THE INFLUENCE OF TIME-EQUATED TRAINING PROGRAMS ON MUSCLE HYPERTROPHY, STRENGTH, AND BODY COMPOSITION

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Michael C. Zourdos, Department of Exercise Science and Health Promotion, and has been approved by the members of his supervisory committee. It was submitted to the faculty of the College of Education and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

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The purpose of this study was to determine if barbell circuit training (RTC) as a model for concurrent training is superior to high intensity interval (CTHI) or moderate intensity continuous (CTMI) cycling for changes in muscular strength, hypertrophy, and body composition. Eleven trained males were recruited and counterbalanced into three groups. Each program featured three alternating days of resistance training per week, with one of the above time-equated (30-minute) concurrent training modalities between sessions. All groups increased muscular strength ($p<0.05$, RTC=7.48%, CTHI=10.32%, CTMI=15.74%) with no group differences ($p>0.05$). Increases in upper body muscle hypertrophy were similar in RTC and CTMI ($p<0.01$, RTC=20.18%, CTMI=20.97%), increases in lower body muscle hypertrophy only occurred in CTMI (VM: $p=0.01$, 38.59%, VLP: $p=0.07$, 13.33%), while no hypertrophy changes were detected in CTHI ($p>0.05$), no group experienced changes in body composition ($p>0.05$). These findings

suggest similar muscle performance benefits from barbell circuit or cycling concurrent training.

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I: INTRODUCTION

Concurrent training (CT) is the simultaneous inclusion of both endurance and resistance type training within the same exercise program (29). The addition of endurance training (ET) to a resistance training (RT) program is commonly used for body weight management and/or body fat percentage (BF%) reduction. Thus, CT appears to be an attractive training model for strength and weight class athletes (i.e. powerlifters, weightlifters, bodybuilders, wrestlers). Even though CT may aid in desired BF% changes, previous studies (9, 13, 27, 29, 35, 38, 43, 61) have consistently shown that engaging in ET attenuates muscle performance (strength, hypertrophy, and power). This attenuation of muscle performance was coined the *'interference effect'* by Hickson (1980) (29). Currently, two hypotheses (acute and chronic) have been proposed to explain the interference effect.

The acute interference hypothesis has evolved from the observation that when RT is performed within 24 hours following a bout of aerobic exercise a reduction in work capacity is seen in the subsequent RT bout (2, 63). Therefore, an every-other-day approach, or 24 hours of rest between bouts, is imperative for preservation of RT performance.

The chronic interference hypothesis is derived from the attenuation of muscle performance during long-term CT studies (29). Mechanistically, the molecular pathways expressed by RT (mammalian target of rapamyacin-mTOR) and ET (ubiquitin proteasome system) are divergent in nature (14). The anabolic pathway mTOR (14), encoded by the mTOR gene, regulates cell growth, proliferation and motility, as well as muscle protein synthesis (MPS). Conversely, the catabolic ubiquitin proteasome system targets proteins for destruction; several ubiquitin ligases are associated with skeletal muscle atrophy (14). Additionally, the 5′adenosine monophosphate activated protein kinase (AMPK) is a second messenger activated in response to low energy states induced by ET (6, 14, 31). AMPK has been identified as a regulator of MPS via down-regulation of the anabolic pathways (14). Another suggested mechanism of the chronic hypothesis is the possibility of overtraining syndrome with CT compared to RT alone. This is thought to occur simply because most CT protocols have a greater number of total training sessions and, therefore total work when compared to RT alone (25, 29, 42, 52, 54, 56).

Further, the intensity and duration of exercise seems to be important with regard to the interference effect (66). Balabinis et al. (8) utilized a model of CT featuring repeated effort sprint training (i.e. HIIT) in trained individuals. It was demonstrated that strength and power increases over seven weeks were similar in CT compared to RT alone. These results are not surprising as sprinting primarily stresses the adenosine triphosphate phosphocreatine (ATP-PCR) energy system, recruits high threshold motor units, and requires rapid force development, similar to RT. Furthermore cardiovascular improvements (i.e. VO_2max) were demonstrated in CT that exceeded ET alone. Therefore, it seems that the addition of high intensity, short duration, and sport specific exercise can produce concomitant strength, power and endurance adaptations (8, 66).

Despite specificity being paramount for muscle performance, there is no data, which simply examines the effects of additional RT to ET as a metabolic stimulus for BF% changes. Commonly, RT as circuit training is performed with low loads and high repetitions to improve aerobic performance and local muscular endurance. Recently, studies have investigated the efficacy of heavy resistance circuits (i.e. 6RM loads) for improving muscular performance and BF% (4, 5). The results have indicated that similar muscular strength, hypertrophy, and BF% changes are elicited by heavy resistance circuits alone when compared to RT alone. This approach to circuit training has yet to be investigated as a CT option. Performing such training would increase training total volume (i.e. Sets x Repetitions x Weight Lifted -TV), which is the acute training variable most closely related with increases in skeletal muscle hypertrophy and strength (11, 25, 46), while also serving as an additional metabolic stimulus to reduce BF%, making it appear to be an attractive strategy for CT when anaerobic performance is of primary concern.

Even with over four decades of CT research, there is still much to be uncovered to optimize training for maximizing muscle performance and BF% results concomitantly. Therefore, the primary aim of this study was to compare the effects of three different CT programs in resistance trained individuals: 1) resistance training + barbell circuit training (RTC), 2) resistance training + high intensity interval cycling (CTHI), and 3) resistance training + moderate intensity continuous cycling (CTMI) on muscular strength, hypertrophy, and body composition over a six week training program. It is hypothesized that 1) RTC will demonstrate the greatest increases in total muscular strength (i.e. back squat, bench press, and the exercises combined), hypertrophy (chest and thighs), and the greatest reduction in BF%, 2) CTHI group will experience the above changes to a lesser magnitude than RTC, but greater than CTMI.

II: REVIEW OF LITERATURE

Different modes of exercise training must be utilized to elicit desired performance adaptations. These adaptations may be anaerobic in nature, including the augmentation of muscle cross-sectional area (CSA) and maximal strength, or aerobic in nature, improving aerobic capacity and oxygen transporting capabilities. Furthermore, the training modality must be specific to the goal; as the activation of different intracellular signaling pathways responsible for the varying types of adaptations are induced by the different modes of exercise performed (14, 48). As such, this review will examine the effects of RT and ET individually as well as when they are combined as CT. CT is commonly used when strength and weight class athletes desire to improve body composition through the reduction of BF% and preservation of lean body mass (LBM). This investigation will lead to recommendations for such athletes with respect to improving muscle performance and reducing BF% concomitantly.

I. RESISTANCE TRAINING ADAPTATIONS

RT is performing repeated patterns of movement against external resistance to stimulate the skeletal muscle system. This is the optimal method of training when the desired outcomes consist of increasing muscular hypertrophy, strength, and power.

Upon the initial exposure to RT, the voluntary activation of all motor units is not possible. However, with practice, the ability to voluntarily recruit motor units increases (22, 59). This increase in motor unit activation can be measured through the surface electrical activity of whole muscles, otherwise known as electromyography or EMG.

During the early stages of training, the increase in muscle activity without an increase in cross sectional area is known as neural drive, (22). Increasing the motor-unit firing rate is an early and transient adaptation to resistance training. Additional training leads to the enhancement of motor-unit synchronization (60), which can further augment strength. When neuromuscular coordination and synchronization is achieved, activation of synergistic muscles and inactivation of antagonistic muscles, further increases of strength appear to be dependent on hypertrophy (59).

External loading produces mechanical stress that triggers the above adaptations in the skeletal muscle tissue under stress (31, 68). This mechanical stress is commonly referred to as tension, which is produced by changing the length of muscle tissues against resistance. These conditions are the driving forces behind a cell-signaling web that produces training adaptations via the activation of specific anabolic pathways (11, 24)

The mTORC1 pathway is commonly recognized as the major anabolic signaling pathway that regulates muscle protein synthesis (MPS) (6, 14). The activity of this pathway can be influenced by the availability of nutrients, energy, presence of growth factors, and mechanical stimulus (31). The stimulation of MPS also involves the activity of ribosomal protein kinase s6 (p70S6K) (31, 46). P70S6K lies downstream of mTORC1 and is active through the translation initiation stages of protein synthesis (31). During these stages, specific messenger ribonucleic acid (mRNA) activity is increased, resulting in the production and addition of skeletal muscle proteins, thus eliciting hypertrophy (11, 68), this process appears to be volume dependent (11, 52, 56). Therefore, increasing the work performed increases the activity of p70S6K and in turn MPS, ultimately resulting in skeletal muscle hypertrophy (11).

The activation, proliferation, and differentiation of satellite cells (SC) is another important component of hypertrophy (65). SCs reside within the muscle fibers and are believed to be involved with muscular hypertrophy due to their role in the myonuclear domain theory (62). This theory stipulates that a nucleus can only provide for and maintain a limited amount of muscle before additional nuclei are required to further muscle growth. The SCs are the nuclear donors responsible for enabling continued hypertrophy (65). The activation of SCs is dependent upon RT causing stress to the contractile units of muscle fibers. This muscle damage causes a release of growth factors triggering the activation of SC's and their restorative processes, thus inducing hypertrophy (65).

Often, changes in muscle cross sectional area, or hypertrophy from training, are accompanied by an increase in maximal contractile force (1). By increasing the cross sectional area of a muscle, the maximum amount of actin and myosin cross bridges that can occupy that muscle are also increased. Increasing the absolute number of cross bridges leads to the increased potential for force generation (1).

TV is defined as the number of sets performed, multiplied by the number of repetitions performed, multiplied by the load or weight lifted (i.e. Sets X Repetitions X Weight Lifted). TV appears to be the major factor that positively influences strength and hypertrophy gains (11, 25, 42, 46, 52, 54, 56). Muscle tissue remodeling is dependent upon the total work performed as opposed to the amount of acute exercise induced myofibril damage (21). As such, increased TV results in greater cellular signaling responses, which elicits more robust adaptations (11, 25, 42, 46, 52, 54, 56).

II. ENDURANCE TRAINING ADAPTATIONS

ET traditionally consists of long duration continuous exercise, reoccurring bouts of this type of exercise produces adaptations to increase aerobic work capacity. Large energy demands are placed upon the body systems to sustain the cyclic muscular contractions of locomotion during ET. As such, adaptations are made to the cardiovascular system to increase oxygen and nutrient delivery to the muscles to supply these demands. The amount of blood the heart can pump each beat, stroke volume (SV), at rest and during exercise increases to facilitate the nutrient and oxygen delivery demands of the muscles. With increased SV the work demands on the heart, during periods of rest and submaximal exercise, are reduced. As such, a slower heart rate (HR) at rest and during submaximal exercise is commonly observed in endurance athletes (7, 39). In addition to the increased SV, contractility, or the strength of heart contractions, is concomitantly increased by ET. The overall resultant of these central adaptations is an increase in cardiac output (the product of HR and SV; Q = HR X SV), that persists at rest and during exercise (39).

To aid in the delivery of nutrients, oxygen, and hormones, capillary density of the working skeletal muscles increases (7). The degree of capillarization is affected by the volume and intensity of the endurance exercise performed. Increasing the absolute number of capillaries per muscle increases the surface area available for gas and nutrient diffusion. This effectively decreases the distance oxygen and energy substrates need to travel to supply the metabolic demands of exercise (7).

The respiratory system adapts to increase the efficiency of ventilation during exercise. Tidal volume, or the amount of air moved in and out of the lungs during normal breathing, and respiratory rate are increased or decreased as a result of endurance exercise. During rest and submaximal exercise tidal volume is increased and respiratory rate is reduced, resulting from the more efficient gas exchange. However, during maximal aerobic exercise, both tidal volume and respiratory rate must be increased to meet the demands of exercise (7).

The cyclic contractions of ET leads to an increase in motor efficiency. This increased efficiency reduces the energy cost of locomotion during long duration exercise (58). Further, the skeletal muscles responsible for locomotion during ET adapt to increase their aerobic capacity. These muscles become more adept at utilizing fat for energy in place of carbohydrates, which increases time to exhaustion (30). By transitioning to a more efficient process of energy production, the production and accumulation of lactic acid occurs at later stages during endurance exercise. Additionally, the muscles become more efficient at buffering and removing lactic acid resulting in further increases in time to exhaustion (39).

The mitochondrial density of the muscle will also increase through a process known as mitochondrial biogenesis (23). The mitochondria use oxygen, supplied via myoglobin, to produce adenosine triphosphate (ATP), the major energy molecule used by the body. The major metabolic pathway that is activated by ET is the AMPK signaling pathway. Muscular contractions cause ATP to be hydrolyzed to provide energy, which results in the formation of adenosine diphosphate (ADP) molecules. ADP molecules will then relinquish a phosphate to other ADP molecules resynthesizing ATP molecules. The donor ADP molecules become adenosine monophosphate (AMP) molecules. The increasing AMP levels resulting from energy production activates the AMPK signaling pathway. AMPK is a key regulator of cellular energy, and ET constantly depletes ATP supplies and increases AMP levels. AMPK activation has been associated with regulating mitochondrial biogenesis (51). AMPK activation leads to the downstream activation of peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α), which is the master regulator of mitochondrial biogenesis. In addition to the AMPK pathway acting on PGC-1α, calcium movement within the cell due to muscle contractions activates the calcium calmodulin-dependent protein kinase pathway that also acts directly on PGC-1α, further increasing its expression and activity. PGC-1α acts upon nuclear respiratory factor 1(NRF1), and nuclear factor erythroid 2-related factor (NRF2), which act together to replicate mitochondrial DNA and induce mitochondrial biogenesis (67).

III. CONCURRENT TRAINING

As previously mentioned, strength and weight class athletes often engage in CT to regulate body weight, even though it may impede anaerobic muscle performance adaptations. Since Hickson's (1980) pioneer study (29), several researchers have continued to investigate the muscle performance attenuations of CT. However, these impairments produced during CT are not fully understood. Researchers have investigated effects from different ET intensities, modalities, muscle groups, and recovery times in an effort to achieve optimal adaptations to CT.

