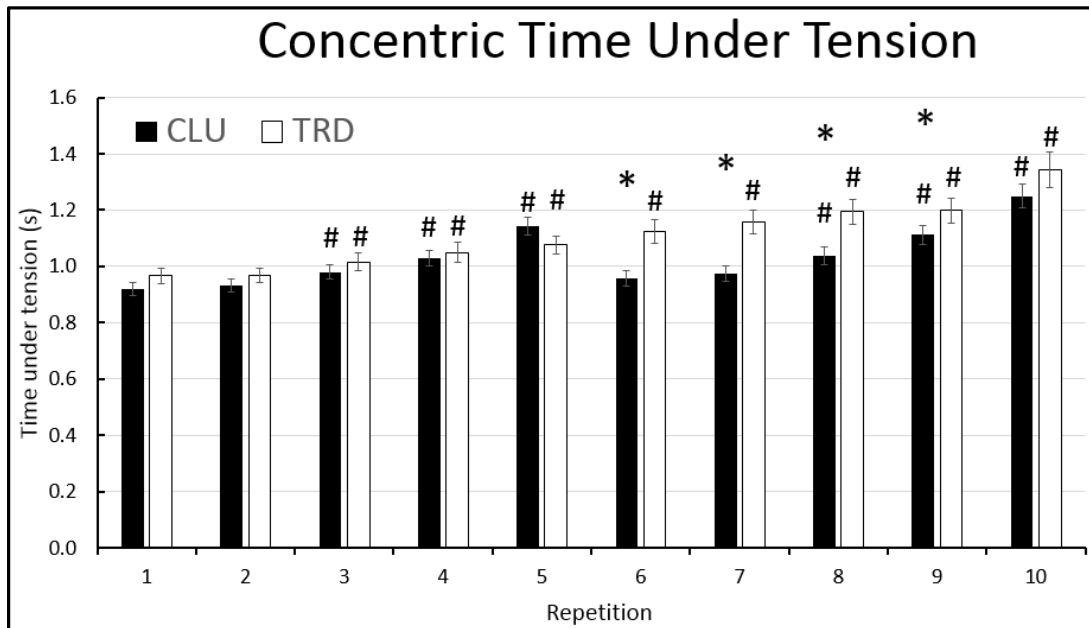
FIGURE 7 – Concentric time under tension (s) by repetition during exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. * = sig. diff. from TRD; # = sig. diff. from rep 1; p < 0.05.

Eccentric time under tension

Main effects for set (p = 0.003) and rep (p < 0.001) were observed for ECC TUT. ECC TUT was significantly greater in Set 4 when compared with Sets 2 (p = 0.006) and 3 (p = 0.011). Further, ECC TUT was significantly shorter at repetitions 3 (p = 0.003) and 4 (p = 0.048) when compared with repetition 1 in both conditions. There were no differences between conditions or training status in average or total ECC TUT.

Total time under tension

Similar to CON TUT, a condition x rep interaction (p < 0.001) and main effect for set (p < 0.001) were observed for TOT TUT. Total time under tension was greater (Fig. 8) during TRD when compared with CLU at repetitions 6 (p = 0.029), 7 (p = 0.004), and 8 (p = 0.004). There was a progressive increase in average TOT TUT starting at set 3, with the greatest times recorded in set 4. There was no difference in any TUT measurements between subjects of different training status.

Acute kinematic, kinetic, and hormonal responses to cluster sets
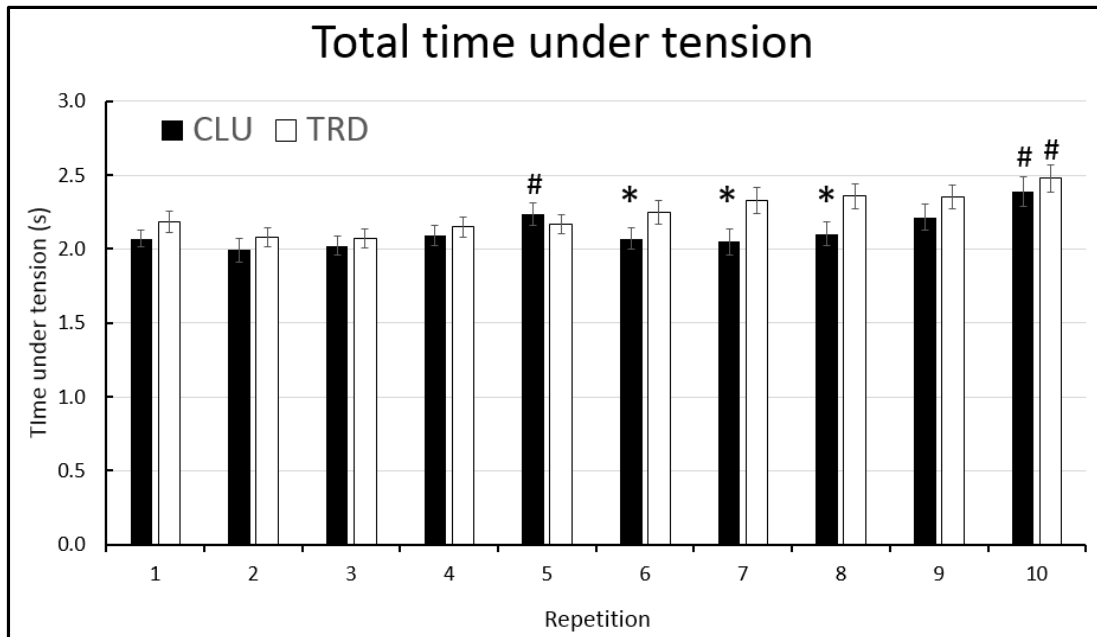
FIGURE 8 – Total time under tension (s) by repetition during exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. * = sig. diff. from TRD; # = sig. diff. from repetition 1; p < 0.05.