Dudley and Djamil followed up Hickson's study by investigating the effects of CT on the force-velocity relationship of skeletal muscle using high intensity cycling and high velocity isokinetic knee extensions (19). It was observed that interference in strength development did not occur during slow-velocity high-force conditions, however in the high-velocity low-force condition strength development was impaired (19). There have been two mechanisms proposed as being responsible for these differing adaptations. The first one suggested is of neural origin, and suggests that a tension-limiting mechanism is at work with slow speeds of contraction but not fast speeds of contraction, this mechanism was seemingly unaffected by CT (19). Secondly, another independent mechanism suggests that the intrinsic properties of muscle regulate strength development at fast speeds of contraction, which appeared to be affected by CT (19). However it is unclear whether the lack of strength development in high-velocity low-force condition of the CT group can be attributed to the disruption of one or both of the above mechanisms (19).

Abernethy and Quigley investigated the effects of CT similarly to Dudley and Djamil, however the arm muscle groups were used to determine whether the velocity and force interaction existed in other muscle groups (3). The same effects were not observed in the arms using a similar arm ergometer and isokinetic arm curl protocol (3). Further, Craig, et al. investigated the effects of running on bench press and leg press strength (16). It was demonstrated that bench press strength was uninhibited by the lower body endurance training, while leg press strength was attenuated (16). In a later study, Leveritt and Abernethy (37) further investigated the effects of high intensity ET on isotonic and isokinetic strength. Reductions in the ability to perform squat repetitions as well as to produce torque during leg extensions once again displayed inhibitory effects on subsequent lower body muscle performance (Leveritt & Abernathy, 1999). Thus, it appears as though the upper body is less susceptible to the interference effect associated with CT, whether the aerobic training uses the arms or the legs. While the lower body appears to be very susceptible to the interference effect when both endurance training and anaerobic training involve the leg muscles.

The effects of moderate intensity cycling and high intensity cycling with various recovery periods on muscle performance were observed in the acute timeframe (63). It was found that the intensity of cycling exercise and length of recovery time between training sessions once again had no effects on upper body performance. Conversely, lower body performance was negatively impacted when recovery times were short (i.e. 4 and 8 hours) with no difference between either intensity cycling. However, 24 hours of recovery resulted in no difference in performance after either intensity cycling. A later study also did not experience an attenuation of lower body performance when utilizing high intensity CT (8). However, this protocol featured sprints 100-500m in distance. High intensity short duration sprinting is still anaerobic in nature requiring high threshold motor unit recruitment, rapid force development, and stresses the same energy system(adenosine triphosphate phosphocreatine; ATP-PCR) as RT. Interestingly however, the recovery period between sessions was only 7-hours. This study, unlike others, used trained individuals along with “sport specific” principles, possibly explaining the positive anaerobic performance outcomes in spite of less than 24 hours of recovery time (8).

The effects of running on anaerobic muscle performance was investigated (16). It was observed that the combination of running and weightlifting did not hinder the growth or strength of the upper body, however, leg press strength and thigh girth was attenuated (16). Conversely, cycling ET did not exhibit detrimental effects lower body muscle performance (57). Further, a recent meta-analysis has implicated running to be more detrimental to overall anaerobic muscle adaptations when compared to cycling (66). Currently, there are two explanations regarding this interaction. The first stipulates that a greater biomechanical similarity in the lower body exists in cycling when compared to running and weightlifting, which produces less performance decrement (20, 26, 41). Further it is postulated that the increased muscle damage incurred during running, through the increased eccentric activity of the leg muscles, is more deleterious to anaerobic performance than cycling, which is mostly concentric and produces less myofibril damage (34). It appears as though utilizing cycling when CT must be performed is preferred to running, as there is less overall attenuation of anaerobic muscle performance adaptations (66).

ET preceding resistance training in the acute time frame is detrimental to TV (63). However, the mechanisms behind these interactions have not yet been elucidated, it has been postulated to be the result of local metabolic stress or fatigue within the muscles (50, 63), which causes a reduction in TV and force output. A decrease in strength will also decrease the quality of the TV performed via a reduction in tension (31). Tension is a primary initiator of adaptations associated with resistance training (68), and TV is a driver of those adaptations (52, 54, 56). It appears as though performing CT, regardless of intensity, is best done on alternating days to allow for 24 hours of recovery to preserve TV (63). Finally, no studies have reported greater strength gains in CT when compared to RT alone (8, 9, 13, 27, 29, 35, 38, 43, 61). As such, CT does not appear to be optimal for enhancing the performance of strength and weight class athletes.

Table 1: Outcomes of Concurrent Training Studies

Study	Duration, Frequency, and Subjects	Training Protocol	Outcome
Hickson et al. (29)	10 weeks, 5-6 d/wk 2 groups, recreationally active subjects. 1. Strength (S): n=8, 7 M, 1F 2. Endurance (E): n=8. 5 M 3 F Strength and Endurance (S+E): n=7, 5 M 2 F	1. S: 30-40 min/d, 5 d/wk. Major muscle groups. 2. E: 40 min/d, 6 d/wk Alternating interval and continuous running 3. S+E: same regiments as S and E separated 2 hours.	**S:** ⇑ Body Mass and thigh circumference. ⇑ Strength throughout the 10 weeks, avg improvement 44%. **E:** ⇓Body fat **S+E:** ⇑ thigh circumference. ⇓Body fat. ⇑Strength for 7 weeks. ⇓Strength final 3 weeks. Peak improvement 34%, avg at the end of training 25%.
Kraemer et al. (35)	12 weeks, 4 d/wk 4 groups, healthy male subjects. 1. High-intensity strength and endurance training (C): n=9 2. Upper body only high-intensity strength and endurance training (UC): n=9 3.High-intensity endurance training (E): n=8 4. High-intensity strength training (ST): n=9	1,2,4: Strength training: Monday-Thursday alternating hypertrophy (3x10) and strength (5x) 1,2,3: Endurance training: Monday-Thursday alternating distance and interval exercise (200-800m intervals)	Strength: leg press ST > C > UC > E double leg extension C and ST > UC > E

Table 1: Continued

Study	Duration, Frequency, and Subjects	Training Protocol	Outcome
Bell et al. (9)	16 weeks 3d/wk 22 College Rowing Club members (14 M 8 F) and 14 Student body volunteers (8 M 6 F) Novice (6mos to 1 year) to several years experience. Women Strength only =6, Women concurrent training (rowers) = 8, Men Strength only =8, Men concurrent training (rowers) = 14	Resistance training 3 d/wk. Volume and intensity altered every 4 wks. Concurrent training (rowers only): 2 d/wk continuous rowing concept II rowing Interval training 1 d/wk.	Concurrent training and strength training men experienced similar increases in incline leg press and bench press strength. . Strength training only women experienced greater increases in incline leg press and bench press than concurrent training women.
McCarthy et al. (43)	10 weeks, 3 d/wk 3 groups, Sedentary healthy male subjects. High intensity strength training (S): n= 10 Cycle endurance training (E): n= 10 Concurrent strength and endurance training (CC): n=10	1. S: 3 d/wk. Major muscle groups. 2. E: 3 d/wk 50 minutes continuous cycling. 3. CC: Completed both protocols, rotating order.	**S** ⇑ thigh extensor and flexor/adductor CSA, type I and II myofibril area, isometric knee extension torque. **CC** ⇑ thigh extensor and flexor/adductor CSA, type II myofibril area, isometric knee extension torque.

Table 1: Continued

Study	Duration, Frequency, and Subjects	Training Protocol	Outcome
Hakkinen et al. (27)	21 weeks, 2-4 d/wk 2 groups, healthy male subjects, Strength training (S) n=16 Strength and endurance training (SE) n=11	1. S, SE: 2 d/wk Major muscle groups. Volume and intensity changed every 7 weeks. 2. SE: 2 day/week One day steady state, the second varying training zones.	No significant group differences in strength. No significant group differences iEMG. **S** ⇑ RFD
Leveritt et al. (37)	6 weeks, 3 d/wk 3 groups, Active university students Resistance (R) n=8 (5 M 3 F) Endurance (E) n=9 (3 M 6 F) Concurrent (C) n=8 (3 M 6 F)	1. S: 3 d/wk Major muscle groups to failure. 2. E: 3 d/wk 5x5 min cycling 40,60,80,100% VO2 5 min recovery	**R, C** 1RM squat > **E** group.
Balabinis et al. (8)	7 weeks, 4 d/wk 4 groups, Undergraduate male basketball players Strength (S) n=7 Endurance (E) n=7 Strength and endurance (S+E) n=7 Control (C) n=5	1. S: 4 day/week Major muscle groups. Plyometrics added weeks 4 and 5 2. E: 4 d/wk, varied week to week. 3. S+E: both programs 7 hours apart.	**S** ⇑ 16.1%, 23.6%, 8.4%, 17.1% in 1RM squat, bench press, leg press, lateral pull down (front). ⇑ Vertical jump Wingate. ⇓body fat (15 **C** ⇑ 18.9%, 23.1%, 6.5%, 22.4% in 1RM squat, bench press, leg press, lateral pull down (front). ⇑ Vertical jump and Wingate ⇓body fat (15.5%) and body weight (4.3%)

Table 1: Continued

Study	Duration, Frequency, and Subjects	Training Protocol	Outcome
Chtara et al. (13)	12 weeks, 2 d/wk 5 groups, Male physical education students Control(C) n=9 Endurance (E) n=10 Circuit training (S) n=9 Endurance pre circuit (E+S) n=10 Circuit pre endurance (S+E)10	1. S: 2 d/wk 3-week periods: 1st and 2nd strength endurance 3rd and 4th explosive strength and power. Rest between sets decreased the second week of each period. 2. E: 2 d/wk 5 intervals at VO2 max active recovery at 60% VO2 max. 3. E+S, S+E: differed in order but completed both sessions in the same day separated by 15 minutes.	⇓body fat all groups, ⇑Body mass all groups, ⇓ **body mass** endurance training **S** ⇑1RM significant over S+E and E+S groups. Peak-jumping force, peak-jumping explosive strength and power, and in peak jumping height compared to both the S+E and E+S groups.
Shaw et al. (61)	16 weeks, 3 d/wk 3 groups, Sedentary healthy males Control (Con) n=12 Resistance training (Res) n=13 Concurrent training (Com) n=13	1. Res: 3 d/wk. 3x15 60%1RM Tested and adjusted every 4 weeks. 2. Com: 3 day/week Resistance training 2x15 60%1RM Tested and adjusted every 4 weeks. Endurance training 22 minutes at 60% APHRmax, treadmills, rowers, steppers, and cycles.	**Res** ⇓ body mass ⇑ lean body mass. **Com** no effect on body mass. ⇑ lean body mass. **Res** and **Com** no difference in strength gains.

Some of the limitations within the literature include using subjects with a low training status (10, 12, 13, 16, 18, 19, 27, 29, 33, 38, 43, 61), protocols with low training frequency (9, 13, 16, 27, 37, 43, 61), and short recovery periods between endurance and resistance training (3, 8, 13, 16, 29, 35, 38, 43, 61). When the currently available literature is not used to optimize the design of a CT protocol, TV, the driving factor of muscle adaptations (11, 52, 56), will be sacrificed, resulting in decreased anaerobic muscle performance.

IV. CONCLUSION

This review discussed the adaptations and compatibility of RT and ET, and the resulting efficacy of CT. It is common for athletes that compete in strength and weight class dominated sports to engage in CT to manipulate body weight and BF%. However, the results in the literature question the efficacy of such practices. RT is the optimal way to elicit beneficial adaptations to sports such as powerlifting, weightlifting, and bodybuilding; engagement in ET for BF% changes is unspecific and appears to be detrimental to TV and resultantly attenuates adaptations of strength, hypertrophy, and power.

III: METHODOLOGY

Experimental Design

This study examined muscle performance (i.e. muscular strength and hypertrophy) and body composition (i.e. body mass, lean body mass, BF%) responses to three different CT programs 1) resistance training + barbell circuit training (RTC), 2) resistance training + high intensity interval cycling (CTHI), and 3) resistance training + moderate intensity continuous cycling (CTMI), in resistance trained males. Training spanned eight weeks and included an initial familiarization week (i.e. introductory microcycle) following pre-training measures, six weeks of the core training program, and a one week taper period (i.e. reduced TV) preceding post-training measures. The subjects were required to perform a standardized RT protocol three days per week (i.e. Monday, Wednesday, Friday), and their respective CT protocols two days per week (i.e. Tuesday and Thursday).

Subjects reported to the training laboratory a total of 42 days out of 60 days (see Table 10 for details). The first 1.5 weeks served as pre-training measures followed by introductory training, while the final week served as taper training and post-training measures. Pre-training measures of muscle thickness (MT), BF%, and 1RM of the back squat and bench press was conducted during the initial laboratory visit, followed by a peak aerobic power cycling test (VO_2peak) 48 hours later during visit two. Subjects returned 48 hours after visit two for introductory training (see Tables 2, 3, 4, and 5 for details).

During the introductory week and next six weeks of training, subjects trained five days per week (i.e. Monday-Friday) with RT occurring on three non-consecutive days (i.e. Monday, Wednesday, Friday - see Table 2 for details); and either barbell circuit training, high intensity interval cycling, or moderate intensity continuous cycling on the days tween the RT sessions (i.e. Tuesday and Thursday -see Tables 3, 4, and 5).

Seventy-two hours after the final training session subjects began taper training. Taper training consisted of three sessions of reduced volume on consecutive days (i.e. Monday, Tuesday, and Wednesday), followed by 48 hours of rest before their post-training MT, BF%, and 1RM. Finally, following another 48 hours of rest subjects returned for the final visit to perform a VO_{2peak} test (see tables 2, 3, 4, and 5). Additionally, subjects were fed branched chain amino acids (BCAAs – Scivation, XTEND) containing 3.5g of leucine 30 minutes prior to each testing and training session along with 30g of whey protein (Scivation, Scivation Whey) immediately after each testing and training session. This strategy was implemented to control for consistency of nutrient timing between all subjects.