Hormonal and metabolic responses

Total testosterone

A main effect of training status was observed in TT (p = 0.034). RT subjects had higher overall levels of TT (662.0 ± 34.7 ng·dL$^-$1) compared with UT subjects (548.1 ± 36.3 ng·dL^{-1}). The condition x time (p = 0.095) interaction approached significance. However, no differences were observed between TRD and CLU at any measurement. TT increased immediately post and remained elevated through 30P (Fig. 9).

Acute kinematic, kinetic, and hormonal responses to cluster sets
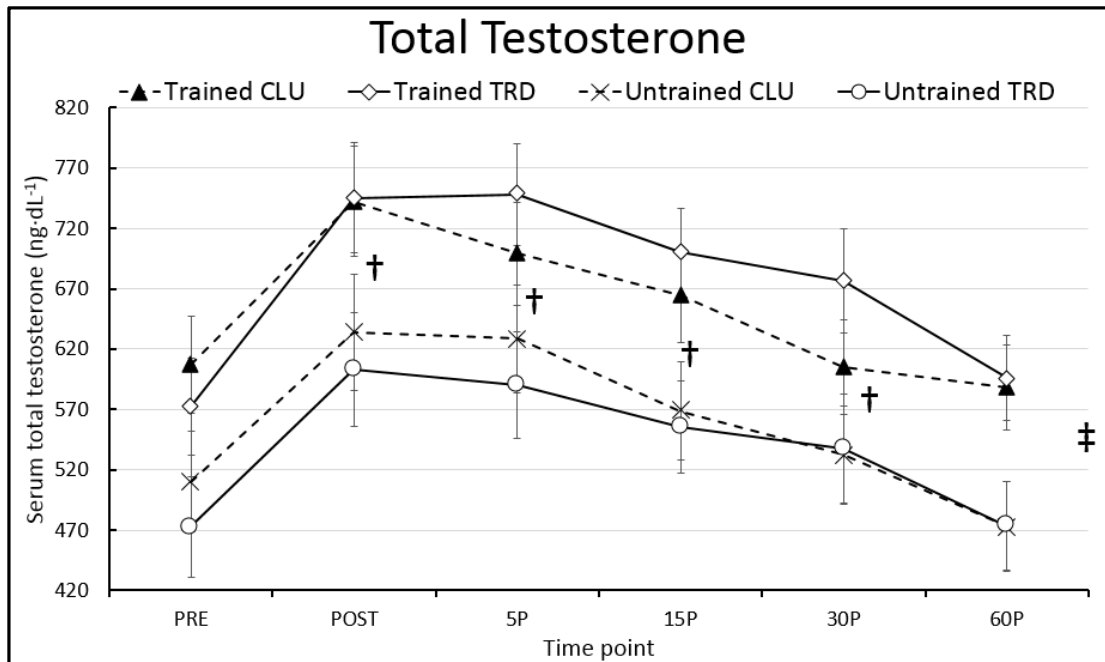
FIGURE 9 – Serum total testosterone concentration (ng·dL^{-1}) before (PRE), immediately following (POST), as well as five (5P), fifteen (15P), thirty (30P) and sixty (60P) minutes after exercise with cluster (CLU) and traditional (TRD) set configurations † = sig. diff. from PRE; ‡ = main effect for training status; p < 0.05.

Free testosterone

       A main effect for time (p < 0.001) was observed for FT. Free testosterone concentrations

(Fig.10) were significantly elevated (p < 0.001) in all subjects immediately following exercise

and remained elevated through 30P (p = 0.033) with no difference between conditions (p =

0.247). There was no difference in FT response based on training status (p = 0.139).

Acute kinematic, kinetic, and hormonal responses to cluster sets
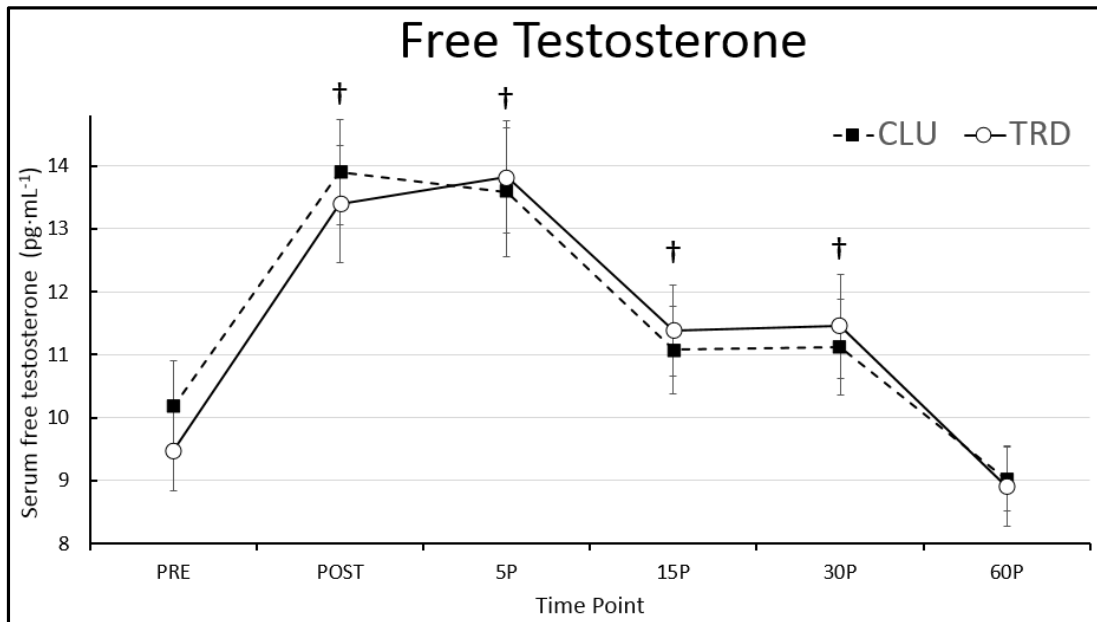
FIGURE 10 – Serum free testosterone concentration (pg·mL⁻¹) before (PRE), immediately following (POST), as well as five (5P), fifteen (15P), thirty (30P) and sixty (60P) minutes after exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. † = sig. diff. from PRE; p < 0.05.