Subjects

Eleven college-aged resistance trained males were recruited for this study. Subjects were counterbalanced into three groups: 1) RTC, 2) CTHI, 3) CTMI, through the use of separate one-way analysis of variances (ANOVA) to ensure no differences in absolute strength (one repetition maximum - 1RM) and relative strength (Wilks coefficient) of the squat, bench press, and two exercises combined (total strength – TS), as well as BF% existed at baseline. Minimum strength level requirements for study inclusion were one-repetition maximum (1RM) of 1.5 times body weight for the back squat; and 1.25 times body weight for the bench press. Additionally the following three criteria were required: 1) A minimum of two years resistance training experience, 2) An average training frequency of at least three days per week, 3) A minimum back squat and bench press exercise frequency of at least one session per week for the previous six months. A physical activity questionnaire was used to confirm inclusion criteria were met prior to study participation. Additionally, subjects completed a health history questionnaire to screen for any contraindications to exercise before study participation. If a subject did not meet minimum strength requirements, or had any contraindications to exercise, they were excluded from participation. All subjects provided informed written consent approved by the Florida Atlantic University Institutional Review Board.

One-Repetition Maximum (1RM) Testing

1RM testing was performed following a standardized dynamic warm-up designed to prepare their muscles for exercise. Squat and bench press 1RM testing was administered according the guidelines of the National Strength and Conditioning Association (NSCA) (7). Subjects performed five repetitions with 20% of their estimated 1RM, followed by three repetitions at 50% of estimated 1RM, and two repetitions at 75% of estimated 1RM. Next, one repetition at 85% of estimated 1RM was performed and then weight was increased on subsequent attempts to find their 1RM. The investigator used the average velocity of each attempt in addition to subject feedback from the RIR/RPE scale to determine the weight of all 1RM attempts. Each subject was given five to seven minutes of rest between 1RM attempts. 1RM was accepted as valid if one of three conditions was met: 1) Subject reporting a ‘10’ on the RIR/RPE scale and the investigator determining a subsequent attempt with increased weight would not be successfully completed, 2) Subject reporting a ‘9.5’ on the RIR/RPE scale and failing the subsequent attempt with a load increase of 2.5 kg or less, 3) Subject reporting a ‘9’ or lower on the RIR/RPE scale and failing the subsequent attempt with a load increase of 5 kg or less.

All exercises were performed under the rules and regulations set forth by United States of America Powerlifting (64). For the back squat, subjects stood with their knees and hips locked, and the bar resting across their upper back and shoulders. After a verbal cue was given, subjects descended by bending the knees and hips until the hip crease was below the top of the knee when viewed from the lateral perspective. After achieving appropriate depth, subjects reversed the motion and returned to the starting position. For the bench press, subjects were supine on a weight bench. Their feet were required to be flat on the floor, and their gluteus, shoulders, and head required to maintain contact with the bench for the duration of the lift. Subjects took the bar out of the racks and held it with extended arms until a start command was given. The bar was lowered until it contacted the chest, after the bar was pressed until arms were fully extended and locked out.

Anthropometric and Body Composition Testing

During pre- and post-training measures, anthropometric testing was performed. Subject’s height were measured in centimeters (cm) using a wall-mounted stadiometer and total body mass (BM) measured in kilograms (kg) by a calibrated digital scale. BF% was assessed with the Body Metrix BX-2000 A-mode ultrasound (BodyMetrix, IntelaMetrix, Livermore, CA). The lean body mass (LBM) of each subject was calculated as follows: LBM = BM – (BM x BF%).

To assess subcutaneous fat thickness the probe emits a single beam with a standardized frequency of 2.5 MHz. The probe was connected by USB to a laptop loaded with the manufacturer software (BodyView Professional Software). Measurements were taken from the right side of the body, while the subject was standing, as instructed by the manufacturer software. The measured sites included the thigh, chest, and abdomen. During sampling, the probe was held perpendicular to the subject with minimal movement across the skin (+/- 5mm), and enough pressure to maintain surface contact between the device and subject but not depress the subject's subcutaneous fat tissue. Two to three scans were performed at each site following the instructions of the manufacturer's software. The subcutaneous fat thickness was calculated by averaging the scans, based upon the software's agreement between measurements, and that average represented the final site-specific subcutaneous fat tissue thickness measurement. The software calculated BF% via the Jackson and Pollock 3-site skinfold equation using the sampled data.

Ultrasonography Scanning Muscle Thickness (mm)

MT was assessed during pre- and post-training measures with a panoramic scan of specific sites via the Body Metrix BX-2000 A-mode ultrasound (BodyMetrix, IntelaMetrix, Livermore, CA). The ultrasound settings (Frequency: 2.5 MHz, Depth: 60 mm) were kept constant to standardize the thickness measurements of the targeted muscles. If the entire fascicle border of the scanned muscle was not visible, subsequent scans were performed with increased depth to determine MT. The muscles were examined on the right side of the body and included the pectoralis major, vastus lateralis, and vastus medialis. To identify sites all subjects were positioned supine in anatomical position on an athletic training table. The pectoralis major site was measured at 50% of the distance between the anterior axillary line and the proximal border of the nipple. The vastus lateralis was measured at 50% and 70% of the distance between the greater trochanter of the femur and the lateral joint space of the patella. The vastus medialis was measured at the distal 70% of the distance between the greater trochanter of the femur and the medial joint space of the patella. Before performing any scans the site was cleaned with isopropyl alcohol pads. Following site cleaning, an acoustic gel was applied to the skin surrounding the sites to complete subject preparation. To assess MT the ultrasound probe was held perpendicular to the skin with even pressure from the visible lateral muscular border to the visible medial muscular border at each site specified above. Multiple scans were performed for each site until two scans agreed within the range of 2.0 mm of thickness. The thickness was identified as the distance between the subcutaneous fat and muscle interface to the deepest fascicle border. Only pictures of scans that were continuous without image distortion were accepted. The same investigator performed all scans and analysis for the duration of the study.

VO_2peak Cycle Test

Pre- and post-training VO_2peak was tested using a previously validated protocol (38). Upon arrival to the laboratory subjects resting measures were recorded. After which, each subject was outfitted with a heart rate monitor (FT1 Heart Rate Monitor, Polar, Kempele, Finland) and fed BCAAs prior to exercise. An electronically braked cycle ergometer (Excalibur Sport, Lode, Netherlands) was used for the incremental exercise test. After a three-minute warm-up at 25W, one-minute stages were employed, starting at 50W and increasing in workload by 25W each stage, until test termination.

Participants pedaled at a fixed cadence of 80 rpm. During the test, respiratory gases were monitored and continuously analyzed by open-circuit spirometry (True One 2400+ Metabolic Measurement System, Parvo-Medics Inc., Provo, UT). The metabolic system measured minute ventilation (V_E), oxygen consumption rate (VO_2), carbon dioxide expiration rate (VCO_2), and respiratory exchange ratio (RER). Data were averaged over 30s intervals. The metabolic cart was calibrated prior to each test with room air for flow rate and gases (i.e. O_2, CO_2) of known volume and concentration. Heart rate (HR), power output (W), and RPE (Borg 20-point scale) were measured and recorded at the end of every stage (last five seconds). Tests were terminated when the pedal cadence of 80rpm could not be maintained for > 10 seconds or volitional fatigue. Tests were accepted as peak tests if participants met any two of the following criteria: plateau in VO_2 despite an increase in workload (<150 ml/min); RPE ≥ 17; RER > 1.15; HR ≥ 95% of age-predicted maximum (220-age). After the test, participants performed active cool-down on the cycle ergometer at 25W as needed. Additionally, peak heart rate (HR_{peak}) and peak power output (W_{peak}) were measured and/or calculated coincident with VO_{2peak}. Peak power output was calculated from the formula:

$$W_{max} = W_f + (t/180) \cdot 25$$

W_f = the value of the last completed workload (W); t = the time the last workload was maintained (seconds), and 25 = the power output difference between the last two workloads (W)

Experimental Groups: CTMI, CTHI, RTC

As briefly described, this study consisted of three different training protocols. Although the protocols differ in CT intervention, the three day per week RT program (i.e.

Monday, Wednesday, and Friday) utilized a daily non-linear periodization model with equated TV for each group. Additionally, total training session frequency (i.e. five days per week) and total training time (i.e. standardized rest intervals and training session durations) were equated. During the three day per week RT program (see Table 2 for details), each group performed five exercises. Primary exercises included the back squat and bench press, while accessory exercises included the barbell row, barbell overhead press, and barbell curl.

Training Program

The six week training program was preceded by an introductory week. This week was lower in volume and intensity than the subsequent weeks of training to prepare the subjects for the demands of the training protocol. The first day of the three day per week resistance training program consisted of four sets of eight repetitions for the back squat and bench press at 70%1RM. The barbell row, overhead press, and curl were performed for three sets of 10 repetitions working to a rating of '8' on the RT specific repetitions in reserve based rating of perceived exertion scale (RIR/RPE), with a score of '8' denoting two repetitions in reserve (see Table 8 for details) (69).

The second day of the RT program consisted of four sets of six repetitions for the back squat and bench press at 75%1RM. The barbell row, overhead press, and barbell curl were performed for three sets of eight repetitions at a rating of '8' on the RIR/RPE scale.

The third day of the RT program consisted of five sets of four repetitions at 80%1RM for the back squat and bench press. The fifth set served as a 'plus set', during which as many repetitions as possible were completed. Performance on this plus set determined a standardized absolute load adjustment for the following week (see Table 7 for details). The barbell row, overhead press, and curl were performed for three sets of six repetitions at a rating of ‘8’ on the RIR/RPE scale.

If a subject failed to complete the prescribed sets and repetitions for a primary exercise at any point during training, there was a reduction in weight on subsequent sets depending upon the amount of repetitions failed (see Table 6 for details). Further, a reduction in weight by 2.5 kg on subsequent training days in the same week were made. Additionally, any plus set adjustments were reduced to half of the standardized absolute load progression following the week the repetition failure occurred. To control for training session time, rest intervals lasted from five to seven minutes during primary exercises.

Accessory exercise (i.e. barbell row, overhead press and curl) weight was determined every session based upon subject reported RIR/RPE scale values after each set (see Table 8). The first set of each accessory exercise during the first training session of the week (i.e. Monday) was the weight which was reported as an ‘8’ on the RIR/RPE scale from the same training session the previous week. Additionally, the first set of each accessory exercise on each subsequent training day within that week (i.e. Wednesday and Friday) was increased by 2.5 kg (i.e. Monday 80 kg, Wednesday 82.5 kg, and Friday 85 kg), subsequent sets were adjusted by RIR/RPE values. To control for training session time, rest intervals lasted from one to three minutes during the accessory exercises.

RTC Group

The RTC group performed the same exercises from the RT program in a circuit on alternating days between RT sessions (see Table 3 for details). The primary exercises (back squat, and bench press) were performed at 40%1RM and the accessory exercises (overhead press, barbell row, and barbell curl) were performed at 75% of the load used for the first day of each week (i.e. Monday). The exercises were organized in the following series: back squat, overhead press, bench press, barbell row, and barbell curl. The circuit was performed in the above order with all repetitions completed for each exercise before progressing to the subsequent exercise for 30 minutes during all sessions. During weeks one and two, eight repetitions were performed for all exercises. Repetitions for all exercises were increased by one repetition bi-weekly. All subjects were instructed to select their own rest periods between exercises and rounds, with the objective of completing as many rounds as possible in 30 minutes.

CTHI Group

The CTHI group performed 30 minutes of high intensity interval cycling on alternating days between RT sessions (see Table 4 for details). The intervals consisted of 60 seconds of work followed by 120 seconds of active recovery (1:2 work:recovery). The intensity was set to 100% peak power for weeks one and two, 105% peak power for weeks three and four, and 110% peak power for weeks five and six. All subjects were instructed to cycle as fast as possible for as long as possible during the work period. During the active recovery period slow cycling was maintained without any resistance.

CTMI Group

The CTMI group performed 30 minutes of continuous cycling at moderate intensity (i.e. 40-60% VO_{2peak}) (45) on alternating days between RT sessions (see Table 5 for details). The cycling workload was 40%VO_{2peak} during weeks one and two, 45%VO_{2peak} during weeks three and four, 50%VO_{2peak} during weeks five and six. All subjects were instructed to pedal at a maintainable pace with minimal RPM variation for the duration of the exercise session.

Taper Training

All subjects began taper training 72-hours after the conclusion of the 6-week training protocol. The taper training consisted of two sessions of RT and one session of the CT interventions (see Tables 2, 3, 4, 5 for details). Taper training featured reduced TV to allow for rest and recovery in preparation for post-training. 48-hours after the final taper training session, post-training measures were performed congruently to the order and procedures of pre-training measures.

Statistical Analyses

A one-way ANOVA was used to examine strength and body composition for the purpose of counterbalancing the experimental groups at baseline. Repeated measures ANOVA models were used to determine pre- to post-training changes of the major outcome variables. The measures analyzed included: 1RM squat, bench press, and total strength (i.e. squat and bench press combined-TS); Wilks coefficient squat, bench press, and TS; BM, BF%, and LBM; MT of the chest and thighs; VO_{2peak} and W_{peak}.

Data were screened for normality and outliers. If there were outliers or a lack of normality, the data was transformed to attempt to correct for these conditions. If the data was not transformed, then the statistical analysis was performed using the regular and irregular points. If the irregular points affected the data they were removed, otherwise they were maintained. A Tukey post-hoc test was used for pairwise comparisons when a significant F-ratio was found. Data are reported as means and standard deviations with significance set at $p \leq 0.05$. The software Statistica 12.5 (StatSoft, Tulsa, OK.) was used for all analyses.