Growth Hormone

Main effects for time (p < 0.001) and condition (p = 0.040) were detected for growth hormone. GH levels were significantly greater during TRD (15.5 ± 3.0 ng·mL⁻¹) when compared with CLU (10.1 ± 2.0 ng·mL⁻¹). There was no difference between trained and untrained subjects (p = 0.159). GH concentration was elevated immediately following exercise (13.7 ± 2.8 ng·mL⁻¹; p = 0.004), increased progressively until it reached peak values at 15P (19.6 ± 3.2 ng·mL⁻¹; p < 0.001), and returned to resting levels by 60P (8.3 ± 2.6 ng·mL⁻¹; p = 0.227). Figure 11 shows the GH response to both CLU and TRD collapsed by training status.

Acute kinematic, kinetic, and hormonal responses to cluster sets
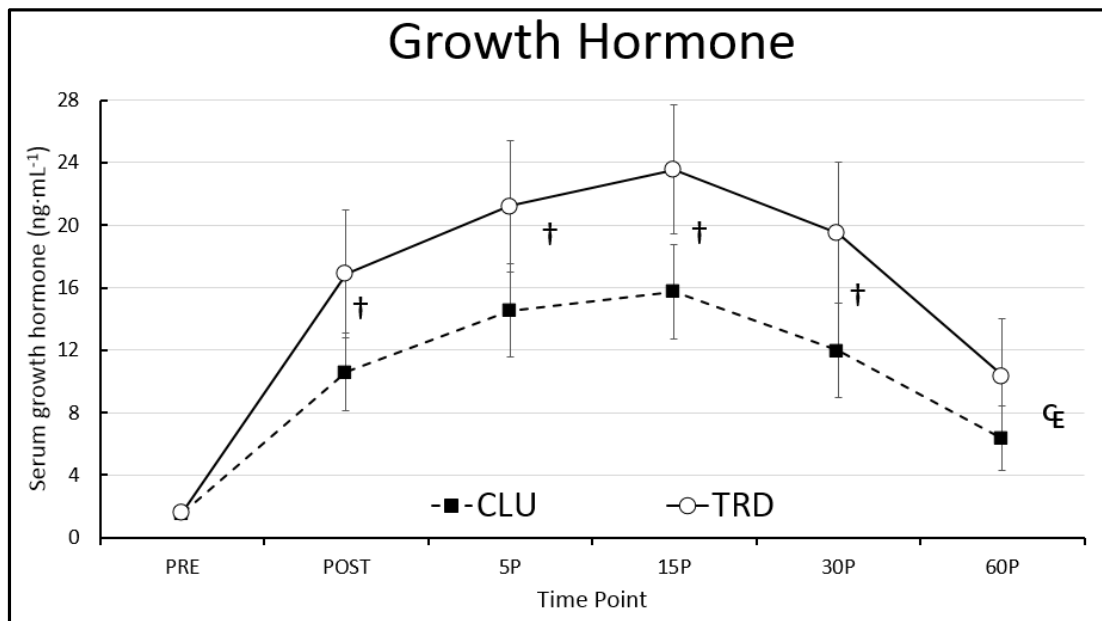
FIGURE 11 – Serum growth hormone concentration (ng·mL^{-1}) before (PRE), immediately following (POST), as well as five (5P), fifteen (15P), thirty (30P) and sixty (60P) minutes after exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. † = sig. diff. from PRE; Ƈ = main effect for condition; p < 0.05.

Cortisol

A condition x time interaction (p = 0.018) was detected for cortisol. C increased in a step-wise fashion following exercise during TRD, with concentrations being significantly greater at 5P when compared with POST (p = 0.023), and a further increase above 5P at 15P (p = 0.017). During CLU, the first significant post-exercise increase was not observed until 15P, at which time C was significantly elevated above POST (p = 0.009) and 5P (p = 0.028). C was raised above baseline levels at 15P in both CLU (p = 0.008) and TRD (p < 0.001). While C continued increasing through 30P during TRD (p = 0.001) it approached baseline levels at the same time point in CLU (p = 0.421) resulting in significantly greater C (p = 0.021) during TRD when compared with CLU at 30P. C approached baseline levels at 60P during TRD (p = 0.204). There was no difference between trained and untrained subjects (p = 0.785). Figure 12 shows C levels for both conditions collapsed by training status.

Acute kinematic, kinetic, and hormonal responses to cluster sets
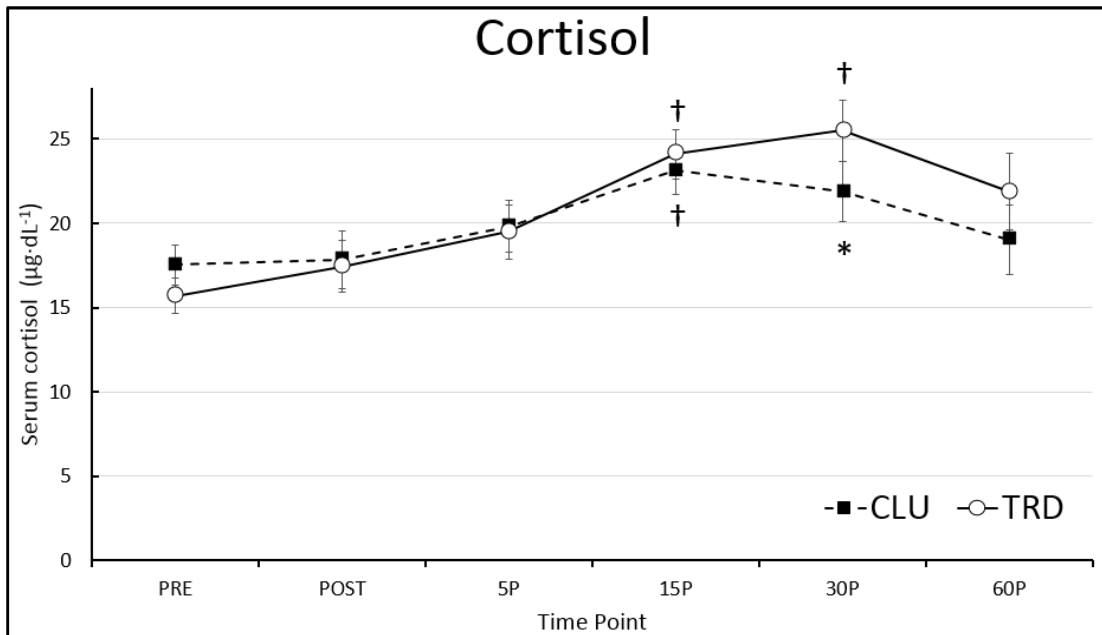
FIGURE 12 – Serum cortisol concentration (µg·dL^{-1}) before (PRE), immediately following (POST), as well as five (5P), fifteen (15P), thirty (30P) and sixty (60P) minutes after exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. * = sig. diff. from TRD; † = sig. diff. from PRE; p < 0.05.