Effect size (ES) data was also calculated using the following formula (ES=(post-training mean – pre-training mean)/ mean of the standard deviations). The magnitude of ES was interpreted as outlined by Cohen (15). ES analysis, such as the above, is more sensitive to changes in studies with smaller sample sizes; therefore utilizing this analysis may be beneficial to the current study.

Table 2: Resistance Training Program

Week	Monday	Wednesday	Friday
Introductory Week	Back squat: 1x9 @60%1RM, 2x8 @ 65%1RM Bench Press: 1x9 @60%1RM, 2x8 @ 65%1RM Row: 2x10 @8RPE Overhead Press: 2x10 @8RPE Curl: 2x10 @8RPE	Back squat: 1x7 @65%1RM, 2x6 @70%1RM Bench Press: 1x7 @65%1RM, 2x6 @70%1RM Row: 2x8 @8RPE Overhead Press: 2x8 @8RPE Curl: 2x8 @8RPE	Back squat: 1x5 @70%1RM, 2x4 @75%1RM Bench Press: 1x5 @70%1RM, 2x4 @75%1RM Row: 2x6 @8RPE Overhead Press: 2x6 @8RPE Curl: 2x6 @8RPE
Week 1	Back squat: 4x8 @70%1RM Bench Press: 4x8 @70%1RM Row: 3x10 @8RPE Overhead Press: 3x10 @8RPE Curl: 3x10 @8RPE	Back squat: 4x6 @75%1RM Bench Press: 4x6 @75%1RM Row: 3x8 @8RPE Overhead Press: 3x8 @8RPE Curl: 3x8 @8RPE	*Back squat: 5x4 @80% 1RM *set 5 to failure *Bench Press: 5x4 @80% 1RM *set 5 to failure Row: 3x6 @8RPE Overhead Press: 3x6 @8RPE Curl: 3x6 @8RPE

Table 2: Continued

Week	Monday	Wednesday	Friday
Weeks 2-6	Back squat: 4x8 +Autoregulated Bench Press: 4x8 +Autoregulated Row: 3x10 @8RPE Overhead Press: 3x10 @8RPE Curl: 3x10 @8RPE	Back squat: 4x6 +Autoregulated Bench Press: 4x6 +Autoregulated Row: 3x8 @8RPE Overhead Press: 3x8 @8RPE Curl: 3x8 @8RPE	*Back squat: 5x4 +Autoregulated *set 5 to failure *Bench Press: 5x4 +Autoregulated *set 5 to failure Row: 3x6 @8RPE Overhead Press: 3x6 @8RPE Curl: 3x6 @8RPE
Taper Week	Back squat: 3x5 @70%1RM Bench Press: 3x5 @70%1RM Row: 1x10 @8RPE Overhead Press: 1x10 @8RPE Curl: 1x10 @8RPE	Back squat: 2x2 @80%1RM, 1x1 @85%1RM Bench Press: 2x2 @80%1RM, 1x1 @85%1RM Row: 1x8 @8RPE Overhead Press: 1x8 @8RPE Curl: 1x8 @8RPE	

Read as Exercise: Sets x Repetitions at Training Load
AR = Autoregulated
RPE = Rating of Perceived Exertion

Table 3: Barbell Circuit Training (RTC) Protocol

Week	Tuesday, Thursday	Duration
Introductory Week	*Circuit 1 (18:00 min) As many rounds as possible: Back squat 10 x 30%1RM Overhead press 10 x75% Monday Bench Press 10 x 30%1RM Barbell Row 10 x 75% Monday Barbell curl 10 x 75% Monday	18:00 min
Weeks 1-6 *Add 1 rep to the main exercises bi-weekly	*Circuit 1 (30:00) As many rounds as possible: Back squat 8 x 40%1RM Overhead press 8 x 75% Monday Bench Press 8 x 40%1RM Barbell Row 8 x 75% Monday Barbell curl 8 x 75% Monday	30:00 min
Taper	*Circuit 1 (30:00 min) As many rounds as possible: Back squat 10 x 35%1RM Overhead press 10 x 70% Monday Bench Press 10 x 35%1RM Barbell Row 10 x 70% Monday Barbell curl 10 x 70% Monday	18:00 min

Read as Exercise: Sets x Repetitions at Training Load

Table 4: Concurrent Training High Intensity (CTHI) Protocol

Week	Tuesday, Thursday	Duration
Introductory Week	6x60:00 sec @90% Peak power 120:00 sec of recovery	18:00 min
Weeks 1 and 2	10x60:00 sec @100% Peak power 120:00 sec of recovery	30:00 min
Weeks 3 and 4	10x60:00 sec @105% Peak power 120:00 sec of recovery	30:00 min
Weeks 5 and 6	10x60:00 sec @110% Peak power 120:00 sec of recovery	30:00 min
Taper Week	6x60:00 sec @95% Peak power 120:00 sec of recovery	18:00 min

Read as: Sets x Duration x Workload

Table 5: Concurrent Training Moderate Intensity (CTMI) Protocol

Week	Tuesday, Thursday	Duration
Introductory Week	18:00 min @30% VO_2 max	18:00 min
Weeks 1 and 2	30:00 min @40% VO_2 max	30:00 min
Weeks 3 and 4	30:00 min @45% VO_2 max	30:00 min
Weeks 5 and 6	30:00 min @50% VO_2 max	30:00 min
Taper Week	18:00 min @35% VO_2 max	18:00 min

Read as: Duration at Intensity

Table 6: Adjustments to Main Exercises Due to Repetition Failures

Number of Failed Repetitions	Adjustment
1	-2.5kg
2	-5kg
3	-7.5kg
4	-10kg

Table 7: Plus Set Weekly Training Load Adjustments

Number of extra reps	Adjustment
-2	-2.5kg
-1	+0kg
0	+1kg
1	+2.5kg
2-3	+5kg
3+	+7.5kg

Table 8: Resistance Exercise Specific Rating of Perceived Exertion (RIR/RPE)

RPE	RIR
10	Maximum Effort
9.5	No further repetitions, but could increase load
9	1 repetition remaining
8.5	1-2 repetitions remaining
8	2 repetitions remaining
7.5	2-3 repetitions remaining
7	3 repetitions remaining
5-6	4-6 repetitions remaining
3-4	Light Effort
1-2	No effort

Table 9: Adjustments to Accessory Exercises Based on RPE

RPE	Weight Adjustment
5-6	+5kg
7	+2.5kg
8	+0kg
9	-2.5kg
10	-5kg

Table 10: Complete Study Schedule

Week	Mon	Tue	Wed	Thu	Fri	Sat	Sun
1				Pre-training1	Rest	Pre-training 2	Rest
2	Intro RT	Intro CT	Intro RT	Intro CT	Intro RT	Rest	Rest
3	RT 1,1	CT 1,1	RT 1,2	CT1,2	RT 1,3	Rest	Rest
4	RT 2,1	CT 2,1	RT 2,2	CT 2,2	RT 2,3	Rest	Rest
5	RT 3,1	CT 3,1	RT 3,2	CT 3,2	RT 3,3	Rest	Rest
6	RT4,1	CT 4,1	RT 4,2	CT 4,2	RT 4,3	Rest	Rest
7	RT 5,1	CT 5,1	RT 5,2	CT 5,2	RT 5,3	Rest	Rest
8	RT 6,1	CT 6,1	RT 6,2	CT 6,2	RT 6,3	Rest	No Visit
9	Taper 1 RT	Taper 1 CT	Taper 2 RT	Rest	Post-training 1	Rest	Post training 2

RT=Resistance Training
CT=Concurrent Training Intervention

IV: RESULTS

Subject Characteristics and Attrition

No difference ($p>0.05$) existed between groups in any baseline strength measure. Further, there were no differences ($p>0.05$) in BF% between groups at baseline. Regarding attrition, initially 13 subjects were recruited, but two subjects were unable to complete the protocol: one due to injuries, and one due to other commitment issues during the study. Therefore, 11 subjects completed the study, and average training session compliance for the 11 subjects was 99.13%.

Absolute and Relative Strength

Mean values for pre- and post-training measures of strength variables for all groups can be seen in Table 11.

Table 11: Mean pre- to post-training changes in strength variables

	RTC (n=4)					CTHI (n=3)					CTMI (n=4)				
	Pre-testing	Post-testing	Percent Change	*p*	*ES*	Pre-testing	Post-testing	Percent Change	*p*	*ES*	Pre-testing	Post-testing	Percent Change	*p*	*ES*
1RM Squat (kg)	135.75 ± 21.85	153.13 ± 18.41*	12.80%	0.01	0.86	144.17 ± 31.46	158.50 ± 23.79+	9.94%	0.07	0.52	130.75 ± 20.45	159.38 ± 27.57*	21.89%	<0.01	1.19
Squat Wilks	95.69 ± 8.89	105.75 ± 10.23*	10.51%	<0.01	1.05	92.71 ± 23.57	101.03 ± 20.04*	8.97%	0.04	0.38	88.15 ± 8.64	106.83 ± 9.92*	21.19%	<0.01	2.01
1RM Bench Press (kg)	110.00 ± 20.61	111.75 ± 17.69	1.59%	>0.05	0.09	114.33 ± 9.78	126.67 ± 10.21*	10.79%	<0.01	1.23	114.63 ± 28.15	124.63 ± 29.75*	8.72%	<0.01	0.35
Bench Press Wilks	77.32 ± 8.29	76.79 ± 7.96	-0.69%	>0.05	-0.06	73.29 ± 8.04	80.45 ± 8.64*	9.77%	<0.01	0.86	76.64 ± 13.29	82.96 ± 12.67*	8.25%	<0.01	0.35
1RM Total Strength (kg)	245.75 ± 42.17	264.88 ± 34.27*	7.78%	0.02	0.50	258.5 ± 40.77	285.17 ± 32.58*	10.32%	<0.01	0.73	245.38 ± 48.37	284.00 ± 56.85*	15.74%	<0.01	0.73
Total Wilks	173.02 ± 16.72	182.43 ± 16.31*	5.44%	0.02	0.57	166.00 ± 31.62	181.48 ± 28.48*	9.33%	<0.01	0.52	164.79 ± 20.95	189.73 ± 21.59*	15.13%	<0.01	1.17

Values are in means ± standard deviation.
*$p \leq 0.05$, significantly different from pre-training
+$p \leq 0.10$, approaching significance from pre-training
RTC=Resistance training + circuit training
CTHI=Resistance training + high intensity interval cycling
CTMI=Resistance training + moderate intensity steady state cycling
1RM=One Repetition Maximum
ES=Effect Size

1RM Squat Strength

There was a significant main effect for time revealing an increase in 1RM squat strength from pre- to post-training ($p<0.01$) with no differences between groups ($p>0.05$). This interaction was driven by pre- to post-training increases in RTC (135.75±21.85 to 153.13±18.41, 12.80%, $p=0.01$, ES=0.86) and CTMI (130.75±20.45 to 159.38±27.57, 21.89%, $p<0.01$, ES=1.19), while CTHI increases only approached significance (CTHI: 144.17±31.46 to 158.5±23.79, 9.94%, $p=0.07$, ES=0.52).

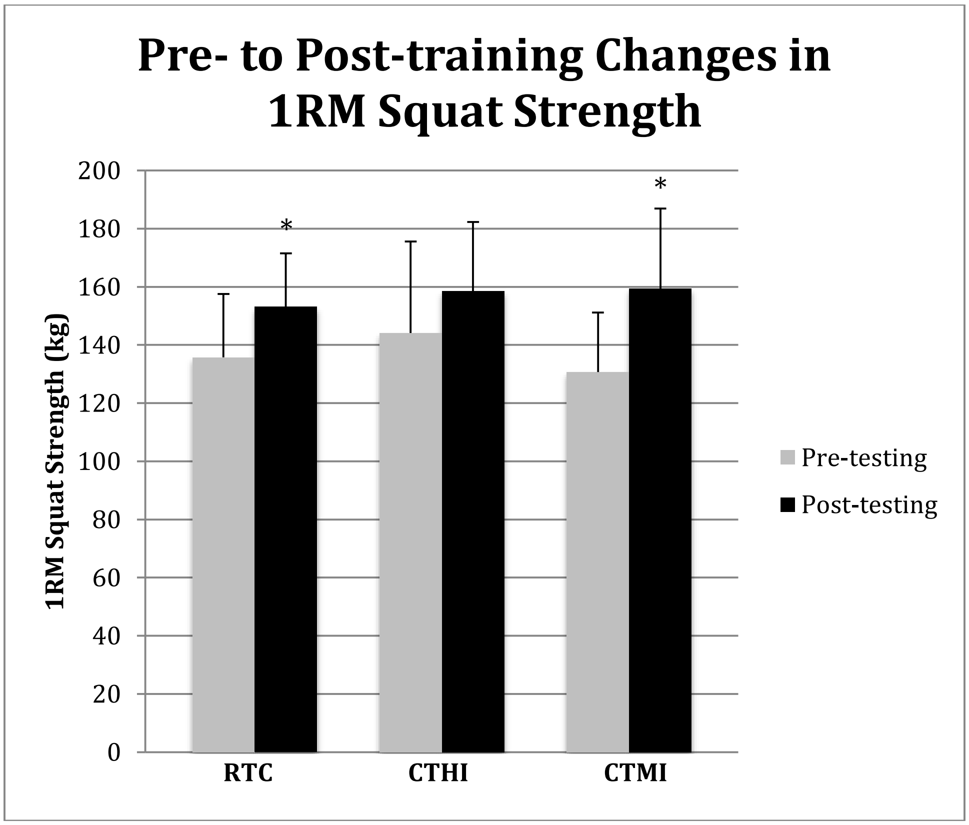

Figure 1: Comparison of pre- to post-training mean 1RM squat strength between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. 1RM=One-repetition maximum. *$p\leq0.05$, significantly different from pre- to post-training. Values are reported in means ± standard deviation.