Blood lactate

A significant condition x time interaction (p < 0.001) was observed for blood lactate. BLa was elevated above resting levels in both conditions starting at S1 (p < 0.001 for both), and remained elevated in both conditions through 30P (CLU: p = 0.005; TRD: p < 0.001). However, BLa was significantly greater during TRD when compared with CLU at time points S2 (p = 0.004) through 30P (p < 0.001). BLa peaked immediately following exercise during CLU (9.39 ± 0.55 mmol·L^{-1}) and five minutes into recovery during TRD (12.71 ± 0.55 mmol·L^{-1}). There was no difference between trained and untrained subjects (p = 0.550). Figure 13 shows BLa responses for both conditions.

Acute kinematic, kinetic, and hormonal responses to cluster sets
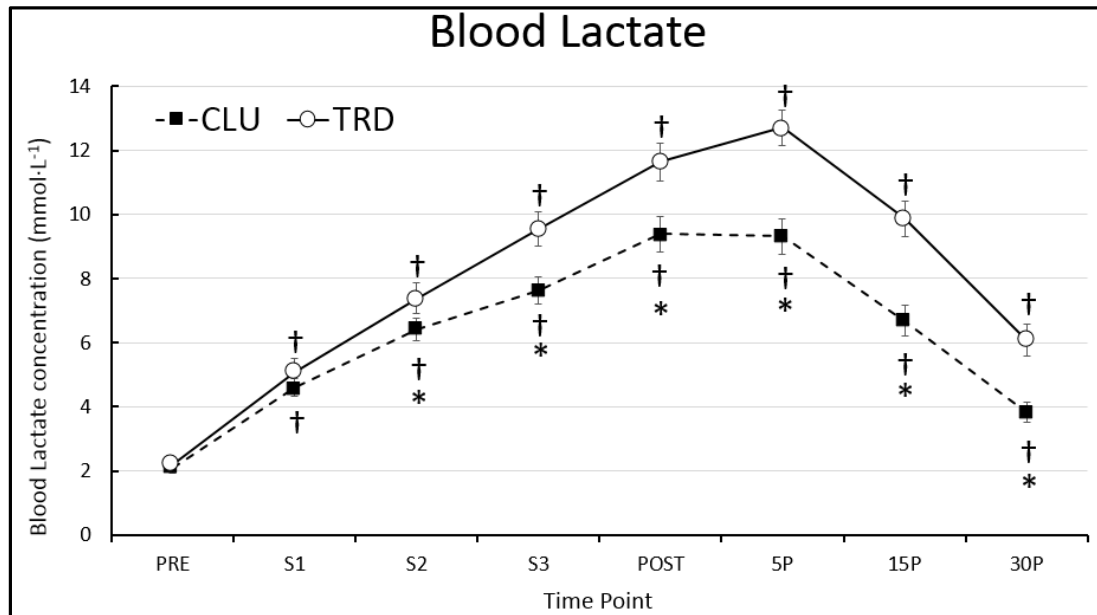
FIGURE 13 – Blood lactate concentration (mmol·L^{-1}) before (PRE), after sets one (S1), two (S2), and three (S3) as well as immediately (POST), five minutes (5P), fifteen minutes (15P) and thirty minutes (30P) following exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. * = sig. diff. from TRD; † = sig. diff from PRE; $p < 0.05$.

Load and Total Volume Load

A condition x set x rep interaction ($p < 0.001$) and a main effect for training status ($p < 0.001$) were observed for load. There was no difference in load in sets 1 through 3. Subjects maintained the initial load for all repetitions in set 4 during CLU (82.583 ± 2.583 kg), but were unable to displace the same load for all repetitions during TRD (Fig. 14). In this final set, subjects moved a greater load during CLU repetitions 6 ($p = 0.043$), 7 ($p = 0.013$), 8 ($p = 0.001$), 9 ($p < 0.001$), and 10 ($p < 0.001$). RT subjects moved a greater average load (102.855 ± 3.657 kg) when compared with UT subjects (61.555 ± 3.657 kg; $p < 0.001$) throughout all exercise bouts. The reduction in load during set 4 of TRD resulted in a greater TVL during CLU (3302.4 ± 102.7 kg) when compared with TRD (3274.8 ± 102.8 kg; $p = 0.001$). Trained subjects completed a significantly greater TVL (4115.2 ± 145.2 kg) when compared with untrained subjects (2462.1 ± 145.2 kg; $p < 0.001$).