Wilks Coefficient Squat

There was a significant main effect for time revealing an increase in squat Wilks coefficient pre- to post-training (p<0.01), with all groups increasing significantly (RTC: 96.69±8.89 to 105.75±10.23, 10.51%, p<0.01, ES=1.05; CTHI: 92.71±23.57 to 101.03±20.04, 8.97%, p=0.04, ES=0.38; CTMI: 88.15±8.64 to 106.83±9.92, 21.19%, p<0.01, ES=2.01), no differences existed at post-training between groups (p>0.05).

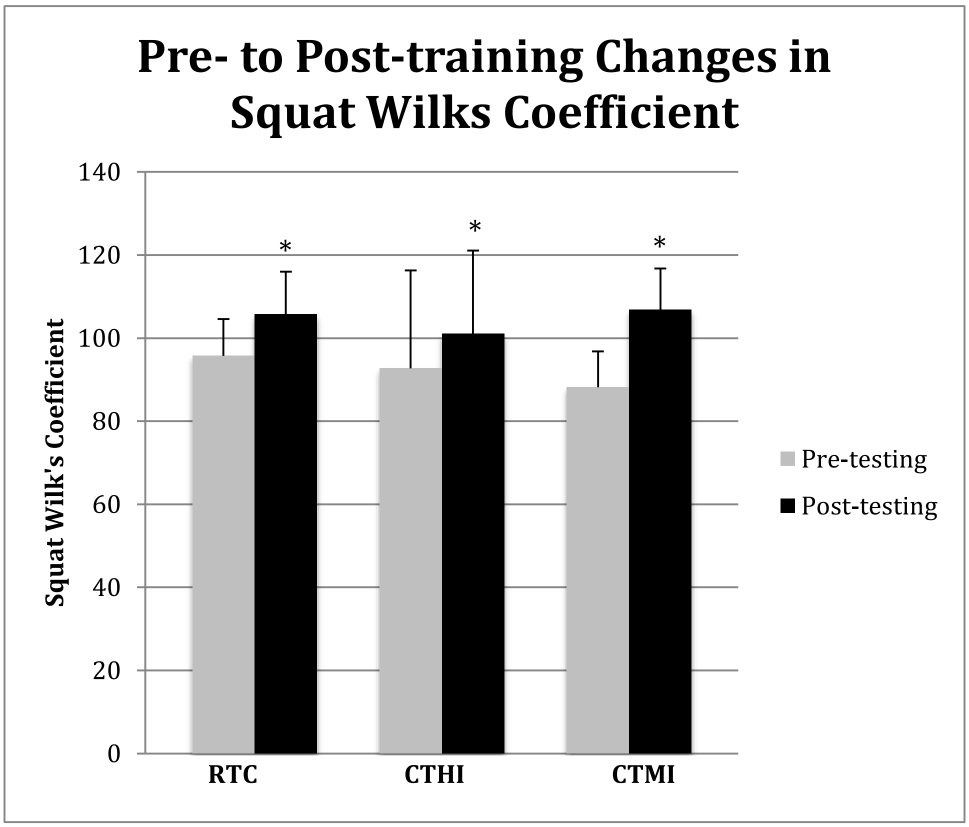

Figure 2: Comparison of pre- to post-training mean Squat Wilks coefficient between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. *$p \leq 0.05$ significantly different from pre- to post-training. Values are reported in means ± standard deviation.

1RM Bench Press Strength

There was a significant main effect for time demonstrating an increase in 1RM bench press strength pre- to post-training ($p<0.01$) with no differences between groups ($p>0.05$). 1RM bench press strength increases occurred in CTHI (114.33±9.78 to 126.67±10.21, 10.79%, $p<0.01$, ES=1.23) and CTMI (114.63±28.15 to 124.63±29.75, 8.72%, $p<0.01$, ES=0.35), while RTC did not experience a significant increase ($p>0.05$).

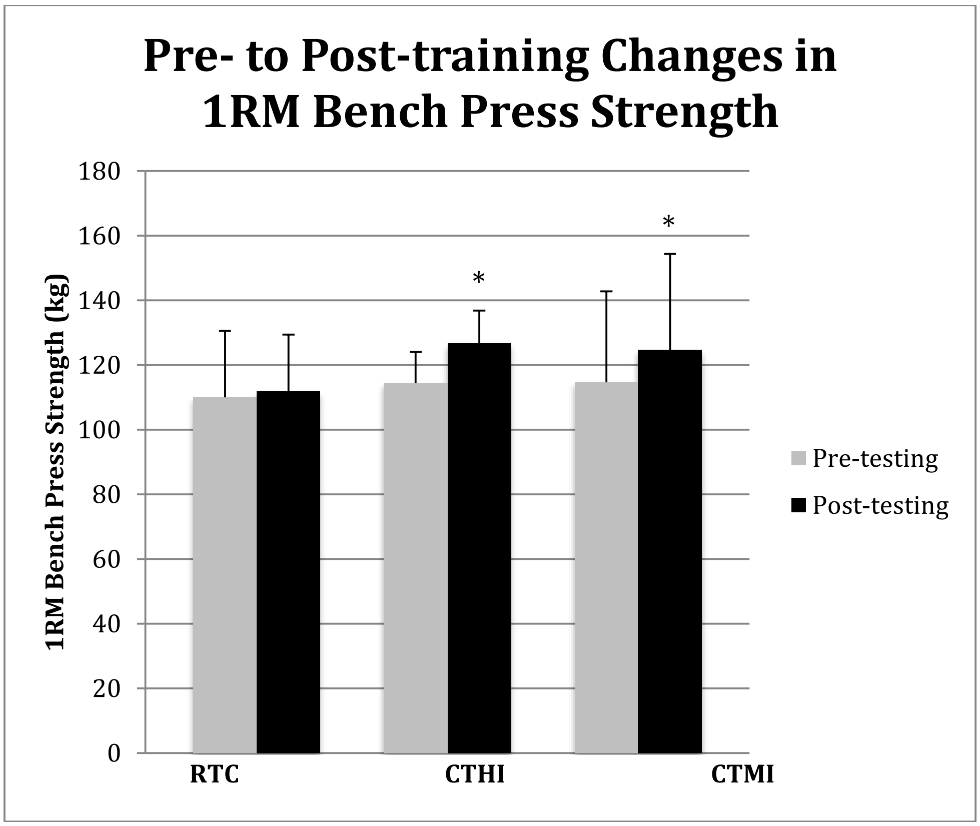

Figure 3: Comparison of pre- to post-training mean 1RM bench press strength between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. *$p\leq0.05$, significantly different from pre- to post-training. Values are reported in means ± standard deviation.

Wilks Coefficient Bench Press

There was a significant main effect for time ($p<0.01$) demonstrating a pre- to post-training increases in bench press Wilks coefficient, while no groups were significantly different from each other at post-training ($p>0.05$). Increases occurred in CTHI (73.29±8.04 to 80.45±8.64, 9.77%, $p<0.01$, ES=0.86) and CTMI (76.64±13.29 to 82.96±12.67, 8.25%, $p<0.01$, ES=0.35), while surprisingly the RTC group did not experience a significant increase ($p>0.05$).

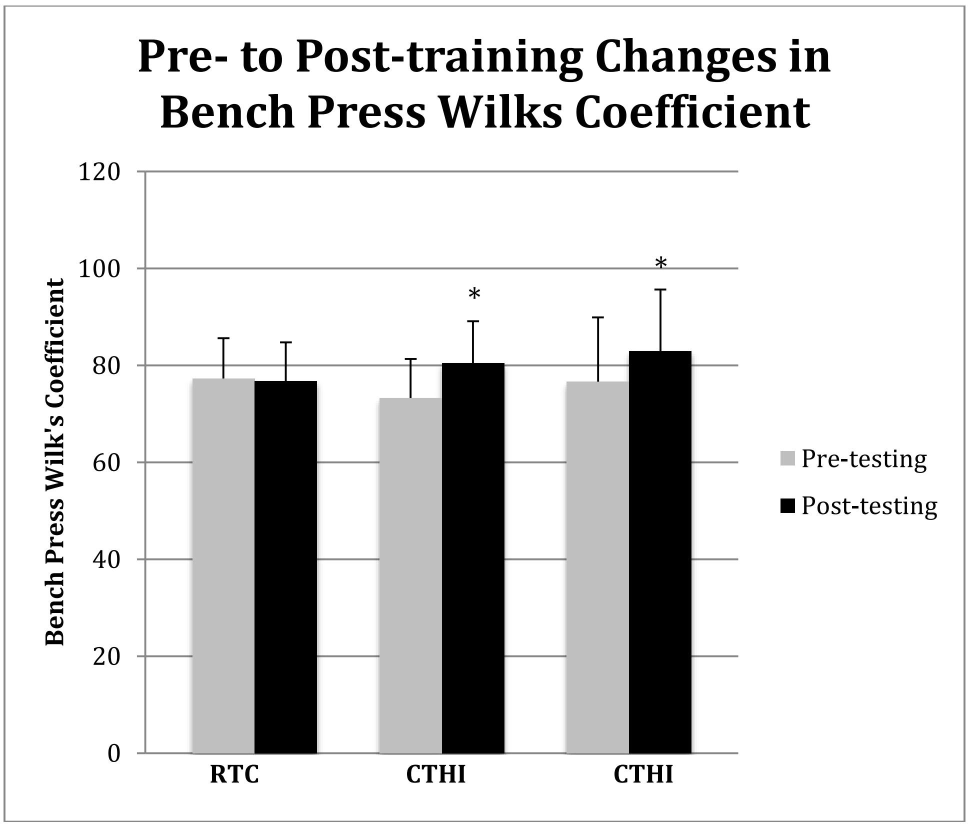

Figure 4: Comparison of pre- to post-training mean Bench Press Wilks coefficient between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. *$p\leq0.05$, significantly different from pre- to post-training. Values are reported in means ± standard deviation.

1RM Total Strength

There was a significant main effect for time (p<0.01) demonstrating a pre- to post-training increases in 1RM TS in all groups (RTC: 245.75±42.17 to 264.88±34.27, 7.78%, p=0.02, ES=0.50; CTHI: 258.5±40.77 to 285.17±32.58, 10.32%, p<0.01, ES=0.73; CTMI: 245.38±48.37 to 284.00±56.85, 15.74%, p<0.01, ES=0.73), while no groups differed at post-training (p>0.05).

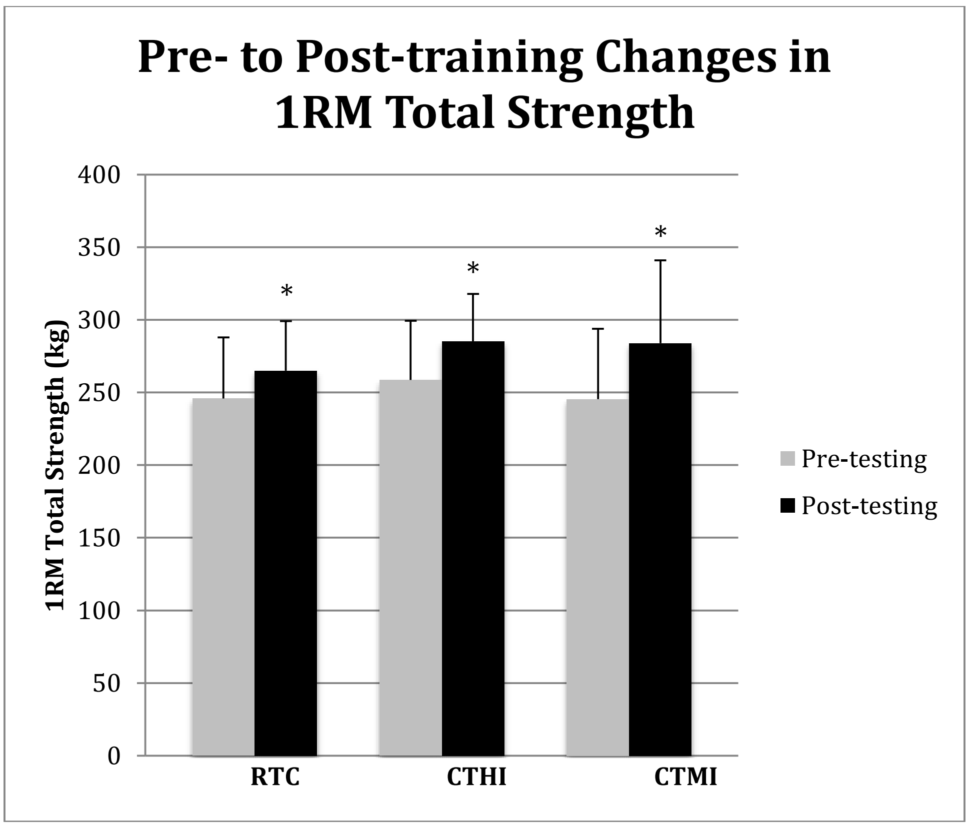

Figure 5: Comparison of pre- to post-training mean 1RM total strength between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. 1RM=One-repetition maximum *$p \leq 0.05$, significantly different from pre- to post-training. Values are reported in means ± standard deviation.

Total Strength Wilks Coefficient

There was a significant main effect for time (p<0.01) demonstrating a pre- to post-training increases in TS Wilks coefficient for all groups (RTC: 173.02±16.72 to 182.43±16.31, 5.44%, p=0.02, ES=0.57; CTHI: 166.00±31.62 to 181.48±28.48, 9.33%, p<0.01, ES=0.52; CTMI: 164.79±20.95 to 189.73±21.59, 15.13%, p<0.01, ES=1.17), but no group differences existed at post-training (p>0.05).

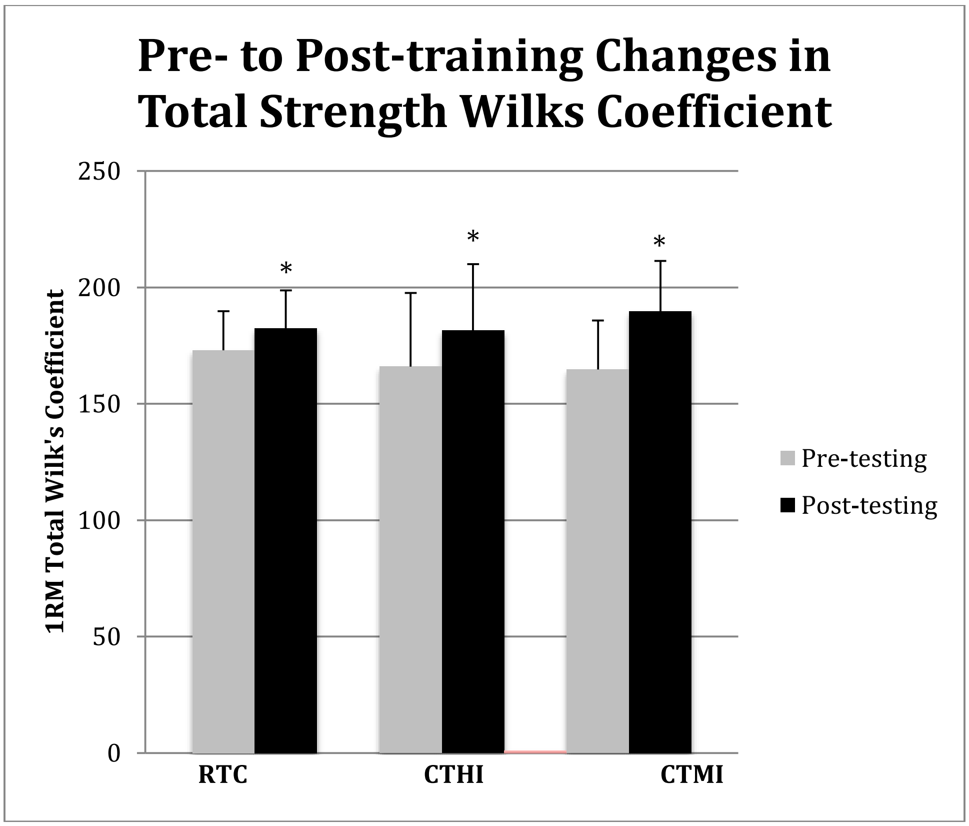

Figure 6: Comparison of pre- to post-training mean total strength Wilks coefficient between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. *$p \leq 0.05$, significantly different from pre- to post-training. Values are reported in means ± standard deviation.

Body Composition and Hypertrophy

Mean values for pre- and post-training body composition and hypertrophy variables for all groups can be seen in Table 12.

Body Mass (BM), Body Fat Percentage (BF%), and Lean Body Mass (LBM)

There was no significant change in any measure of body composition for any group throughout the study (*p*>0.05).

Muscle Thickness Chest

There was a main time effect (*p*<0.01) for pre- to post-training increases in chest MT. However, only two groups exhibited hypertrophy RTC (34.49±7.50 to 41.45±7.28, 20.18%, *p*<0.01, ES=0.94) and CTMI (32.33±4.07 to 39.11±3.77, 20.97%, *p*<0.01, ES=1.73); and there were no differences between groups at post-training (*p*>0.05).

Muscle Thickness Vastus Lateralis Proximal

There was a main time effect (*p*<0.01) present for pre- to post-training increases in MT of the vastus lateralis at the proximal (50%) site. Interestingly there were no significant pre- to post-training increases for any group (*p*>0.05), and there were no between group differences at post-training; however CTMI approached significance with a large ES (27.09±3.22 to 30.70±4.99, 13.33%, *p*=0.07, ES=0.88).

Muscle Thickness Vastus Lateralis Distal

There was a main time effect (*p*<0.01) present for pre- to post-training increases in MT of the vastus lateralis at the distal (70%) site. However, there were no significant increases for any group alone and no between group differences at post-training (*p*>0.05).

Table 12: Mean pre- to post-training changes in body composition and hypertrophy

	RTC (n=4)					CTHI (n=3)					CTMI (n=4)				
	Pre-testing	Post-testing	Percent Change	*p*	*ES*	Pre-testing	Post-testing	Percent Change	*p*	*ES*	Pre-testing	Post-testing	Percent Change	*p*	*ES*
Body Mass (kg)	76.89 ± 10.55	79.3 ± 8.23	3.13%	>0.05	0.26	90.75 ± 10.68	92.54 ± 11.02	1.97%	>0.05	0.17	83.11 ± 13.14	83.93 ± 14.45	0.99%	>0.05	0.59
BF%	11.05 ± 3.61	12.9 ± 4.06	16.74%	>0.05	0.48	13.93 ± 9.77	15.00 ± 8.43	7.68%	>0.05	0.12	10.10 ± 1.76	12.70 ± 1.43	25.74%	>0.05	0.40
Lean Body Mass (kg)	68.27 ± 8.82	69.08 ± 8.00	1.19%	>0.05	0.10	77.41 ± 0.99	78.06 ± 2.22	0.84%	>0.05	0.40	74.62 ± 11.01	73.12 ± 11.50	-2.01%	>0.05	-0.13
MT Chest (mm)	34.49 ± 7.50	41.45 ± 7.28*	20.18%	<0.01	0.94	32.88 ± 8.16	36.23 ± 9.92	10.19%	>0.05	0.37	32.33 ± 4.07	39.11 ± 3.77*	20.97%	<0.01	1.73
MT VLP (mm)	24.16 ± 2.74	26.79 ± 3.13	10.89%	>0.05	0.89	28.40 ± 3.26	30.18 ± 4.55	6.27%	>0.05	0.46	27.09 ± 3.22	30.70 ± 4.99+	13.33%	0.07	0.88
MT VLD (mm)	23.73 ± 1.60	25.15 ± 2.32	5.98%	>0.05	0.72	23.05 ± 0.67	26.47 ± 1.30	14.84%	>0.05	3.40	23.29 ± 4.36	26.36 ± 5.19	13.18%	>0.05	0.64
MT VM (mm)	21.9 ± 6.37	25.68 ± 5.80	17.26%	>0.05	0.62	30.17 ± 7.19	28.67 ± 8.77	-4.97%	>0.05	0.19	18.76 ± 4.65	26.00 ± 4.46*	38.59%	0.01	1.59

Values are in means ± standard deviation.
*$p \leq 0.05$, significantly different from pre-training.
+$p \leq 0.10$, approaching significance from pre-training.
RTC=Resistance training + circuit training.
CTHI=Resistance training + high intensity interval cycling.
CTMI=Resistance training + moderate intensity steady state cycling.
BF%=Body Fat Percentage
MT=Muscle Thickness
VLP=Vastus Lateralis Proximal
VLD=Vastus Lateralis Distal
VM=Vastus Medialis
ES=Effect Size

Muscle Thickness Vastus Medialis

There was a main time effect ($p<0.01$) present for pre- to post-training increases in the MT of the vastus medialis site. Only CTMI experienced significant hypertrophy with a large ES (18.76±4.65 to 26.00±4.46, 38.59%, $p=0.01$, ES=1.59), while RTC and CTHI did not experience any changes ($p>0.05$), further there were no differences between groups at post-training ($p>0.05$).

Aerobic Performance

Mean values for pre- and post-training VO_2 peak and W_{max} for all groups can be seen in Table 13.

Table 13: Mean pre- to post-training changes in aerobic performance variables

	RTC (n=4)					CTHI (n=3)					CTMI (n=4)				
	Pre-testing	Post-testing	Percent Change	*p*	*ES*	Pre-testing	Post-testing	Percent Change	*p*	*ES*	Pre-testing	Post-testing	Percent Change	*p*	*ES*
VO2 Peak (ml/kg/min)	42.50 ± 2.82	37.83 ± 4.31	-10.99%	>0.05	-1.31	43.68 ± 3.13	43.93 ± 2.42	0.57%	>0.05	0.09	40.68 ± 5.38	40.58 ± 8.23	-0.25%	>0.05	-0.01
Max Workload (W)	248.96 ± 16.00	232.57 ± 11.73	-6.58%	>0.05	-1.18	302.13 ± 24.17	319.58 ± 16.99	5.76%	>0.05	0.85	245.90 ± 38.87	263.13 ± 47.23	7.01%	>0.05	0.40

Values are in means ± standard deviation.
*$p \leq 0.05$, significantly different from pre-training.
RTC=Resistance training + circuit training.
CTHI=Resistance training + high intensity interval cycling.
CTMI=Resistance training + moderate intensity steady state cycling.
ES=Effect Size

VO_2peak

There were no significant pre- to post-training changes for any group in VO_2peak during this study.

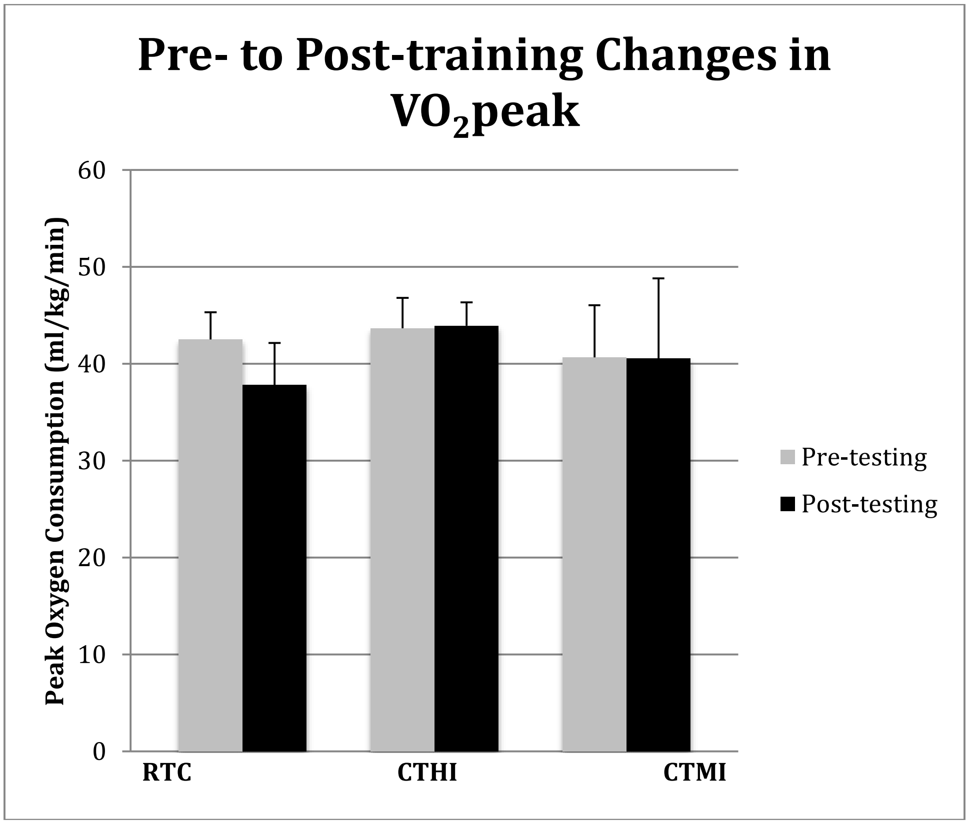

Figure 7: Comparison of pre-to post-training mean VO_2peak between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. Values are reported in means ± standard deviation.

W_{max}

No group experienced significant (p>0.05) pre- to post-training changes in W_{max}. However, CTHI exhibited a significantly greater W_{max} at post-training than RTC (CTHI: 319.58±16.99 vs. RTC: 232.57±11.73, p=0.03).

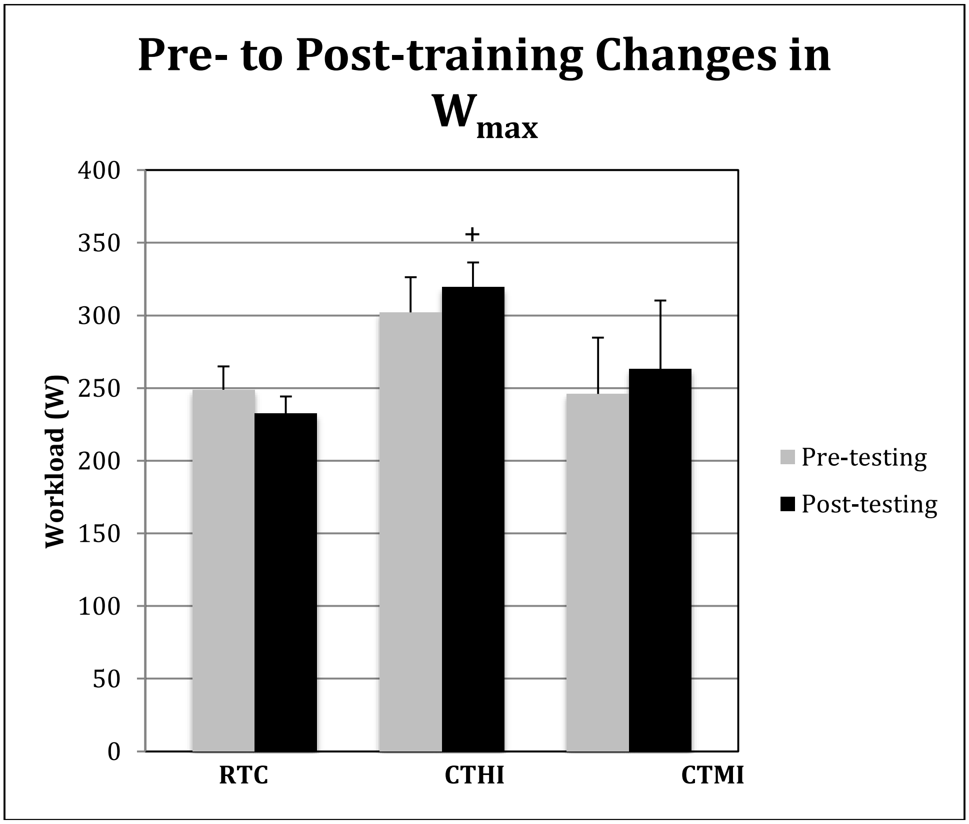

Figure 8: Comparison of pre- to post-training mean maximum workload between groups.