Acute kinematic, kinetic, and hormonal responses to cluster sets
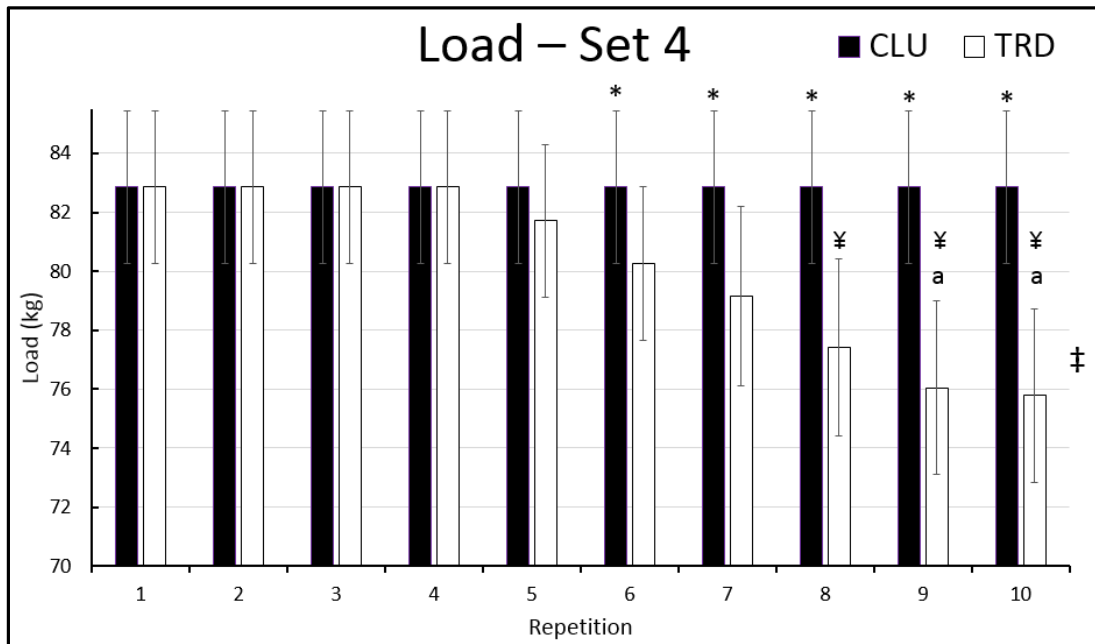
FIGURE 14 – Load (kg) by repetition during exercise with cluster (CLU) and traditional (TRD) configurations collapsed by training status. * = sig. diff. from TRD; a = sig. diff. from peak value within same set; ¥ = sig. diff. from same repetition in set 1; ‡ = main effect for training status; p < 0.05.

Ratings of Perceived Exertion

    A condition x time interaction ($p = 0.022$) was observed for RPE. In both conditions RPE increased progressively from pre-exercise through set 4. However, RPE was greater during TRD when compared with CLU during all sets ($p = 0.044$ to $p < 0.001$). There was no difference in RPE based on training status ($p = 0.215$; Figure 15).

Acute kinematic, kinetic, and hormonal responses to cluster sets
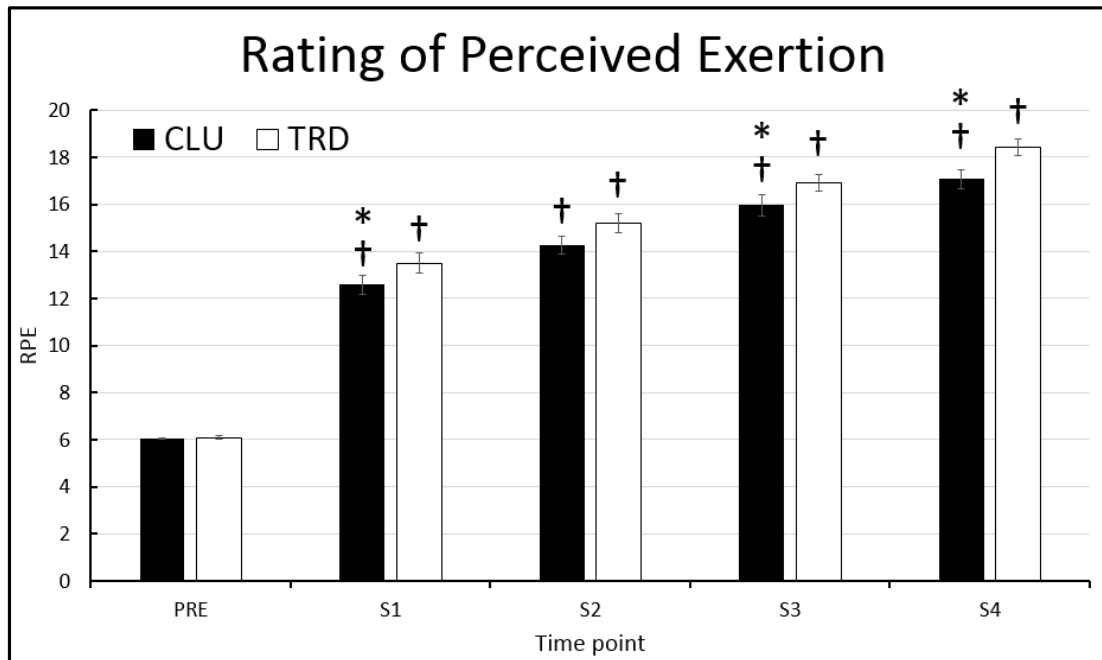
FIGURE 15 – Rating of perceived exertion (RPE) before (PRE), after set one (S1), set 2 (S2), set 3 (S3), and set (4) of exercise with cluster (CLU) and traditional (TRD) set configurations collapsed by training status. * = sig. diff. from TRD; † = sig. diff. from PRE; p < 0.05.