RTC=Resistance training circuit. CTHI=Resistance training high intensity cycling. CTMI=Resistance training moderate intensity cycling. +p=0.03, significantly different from RTC at post-training. Values are reported in means ± standard deviation

V. DISCUSSION

To our knowledge, this was the first study to analyze the efficacy of a barbell circuit as a part of a CT model in comparison to moderate intensity continuous and high intensity interval cycling exercise for muscle performance and body composition. It was hypothesized that RTC would experience greater increases in strength, MT, and greater reductions in BF% than CTHI and CTMI. However, our hypotheses were not supported and the main findings of this study are 1) All groups significantly increased strength, however no group differences ($p>0.05$) existed, 2) Significant increases ($p<0.05$) in MT were detected in the upper body for RTC and CTMI with no group differences ($p>0.05$), but not in CTHI ($p>0.05$), and 3) No group experienced a significant change ($p>0.05$) in BF% from pre- to post-training.

The muscular strength findings of the present study are in agreement with previous literature (8, 12, 17, 32, 43), which has reported increases in strength with CT similar to RT alone. Presently, squat Wilks coefficient (i.e. relative strength) increased to the same extent from pre- to post-training in all groups, however squat 1RM increased in RTC and CTMI ($p<0.05$), but only approached significance for CTHI ($p=0.07$, ES=0.52). Furthermore, CTMI displayed the greatest percentage change and largest ES (+21.89%, ES=1.19). Additionally, 1RM and Wilks coefficient bench press strength increased in CTHI and CTMI, with CTHI experiencing the greatest percentage change and largest ES for this exercise (+10.79%, ES=1.23), while RTC did not significantly improve ($p>0.05$).

These results are surprising when considering the recommendations of meta-analysis data (66) suggesting that RT only, will provide superior strength benefits to CT modalities. However, the RTC group was performing the bench press five sessions per week, thus it was possible that insufficient recovery was given to RTC compromising adaptations. Moreover, even though there is a direct relationship between TV and strength (21), our data reveal that a short term training period (i.e. eight weeks) may not have been long enough to adapt to high volume/frequency training and may result in a period of overreaching.

Additionally, previous research has demonstrated a direct relationship between TV and muscle hypertrophy (11, 25, 36, 46, 56). Despite this relationship, we observed similar chest hypertrophy in CTMI and RTC, and CTMI was the only group to experience significant pre- to post-training changes in lower body hypertrophy (VM: +38.59%, p=0.01, ES=1.59 and VLP: +13.33%, p=0.07, ES=0.88). This was despite the greater TV featured in RTC. However, RTC did have moderate to large ES calculations for all measures of lower body hypertrophy (VLP: ES=0.89,VLD: ES=0.72,VM: ES=0.62), and the lack of statistical significance could be due to the small sample size in RTC (n=4).

Regarding the lower body hypertrophy increase in CTMI, this is contradictory to the long established competing adaptations theory (66), which stipulates that continuous aerobic exercise will attenuate muscle hypertrophy. However, when examining our protocol which consisted of a relatively short duration (i.e. 30 minutes) of continuous cycling exercise, the lack of attenuation in hypertrophy is not that surprising as data have suggested cycling to cause less interference than running, and short duration aerobic exercise to result in less attenuation than long duration (66). Therefore, even though a plethora of data exists demonstrating continuous aerobic exercise to be detrimental to hypertrophy, our data suggests shorter duration cycling is an effective CT modality to avoid an attenuated hypertrophy response.

Regarding body composition, no group experienced significant changes in BF%, BM, or LBM. Traditionally, to alter BM and BF% energy expenditure must exceed caloric consumption by increasing activity, reducing dietary intake or accomplishing both concomitantly (28). The current study did not control for dietary intake, and only requested that subjects continue to eat ad libitum without making any conscious efforts to alter dietary habits. Further, the subjects employed were all trained individuals who exercised regularly, therefore the caloric expenditure during the study was likely not different from what subjects normally experienced. Interestingly, Dolezal et al. (18), found that CT and RT produced improvements in LBM and BF% of non-dieting individuals. However, the frequency and duration of cardiovascular exercise of Dolezal et al. (18) exceeded the present study (i.e. three weekly sessions lasting 25-40 minutes vs. two weekly sessions lasting 30 minutes). Thus, the differing findings for body composition may be explained by the increased cardiovascular exercise demands of Dolezal et al. (18), which likely produced a greater caloric expenditure than the current investigation.

Aerobic performance (VO_{2peak} and/or W_{max}), was not presently affected by any CT training intervention, which is contrasting to previous CT research (8, 9, 12, 16, 19, 27, 29, 32, 35, 55, 57). The American College of Sports Medicine (ACSM) currently recommends an exercise intensity of 60-80% VO_{2max} for healthy individuals to improve cardiorespiratory fitness. In the current study, individuals performed moderate intensity (i.e. 40-50% VO_{2max}) continuous exercise for only 60 minutes per week. Furthermore, studies demonstrating aerobic performance improvements (8, 9, 16, 18, 19, 29, 32, 35, 57) featured more intense endurance training demands (i.e. intensity, duration, or frequency) than the present investigation. Therefore, it seems that all groups had insufficient exercise demands to cause significant aerobic adaptations in the present study.

Recently, Alcaraz et al. (2011) demonstrated that resistance circuit training could produce strength and hypertrophy adaptations similar to RT, and reduce BF% in six weeks (4). However, substantial design differences exist between Alcaraz et al. and the present study. We are the first to incorporate barbell circuit training as a CT strategy (i.e. in addition to traditional RT), rather than comparing only resistance circuit training to traditional RT. Further, the current study utilized all free weight barbell exercises as opposed to 'smith' machine and machine exercises (4). Additionally, Alcaraz et al. permitted three-to-six rounds of two different three exercise circuits (starting at three and progressing by one round bi-weekly) with 35 seconds of rest between exercises and two minutes rest between circuits (4), while the current study featured a 30 minute time period for subjects to complete as many rounds of a five exercise circuit for eight-to-ten repetitions (starting at eight and progressing by one repetition bi-weekly) as possible. Lastly, Alcaraz et al. used loads corresponding to 6RMs in the two different circuits, while the current study used 40%1RM loads for main exercises and 75% '8RPE' (i.e. 2 repetitions in reserve) loads for accessory exercises in a single circuit. This was due to the nature of the RTC group in the present study, which was not conducive to using heavier loads more similar to Alcaraz et al. While there are both similarities and differences present in the designs of the barbell circuit training, it appears as though increases in muscular strength and hypertrophy can be made when this training style is used as a form of CT. However the inclusion of barbell circuit training did not appear to either enhance or impair muscle hypertrophy and strength when compared to the other CT options of the present study.

The design of the present study achieved further novelty by integrating the recommendations of the meta-analysis (66) regarding the minimization of the *'interference effect'* into a daily undulating periodization design with components of auotregulation. In accordance with previous literature the present study demonstrates the efficacy of daily undulating periodization at producing robust increases in muscular strength and hypertrophy (47, 49, 53). Currently, autoregulatory approaches have been used to modulate training loads weekly based on performance (40), or daily based on individual preference (44). In addition to progressing load based upon the previous week's performance (40), the current study was the first to utilize the recently validated resistance training specific RIR-based RPE scale (69) as a method to modulate training loads of accessory exercises on a set-by-set basis. These strategies allowed for training load adjustments to be progressed appropriately based on each individuals rate of adaptation. The results of this study further demonstrate the ability of autoregulated progression to produce strength enhancement in trained individuals (23).

One limitation of the current study is that the changes in muscle performance and body composition as a result of the CT models were not compared to a RT only control group. Thus, even though comparisons between the groups in this study can be made, the magnitude of muscle performance attenuation (if any exists) cannot be determined from the results as a true control group is not present. Further, the study population only included well-trained male individuals, thus the results may not be extrapolated to other populations. The present study's sample size is small; therefore future studies should employ a large population to gain statistical power. Finally, the lack of dietary control may account for the lack of body composition improvement. Therefore further studies should aim to compare the impact of the present CT protocols with a RT only program in a calorically restricted subject population.

In conclusion, our results show that when equated for time and frequency, barbell circuit training as a CT model produced similar muscle performance enhancement when compared to more traditional CT models. While it is unknown if muscle performance differences exist between the present CT strategies and a RT only model, the present study is impactful in finding that strength and hypertrophy results were similar between barbell circuit training, high intensity interval exercise, and moderate intensity continuous exercise. Moreover, the current study provides further demonstration that DUP is an efficacious for inducing strength adaptations in trained individuals over a short period of time. Additionally, this study adds support to the use of autoregulation as a viable option for progression within a sound periodization model. Finally, this study was the first to successfully display the efficacy of set-by-set load selection based on the resistance training specific RIR based RPE scale as a form of training load modulation.

From a practical standpoint we recommend personal preference play a role when selecting a CT model, as adherence to training is likely to increase when the preferred exercise modality is employed. However, if aerobic performance improvements are desired it may be required to include more intense aerobic exercise demands than the present study.

APPENDICES

Appendix A: Medical History Form

Florida Atlantic University

Medical History Form

Demographics:

Name: ________________________________ Sport: ___________ Pos.: _______________

Date: ___________ Age: _______________ Birth Date: ____/____/____

Family History:

Has anyone in your immediate family had any of the following: Please circle yes or no.

Heart Disease	Yes No		Diabetes	Yes No	
High Blood Pressure	Yes	No	Cancer	Yes	No
Stroke	Yes	No	Tuberculosis	Yes	No
Sudden Death (before 50)	Yes	No	Asthma	Yes	No
Epilepsy	Yes	No	Gout	Yes	No
Migraine Headaches	Yes	No	Marfan's Syndrome	Yes	No
Eating Disorder	Yes	No	Sickle Cell	Yes	No

Personal History:

1. Have you ever been hospitalized? Yes No
   Have you ever had surgery? Yes No
   Are you presently under a doctor's care? Yes No
   Please explain and give dates for all "Yes" answers:

____

____

____

2. Please list any medications you are currently taking and for what conditions.

____

____

3. Please list any known allergies. ____

____

4. Have you ever had a head injury / concussion? Yes No
   Have you ever been knocked out or unconscious? Yes No
   Have you ever had a seizure, "fit", or epilepsy? Yes No
   Have you ever had a stinger, burner, or pinched nerve? Yes No
   Do you have recurring headaches or migraines? Yes No
   Pleas explain and give dates of "Yes" answers: ___________________________________

____

____

____

5. Have you ever had the chicken pox? Yes No
   If yes, at what age? __________

6. Have you ever had the mumps or measles? Yes No

7. Do you have a history of asthma? Yes No

8. Are you missing an eye, kidney, lung, or testicle? Yes No

9. Do you have any problems with your eyes or vision? Yes No

10. Have you ever had any other medical problems (mononucleosis, diabetes, anemia)? Yes No

11. Have you ever taken any supplements for improved performance? Yes No

12. Are you presently taking any supplements for diet or performance?
(creatine, protein, etc.)? Yes No
If Yes then what substance? ____________________________

13.What is the lowest weight you have been at in the last year _____,
highest _____? What is your ideal weight _______?

14. Do you have any trouble breathing or do you cough during or after practice? Yes No

15. Have you ever had heat cramps, heat illness, or muscle cramps? Yes No

16. Do you have any skin problems (itching, rashes, acne)? Yes No

Explain all "Yes" answers for questions 5 – 16:
____
____
____
____
____
____

17. Have you ever passed out during or after exercise? Yes No
Have you ever been dizzy during or after exercise? Yes No
Have you ever had chest pain during or after exercise? Yes No
Have you ever had high blood pressure? Yes No
Have you ever been told you have a heart murmur? Yes No
Have you ever had racing of you heart or a skipped heart beat? Yes No
Has anyone in your family died of heart problems or a sudden death before the age of 50? Yes No
Have you ever had an EKG or echocardiogram? Yes No

Explain all "Yes" answers for question 17:
____
____
____
____

____
____

18. Have you ever sprained / strained, dislocated, fractured, or had repeated swelling or other injury of any bones or joints? Explain any "Yes" answers.

Head/Neck Yes No
____

Shoulder Yes No
____

Elbow & arm Yes No
____

Wrist, hand & fingers Yes No
____

Back Yes No
____

Hip / Thigh Yes No
____

Knee Yes No
____

Shin/Calf Yes No
____

Ankle, foot, toes Yes No
____

19. What is the average number of hours you sleep per night? _________________

20. What time do you usually go to sleep at night? And, what time do you usually wake-up in the morning? _________________

21. What time did you go to sleep last night and what time did you wake up this morning? _________________

Would you like to speak to a medical staff member regarding any topics or concerns? (i.e., nutrition, supplements, drugs, heart problems, weight loss/gain, sexual diseases, concussions, etc.,)? Yes No

If yes then what topic? ____

Please sign:

I hereby state that, to the best of my knowledge, my answers to the above questions are correct.

____

Athlete's Signature Date Signed

Appendix B: Physical Activity Questionnaire

Physical Activity Questionnaire

Think about all the exercise training in which you engage. Use that information to appropriately answer the following questions.