CHAPTER V

Discussion

Key findings

The main finding of the current study is that CLU with loads associated with hypertrophy result in a similar acute anabolic hormone response as evidenced by that study was that CLU produced similar TT and FT responses when compared with TRD while allowing for greater average force, velocity, and power output during hypertrophic back squat exercise in both untrained and trained subjects. Further, CLU elicited smaller lactate and cortisol responses, suggesting that exercisers using CLU during hypertrophic workouts can reap the same beneficial anabolic hormonal response while experiencing attenuated metabolic and hormonal stress. This reduced stress elicited by CLU was reflected in lower RPE during CLU when compared with TRD. When performing CLU, subjects were able to produce a significantly greater TVL, which plays a

Acute kinematic, kinetic, and hormonal responses to cluster sets

significant role in muscular strength development as well as the hypertrophic response to exercise (61).

Kinematic and kinetic variables

Force, velocity, and power

As observed in figures X, y, and Z, the greater average power observed in CLU was driven by the Our findings that CLU produced greater force (32), velocity (24, 29, 32) and power output (29, 32, 49) when compared with TRD were in agreement with previous findings. Lawton et al. (49) as well as Hardee et al. (32) observed a near linear decline in power output during TRD, resulting in greater overall power output during CLU. While those studies were using power and strength schemes, our study showed similar beneficial effects in a hypertrophic exercise setting. Joy et al. (38) were the first to investigate acute effects of CLU on power output in a hypertrophic scheme. When performing the parallel back squat at 75% of 1RM, subjects in the Joy et al. study produced significantly greater power during later repetitions of each set of CLU when compared with TRD. Mean power output decreased by $29.9 \pm 3.0\%$ from repetition one through repetition ten during TRD, whereas the decrease was attenuated during CLU. Similarly, subjects in the present study experienced a decrease in power output during TRD of $25.3 \pm 3.4\%$ from repetition one to repetition ten, with a comparable pattern of recovery during CLU. While Joy et al. provided 60 s of rest between clusters of five repetitions, we only allowed 30 s. This shows that intra-set rest periods as short as 30 s allow for recovery of power during hypertrophic back squats using CLU configurations. Further, the present study was the first to show that the benefits of CLU regarding acute velocity and force output found at intensities of 80-120% of 1RM translate effectively into a hypertrophic setting.

Hardee et al. (32) observed a near-linear decrease in peak force output from repetition 1 through repetition 6 across all 3 sets in TRD. Participants in the present study did not experience

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this pattern of decline in the present study. While force output decreased significantly during the later repetitions of set 4, a significant decline in later repetitions across all sets was not observed. The discrepancies in the findings of these two studies are most likely due to the difference in the exercise performed. While participants in the present study performed the parallel back squat, subjects in the Hardee et al. study performed the power clean. When performing the parallel back squat vertical bar displacement remains constant from repetition to repetition, whereas it may significantly differ between repetitions in the power clean. Hardee et al. (31) observed a significant decrease in vertical bar displacement from repetition 1 to repetition 6 in all three sets. This decreased the amount of force necessary to displace the bar by that difference. On the other hand, in the present study, subjects had to continually displace the bar the same distance, necessitating the same amount of force to be produced to successfully complete the movement.

In the present study, mean velocity was different between conditions at repetition one (p = 0.019). Upon further examination of raw velocity data, this divergence did not manifest until the third set. This suggests that the additional mid-set recovery during CLU allowed subjects to begin later sets at a greater velocity when compared with TRD. Furthermore, CLU produced significantly greater power at an increasing number of repetitions from set one to set four. This further substantiates the finding that the beneficial effects of CLU are intensified during the later part of an exercise bout. The decline in mean force at the end of set four of TRD was magnified due to the need to decrease the load for twelve subjects (four trained; eight untrained) to allow for completion of the entire exercise bout.

Slower movement velocities during TRD caused greater CON and TOT TUT when compared with CLU. The greatest effect of movement velocity on TUT was observed in the concentric phase, during which subjects were instructed to move "as explosively as possible". As muscular fatigue increased, CON TUT became greater in both conditions. CON TUT was elevated

above repetition-one values in both CLU and TRD at repetitions three, four, and five. However, after subjects received a 30 s break following repetition five during CLU, CON TUT returned to initial levels and was significantly shorter than during TRD at repetitions six, seven, eight, and nine. This divergence caused greater total CON TUT during TRD when compared with CLU. CON TUT displayed an inverse relation to mean velocity. As movement velocity declined progressively from set to set in both conditions, CON TUT increased progressively over the same period of time. Reduced resistance during set four of TRD did not have a noticeable effect on CON TUT, as CON TUT continued to be greater during TRD even after the load was lowered.

The eccentric portion was not controlled, allowing subjects to move at their desired velocity during each repetition. This caused a high inter- and intra-individual variability in ECC TUT. The only meaningful finding on ECC TUT was that it decreased significantly in set four, as muscular fatigue was greatest in both condition. No differences were found between conditions at any time points. Mean TOT TUT followed a similar pattern as CON TUT, being significantly greater during CLU when compared with TRD at repetitions six, seven, and eight. These differences lead to greater total TUT ($p = 0.80$) during TRD when compared with CLU. Similar to CON TUT, TOT TUT increased progressively from set to set, as muscular fatigue increased in both conditions.

CON and ECC TUT were lower in both conditions when compared with other previously published findings on repetition kinematics and kinetics in hypertrophy scheme (13). Crewther et al. (13) asked their subjects to perform ten sets of ten controlled smith-squat repetitions at 75% of 1RM. They provided two minutes rest between sets. The controlled movement technique elicited ECC TUT averaging 1.56 ± 0.11 s, and CON TUT averaging 1.54 ± 011 s per repetition. In the present study mean CON TUT was 1.03 ± 0.03 s during CLU and 1.11 ± 0.04 s during TRD, while ECC TUT was 1.09 ± 0.05 s during CLU and 1.11 ± 0.04 s during TRD. This suggests that

attempting to maximize power output in a hypertrophy by moving "as explosively as possible" will result in diminished TUT during both CLU and TRD when compared with a controlled movement technique.