1. Have you competed before in strength competitions? If so, how often?

Yes or No If so, ___________________ times/year

   a. If yes to #1: How long have you been training for strength competitions?
   ______________ years.

   b. If yes to #1: When you compete, which sport do you compete in (Powerlifting, Strongman, or Bodybuilding)?
   Event:___________________________________

2. Are you currently been in engaged in a structured resistance-training program? If so, how long?

   Yes or No If so, ___________________ years

3. How many hours of resistance training do you perform on average each week?
___________________ hours/week

4. How many times do you resistance train per week? Please indicate if you do more than once a day.
___________________ days/week Average___________________ times/day

5. How many times per week do you perform the following exercises?

   a. Barbell back squat: __________ times/week

   b. Barbell bench press: __________ times/week

   c. Barbell deadlift: __________ times/week

6. How many years of experience do you have with following exercises? What is your estimated 1RM?

   a. Barbell back squat: __________ years; 1RM__________pounds

   b. Barbell bench press: __________ years; 1RM__________pounds

   c. Barbell deadlift: __________ years; 1RM__________pounds

7. Please describe your average resistance training intensity based on your self-estimated maximum load.

____________________ % your maximum

8. Do you incorporate any aerobic training? If so, how many times per week?
Yes or No If so, ____________________ times/week

9. Please describe your average aerobic training intensity on a scale below (as close as possible):

1	2	3	4	5	6	7	8	9	10
Very Light		Light		Moderate			Intense		Very Intense

10. Please best describe your occupation or daily activities other than your exercise training.

11. Do you have any coaching by a certified professional in general resistance training?

Appendix C: Informed Consent Document

RESEARCH SUBJECT INFORMATION AND CONSENT FORM

TITLE: The Influence of Time-Equated Training Programs on Muscle Performance, Body Composition, and Inflammation

PROTOCOL NO.:

SPONSOR: None

INVESTIGATOR: Michael C. Zourdos, Ph.D., CSCS, Chad Dolan, B.S., Justin Quiles, B.S., Rocky Blanco, B.S., Arun Maharaj, B.S., and Marie Wells, M.S.

SITE(S): Skeletal muscle physiology and powerlifting laboratory (GY 170) and Biochemistry lab (GY 152) at Florida Atlantic University, Boca Campus.

STUDY-RELATED
PHONE NUMBER(S): Michael C. Zourdos: 561-297-1317

This consent form may contain words that you do not understand. Please ask the study investigator or the study staff to explain any words or information that you do not clearly understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

SUMMARY
This informed consent provides important information that you need to know for your participation in this research study. This study will examine the effects of 3 different exercise programs on maximal strength, muscle hypertrophy and endurance, body composition, and inflammation. In this consent from you will find the purpose, procedures, risks, and your rights and responsibilities. Do not sign this consent form unless you have had the opportunity to ask questions and have received satisfactory answers. If you have questions about your rights as a research subject or if you have questions, concerns or complaints about the research, you may contact: Institutional Review Board (561-297-0777).

PURPOSE OF THE STUDY

The purpose of this research study is to examine the effects of three time-equated training programs 1. Resistance training and high intensity cycling, 2. Resistance training and moderate intensity cycling, 3. Resistance training and circuit training on maximal strength, muscle hypertrophy and endurance, body composition, and inflammation.

PROCEDURES

If you choose to participate in this study there will be a total of 43 laboratory visits over the course of 60 consecutive days. You will be reporting to the laboratory an average of 5 times per week for 8.5 weeks, each visit will last approximately 120-150 minutes. During your first two and final two visits there will be several measurements taken including:

- One repetition maximum (1RM) strength in the squat, bench press, and deadlift
- Cross sectional area (CSA) of the arms and legs via ultrasound
- Muscle thickness (MT) of the biceps, chest, and thigh muscles via ultrasound
- Peak Aerobic Capacity (VO 2peak) via electronic cycle ergometer
- Body composition by ultrasound (chest, abdomen, thigh)
- Anthropometrics (height & weight)

Measurements of CSA, MT, body composition, and anthropometrics will be completed during the initial visit prior to 1RM testing. 48 hours following the initial visit you will report to the laboratory for your VO2peak cycle test completing the pretesting measures. Additionally prior to all testing or exercise sessions you will be asked to consume branched chain amino acids (BCAAs) containing 3.5g of leucine, 1.75g of Isoleucine, 1.75g of Valine (Ratio of 2:1:1), and 2.5g of glutamine 30 minutes prior to each session; and 30g of whey protein immediately after each training session. These supplements will be supplied by ScivationTM and provided to you from the Department of Exercise Science and Health Promotion (ESHP). You will also be required to fill out a dietary log 24 hours before testing and training days.

Before any performance testing (and all training sessions), you will perform a standardized 10minute dynamic warm-up routine designed to increase the body's core temperature and prepare the muscles for exercises that will be performed. Following the warm-up 1RM testing of the squat, bench press, and deadlift exercises will begin. All 1RM tests will be administered with accordance to the National Strength and Conditioning Association (NSCA) guidelines, and all exercises will be performed to the rules set by the United States of America Powerlifting (USAPL). After determining the 1RM in the squat a 10-minute rest period will precede 1RM testing for the bench press. Similarly, after determining the 1RM in the bench press, a 10-minute rest period will precede 1RM testing for the deadlift.

For the squat you will stand straight with your hips and knees locked, and the barbell placed across your upper back/shoulders. You will then descend with the bending of the knees until the top of your leg at the hip joint is below the top of your knee. Then you will return to your starting position upon your own volition. During the bench press, you will lie supine on a weight bench with your head, butt, and shoulders in contact with the bench and, both feet in flat on the floor at all times. You will remove the bar from the rack and hold it in your hand with your arms extended in a stable position. You will then lower bar until it comes in contact with your chest where it will then be pressed upwards until the arms are once again fully extended. For the deadlift you will approach a bar resting on the ground. You will bend over at the waist and grasp the bar. In one smooth motion you will lift the bar off of the floor into a fully erect standing position. Afterwards you will return the bar to the floor, remaining in contact with the bar the entire lift.

48 hours following your 1RM testing you will return to the laboratory to perform your VO2peak cycle test. Immediately upon entering the lab you will be seated for five minutes so that your resting heart rate and blood pressure may be measured. Following resting measures you will be given BCAA and perform the dynamic warm-up. The VO2peak cycle test is an incremental cycle test, which increases in intensity until you can no longer cycle to measure your peak aerobic capacity. During the test you will be wearing a heart rate monitor and mouthpiece to capture your exhaled breaths for gas analysis via a metabolic cart. The test will begin with a five minute warm-up with 0 watts (W), followed by increases in power on the electronically braked cycle ergometer. The first stage will begin with 50 W and increase by 25 W every minute until you can no longer cycle.

At this time you will be placed into your specific group for the study, and given your specific training protocol. After 48-hours of rest you will begin your introductory training. This training will include 3 alternating days of low volume resistance training (i.e. Monday, Wednesday, and Friday) and 2 additional days of reduced duration and intensity "endurance" training (i.e. Tuesday, Thursday). This lower intensity training is specifically designed for each training group, and will prepare you for the upcoming 6-week long training protocol. Following the introductory training, you will perform the specific 6-week long training protocol you were assigned to, which will follow the same 5-day per week schedule as your introductory training. Lastly, you will begin taper training after completing your final week of your specific protocol. Similarly to the introductory training, taper training will feature lower volume resistance training on 2 alternating days (i.e. Monday and Wednesday) and 1 additional reduced duration and intensity "endurance" training day (i.e. Tuesday). After your second resistance training day you will rest for 48 hours and repeat the pre-study measures of:

- One repetition maximum (1RM) strength in the squat, bench press, and deadlift
- Cross sectional area (CSA) of the arms and legs via ultrasound
- Muscle thickness (MT) of the biceps, chest, and thigh muscles via ultrasound
- Peak Aerobic Capacity (VO 2peak) via electronic cycle ergometer
- Body composition by ultrasound (chest, abdomen, thigh)
- Anthropometrics (height & weight)

Additionally on days which blood draws are scheduled you are required to fast for 3 hours prior to the laboratory visit. It is anticipated that this procedure will take a total of 5 minutes. Blood sampling will occur on the first day of the study, first day of the fourth week of training, and 48 hours after the completion of the 6-week training program prior. You will visit the laboratory for a blood draw immediately before any training that will also be performed that day. Prior to the blood draw a heart rate monitor will assess your resting heart rate and your resting blood pressure will be measured using a sphygmomanometer. Immediately following the assessments above, a trained phlebotomist using standard aseptic techniques will perform blood sampling. A butterfly needle (21 gauges) will be inserted in the superficial vein of the upper right arm. One tablespoon of blood volume will be collected into specific collection tubes for subsequent analysis. After blood samples are collected, plasma will be stored at -80 degree C freezer for further analyses.

RISKS AND DISCOMFORTS
Anytime you engage in exercise there are some inherent risks including: muscle strains, soreness, or joint aches. Since you will perform resistance and aerobic exercise, the muscle soreness caused by muscle damage may be experienced within 24 to 48 hours. The muscle soreness should be eased after 48 or 72 hours. The primary investigator will take measure to alleviate these aches and pains through the use of introductory training designed to elicit the body's protective mechanisms to stress. Further, the testing and training sessions will be monitored by NSCA certified Strength and Conditioning Specialist (CSCS).

Inserting the needle and drawing blood from your arm may cause pain, bruising lightheadedness, fainting, and on rare occasions, infection. There may be some slight discoloration and a bruise at the site of the needle insertion. To minimize these risks, a trained phlebotomy technician will perform all blood sampling. You will receive instructions for care following the needle insertion. While the total amount of blood drawn is small compared to the amount taken when you donate blood, this will minimize the risk of fainting.

NEW INFORMATION
You will be told about anything new that might change your decision to be in this study. You may be asked to sign a new consent form if this occurs.

BENEFITS
The potential benefits to you are:

- Free measurements of body composition, CSA, MT, and 1RM testing
- Free BCAA and whey protein supplementation for the duration of the study
- Access to calibrated training equipment that is approved by and used within the International Powerlifting Federation (IPF) competitive events
- The findings from this study can be applied to clients or athletes that you may coach or train

COSTS
No costs will be incurred to you for any lab visits other than the cost of your time.

CONFIDENTIALITY
Potentially identifiable information about you will consist of a medical history questionnaire and research data sheets. The blood samples will be stored in the freezer in the Exercise Science Laboratory and be discarded into biohazard waste containers within 10 years after completion of the study. Data are being collected only for research purposes. All personal identifying information will be kept in password-protected files and a code number will be used for identification purposes. Data records will be kept in a locked file cabinet in an office within the department of Exercise Science and Health Promotion. Although results of this research may be presented at meetings or in publications, identifiable personal information pertaining to participants will not be disclosed.

COMPENSATION FOR INJURY Florida Atlantic University has no plan for providing long-term care or compensation in the event that you suffer injury because of your participation in this research study. If you are injured or if you become ill because of your participation in this study, contact the Principal Investigator immediately. Your health insurance company may or may not pay for treatment of injuries as a result of your participation in this study.

VOLUNTARY PARTICIPATION AND WITHDRAWAL
Your participation in this study is voluntary. You may decide not to participate or you may leave the study at any time. Your decision will not result in any penalty or loss of benefits to which you are entitled.

Your participation in this study may be stopped at any time by the investigators without your consent for any of the following reasons:

- If it is in your best interest x If it is for your health and safety
- You do not follow instructions
- You do not consent to continue in the study after being told of changes in the research that may affect you
- Administrative reasons require your withdrawal

If you leave the study before the planned final visit, you may be asked by the study investigator to have some of the end of study procedures done.

SOURCE OF FUNDING FOR THE STUDY
Funding for this study will be from the FAU Department of Exercise Science and Health Promotion.

QUESTIONS
Contact Michael C. Zourdos: 561-297-1317 for any of the following reasons:

- If you have any questions about this study or your part in it,
- If you have questions, concerns or complaints about the research

If you have questions about your rights as a research subject or if you have questions, concerns or complaints about the research, you may contact: Institutional Review Board (561-297-0777).

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers.

CONSENT
I have read this consent form (or it has been read to me). All my questions about the study and my part in it have been answered. I freely consent to be in this research study. I have been provided a copy of this consent form for my records.

By signing this consent form, I have not given up any of my legal rights.

____ __________________ Subject name, printed

____ __________________ Subject signature Date

____ __________________ Signature of Person Conducting Informed Consent Date

Appendix D: IRB Approval Letter

FAU FLORIDA ATLANTIC UNIVERSITY

Institutional Review Board
Division of Research
777 Glades Rd.
Boca Raton, FL 33431
Tel: 561.297.0777
fau.edu/research/researchint

Christine Williams, R.N., D.N.Sc., Chair

DATE:	November 18, 2014
TO:	Michael C. Zourdos, Ph.D.
FROM:	Florida Atlantic University Health Sciences IRB
IRBNET ID #:	680161-1
PROTOCOL TITLE:	[680161-1] The Influence of Time-Equated Training Programs on Muscle Performance, Body Composition, and Inflammation.
PROJECT TYPE:	*New Project*
ACTION:	APPROVED
APPROVAL DATE:	November 18, 2014
EXPIRATION DATE:	November 17, 2015
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category #B4

Thank you for your submission of New Project materials for this research study. The Florida Atlantic University Health Sciences IRB has APPROVED your New Project. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

- This study is approved for a maximum of **30** subjects.
- It is important that you use the approved, stamped consent documents or procedures included with this letter.
- **<u>**Please note that any revision to previously approved materials or procedures, including modifications to numbers of subjects, must be approved by the IRB before it is initiated.</u>** Please use the amendment form to request IRB approval of a proposed revision.
- All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All regulatory and sponsor reporting requirements should also be followed, if applicable.
- Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.
- Please note that all research records must be retained for a minimum of three years.
- **This approval is valid for one year.** A Continuing Review form will be required prior to the expiration date if this project will continue beyond one year.

If you have any questions or comments about this correspondence, please contact Angela Clear at:

Institutional Review Board
Research Integrity/Division of Research

- 1 -

Generated on IRBNet

Florida Atlantic University
Bldg. 80, Rm. 106
Boca Raton, FL 33431
Phone: 561-297-0777

* Please include your protocol number and title in all correspondence with this office.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within our records.

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