Load and TVL

Resistance was lowered by 13.6kg during set four of TRD for twelve subjects to allow for completion of the exercise bout. This resulted in significantly greater load during CLU set four at repetitions six through ten. It has been well established that maximum isometric force declines progressively with repeated tetani (3, 70). This decline in force producing capacity may be the main factor causing the inability to complete set four at the original load. Lännergren et al. (47) showed rapid recovery of force production capacity with as little as two seconds of rest during recovery (500 ms, 70-Hz tetani given at two-second intervals) from continuously stimulated depletion (30s, 70 Hz). The 30 s of rest provided after five repetitions of CLU allowed subjects to recover enough to complete set four without a reduction in load. The causes for skeletal muscle fatigue eliciting this reduction in force producing capacity are without doubt multifactorial. There are several factors that might play a role in the observed difference between CLU and TRD in the ability to sustain the original load for all forty repetitions. Inorganic phosphate (P_i) is considered a major cause of fatigue, decreasing myofibrillar force production by negatively effecting cross-bridge function (56, 60) as well as diminishing myofibrillar calcium (Ca^{2+}) sensitivity (56). The original CLU model by Haff et al. (24) was based on the assumption that short intra-set rest periods would provide sufficient time for partial replenishment of PCr. This phosphorylation of creatine to PCr consumes P_i, and thus may attenuate the inhibitory effect of P_i on force production capacity. Gorostiaga et al. (21) showed lower PCr levels following one and five sets of bilateral leg-press (≈80% 1RM) during CLU when compared with TRD, giving further credence to this proposed mechanism.

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Hormonal and metabolic responses

Our findings regarding the hormonal response to CLU when compared with TRD disagree with the observations of Girman et al. (20). The investigators in the latter study found no differences in C and GH responses between conditions, while we observed protocol-dependent dissimilarities in both of those variables. Several factors may have contributed to these discrepancies. Firstly, exercise protocols differed greatly between studies. Subjects in the Girman et al. study performed the clean pull and the back squat at a variety of intensities and repetition ranges followed by two circuits of body weight and light to moderate intensity exercises. Both, exercise volume (54) and intensity (27) have been shown to affect hormonal responses to resistance exercise. Thus, these factors are highly likely to have played a role in the discrepancy in findings between Girman et al. and the present study.

Furthermore, Girman et al. allowed for only 15 s rest between clusters, whereas we provided 30 s of rest. Moreover, Girman et al. controlled repetition velocity at 2-0-2 tempo for all back squat and bench press repetitions. In the present study, subjects were allowed to move at their desired velocity during the ECC phase of the move, and were instructed to move "as explosively as possible". Both, rest time (67) and movement velocity (22) produce variation in hormonal responses to resistance exercise, and thus might in part explain the different findings between Girman et al. and the present study.

Finally, variances in metabolic stress have been linked to differences in magnitude of hormonal response to resistance exercise (23). Both studies observed similar elevations in BLa (marker of metabolic stress). However, the present study found significantly greater BLa concentrations in TRD starting after set one and lasting through 30 minutes of recovery, whereas Girman et al. observed greater BLa accumulation during TRD only mid-exercise. In the latter study

BLa was not different between conditions immediately following exercise, 15 minutes post exercise or 30 minutes post exercise. The prolonged discrepancy in BLa concentrations between conditions in our study may have caused divergences in GH and C responses, while differences in metabolic stress might not have been great enough in the Girman et al. study to cause significant variances.

Total Testosterone

TT was elevated above resting levels immediately following exercise in all subjects during both conditions. The magnitude of TT response as well as its pattern was consistent with previous research using similar schemes in subjects with similar characteristics to the subjects in the present study (2, 44). In concordance with our hypothesis, TT levels were greater in trained when compared with untrained subjects ($p = 0.034$). However, there was no difference between conditions ($p = 0.937$). We had based our hypothesis that TT response would be greater following TRD when compared with CLU on the expected differences in TUT. We equated total rest time and volume, and the original exercise protocol was intended to equate load between both conditions as well, leaving TUT as the primary difference in factors influencing TT response. Due to the inability of several subjects to complete the entire exercise bout at the prescribed resistance, we were forced to decrease load to allow for completion of all repetitions. This resulted in greater TVL during CLU, which presented a confounding factor in TT response. It is possible that the differences in TUT (greater during TRD) were counterbalanced by the differences in TVL (greater during CLU) leading to a similar TT response during CLU when compared with TRD. Both TUT (22) and TVL (62) are important factors in the magnitude of anabolic hormone response. We are not aware of a study comparing the extent of each of these factors to post-resistance exercise TT elevations, and thus were unable to fully elucidate the interplay of TUT and TVL on the TT response observed in the present study.

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Lactate stimulated secretion of testosterone has been proposed by Lu et al. (53). Lin et al. (50) showed dose-dependent responses in testosterone release in an *in vitro* study. Thus a greater TT response could be expected with increased BLa levels. However, greater levels of BLa during TRD in the present study did not elicit an augmented TT when compared with CLU, suggesting that BLa differences between conditions may not have been great enough to produce divergent TT responses.

Free Testosterone

FT response in the current study was in agreement with previous findings. The magnitude and pattern (elevated immediately post exercise through 30P) agreed with studies using hyper-trophic intensities and similar subject populations to the presents study (2, 26). In contrast to the present study, Ahtiainen et al. (2) found a greater FT response in trained subjects when compared with untrained subjects. The non-strength athlete (NA) group in the Ahtiainen et al. study was leaner (12.9 ± 2.3 % body fat) than our untrained group (28.3 ± 7.4 %). Moreover, NA were clas-sified as "physical education students" (2), suggesting greater total physical activity levels than subjects in our mostly sedentary untrained population. Furthermore strength athletes (SA) in the former study had 9.3 ± 6.9 years of training experience, while resistance-trained subjects in the present study averaged 6.1 ± 2.1 training years. Kraemer et al. (28) showed training-induced in-creases in FT response to resistance exercise after a ten week periodized program. This suggests that greater training experience may lead to an increased response in FT. Thus, the aforemen-tioned dissimilarities in body composition/physical activity (untrained vs. NA) and training age (trained vs. SA) might explain the discrepancy in training-status-induced differences between Ahtiainen et al. (2) and the present study.

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Growth Hormone

GH was significantly elevated immediately following both protocols and remained elevated through 30P. While no difference was observed between conditions in TT or FT, GH levels were significantly greater during TRD when compared with CLU. These findings suggest that the influence of exercise-related factors on the secretion differs between these anabolic hormones. Goto et al. (23) observed that exercise-induced metabolic stress is highly associated with GH release. Greater BLa concentrations following TRD suggest that TRD induced significantly greater metabolic when compared with CLU, providing a possible explanation for protocol-dependent differences in GH response. No differences in GH response were observed between trained and untrained subjects (p = 0.159). This discrepancy from previous research (1, 2) might be due to differences in subject characteristics as detailed in the discussion of FT response. Further, great inter-individual differences have been reported in studies investigating GH response to resistance exercise (1, 2, 40, 44, 62). Similarly, the present study produced highly variable responses to exercise, with some subjects experiencing no response and others responding significantly more than others. Thus, comparisons of GH responses between studies is difficult due to potential inter-individual differences in response-rate within different subject populations.

Cortisol

C response to exercise was congruent with previous research investigating catabolic responses to hypertrophic exercise (66, 74) Despite diminished TVL in the continuous scheme, C response was greater during TRD when compared with CLU, suggesting that increased metabolic stress and greater TUT played an important role in catabolic hormone response in the presents study. An acute bout of resistance exercise has been shown to elevate C and adrenocorticotropic hormone (ACTH). ACTH, a pituitary hormone that stimulates C release, is elevated in response to a variety of stressors (58). Thus, greater metabolic stress during TRD when compared

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with CLU may have been the most important factor in eliciting the augmented C response during the continuous scheme. No difference was observed between trained and untrained subjects, confirming previous findings when a using similar load and repetition scheme (2).

Plasma C concentrations have been shown to be a valid predictor for hypertrophy/atrophy in the animal model (14). Thus, greater C response to TRD may negate the beneficial effects of the continuous scheme on GH release, and diminish the benefits of increased TT and FT during recovery.

Blood lactate
BLa response was attenuated during CLU when compared with TRD. This finding agrees with the observations of previous researchers comparing continuous schemes with intra-set rest configurations (20, 21). The 30 s rest period between clusters of five repetitions may have allowed for sufficient replenishment of PCr stores (33, 49, 72), resulting in attenuated demand on anaerobic glycolysis concomitant with less BLa accumulation.

Ratings of Perceived Exertion
The diminished metabolic stress evidenced by attenuated BLa accumulation during CLU was furthermore reflected in RPE. Kraemer et al. (41) first observed significant positive correlations between BLa accumulation and RPE ($r = 0.84$; $p < 0.05$) when investigating the physiological response to heavy resistance exercise with very short rest periods. Similarly the present study revealed an increase in RPE as BLa concentrations rose. Further, CLU resulted in lower perceived exertion when compared with TRD after sets one, two, and three, reflecting the lower metabolic stress elicited by the intra-set rest protocol when compared with continuous performance of repetitions.

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Conclusion and practical applications

The present study provides an applied investigation of the benefits of CLU during hypertrophic exercise. While a variety of confounding factors (TVL, TUT, metabolic stress) prohibit further investigation of the physiological mechanisms eliciting the present responses, our findings show that CLU allow for achievement of greater movement velocity, power output, and TVL while eliciting similar anabolic and reduced catabolic hormonal response. Thus, CLU provide a valuable tool for strength and conditioning professionals, athletes, and recreational weight lifters to optimize kinematic and kinetic variables in a hypertrophic setting, while eliciting desired hormonal responses. These beneficial acute effects of CLU may allow augmented power and strength adaptations while eliciting a similar lean mass gains as evidenced in the study by Oliver et al. (59). In a practical application, the use of CLU could allow athletes to emerge from a hypertrophy cycle with the same gains in muscle mass, and greater strength and power gains. This would attenuate the usual decrease in athletic power/velocity associated with hypertrophic training. As evidenced by the present study, CLU can also provide benefits to recreational weight lifters. Our findings suggest that untrained exercisers can reap the same benefits in kinematic and kinetic as well as hormonal and metabolic variables from the inclusion of CLU into their training regimen. This might allow recreational weight lifters to train hypertrophy, strength, and power concurrently.

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ABSTRACT

ACUTE KINEMATIC, KINETIC, AND HORMONAL RESPONSES TO CLUSTER SETS IN
PARALLEL BACK SQUAT EXERCISE IN TRAINED AND UNTRAINED YOUNG MEN
UTILIZING HYPERTROPHIC INTENSITIES

by Andreas Kreutzer, M.S., 2014
Department of Kinesiology
Texas Christian University

Thesis Advisor: Dr. Jonathan Oliver, Assistant Professor of Kinesiology

To compare kinetic, kinematic and hormonal responses during the parallel back squat, twelve resistance trained (RT; 6.1 ± 2.1 years training), and twelve untrained (UT) men performed traditional (TRD; 4 sets x 10 repetitions; 120 s rest) and cluster sets (CLU; 4x(2x5); 30 s between clusters; 90 s between sets) at 70% 1RM. Significance was accepted at $p<0.05$. CLU resulted in greater velocity at repetition 1 and 6-10. CLU produced greater force in repetitions 7-10 of set 4. CLU elicited greater power in eight repetitions during set 4. RT produced greater force, velocity, and power. CLU allowed greater total volume load while attenuating lactate concentrations. Total (TT) and free testosterone were similar between conditions; RT exhibited greater TT. Growth hormone, cortisol, and concentric time under tension were greater in TRD. Producing greater power and similar hormonal responses acutely, CLU could augment power adaptations while eliciting similar hypertrophy chronically when compared with TRD.