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Responses to Two Weight Training Protocols--One with Integrated High-Intensity Interval Training

Tony P. Nunez
University of New Mexico - Main Campus

Tony P. Nuñez
Candidate

Health, Exercise and Sports Sciences
Department

This dissertation is approved, and it is acceptable in quality and form for publication:

Approved by the Dissertation Committee:

Len Kravitz, Chairperson

Fabiano Amorim, Co-Chairperson

Christine Mermier

Trisha VanDusseldorp

RESPONSES TO TWO WEIGHT TRAINING PROTOCOLS—ONE WITH INTEGRATED HIGH-INTENSITY INTERVAL TRAINING

by

TONY P. NUÑEZ
Degrees
B.S. Kinesiology, Fitness
California State University, Long Beach
2007-2012
M.S. Exercise Science
California State University, Long Beach
2012-2014

DISSERTATION

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Tony P. Nuñez

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California State University, Long Beach, 2012

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Ph.D., Physical Education, Sports and Exercise Sciences
University of New Mexico, 2017

ABSTRACT

Purpose: To examine the physiological effects (energy expenditure, oxygen consumption [VO_2], heart rate [HR], blood lactate [BLa^-], excess post-exercise oxygen consumption [EPOC]) and perception (rating of perceived exertion [RPE] and enjoyment) of the combination of high-intensity interval training (HIIT) exercise with conventional circuit weight training (CWT; nine consecutive exercises)(CWIT) compared to HIIT exercise with tri-set training (3 three-exercise mini-circuits)(TRIIT). **Methods**: Fourteen trained men (25.7 ±4.4 yr) completed two separate resistance exercise protocols. CWIT consisted of six HIIT bouts prior to three rounds of a nine exercise CWT protocol. TRIIT consisted of three rounds of three mini-circuits consisting of three exercises with the integration of three HIIT bouts between the first and second mini-circuits and second and third mini-circuits. Both protocols were matched for exercise load and time. VO_2 was measured via indirect calorimetry, BLa- was measured via portable lactate analyzer, exertion was measured via Borg scale (6-20) and enjoyment was measured via Physical Activity Enjoyment Scale (PAES). Differences between CWIT and TRIIT protocols were analyzed as group means by using paired t-tests and as protocol by time using a 2 x 5 repeated measures ANOVA (SPSS v22.0). **Results**: Average values for CWIT and TRIIT were similar (p>.05) for VO_2 (25.2 ±1.91 vs. 24.8 ±2.12 $mL \bullet kg^{-1} \bullet min^{-1}$), HR (150 ±12.5 vs. 150 ±16.3 $beats \bullet min^{-1}$) and RPE (16 ±1.5 vs. 16 ±1.4). Energy expenditure was significantly higher during the CWIT compared to the TRIIT protocol (494 ±44.8 vs. 475 ±44.6 kcal; p=.012), as well as EPOC (90 ±13.8 vs. 84 ±10.8 kcal; p=.034). BLa^- was significantly higher at all post-exercise time points (immediate, 5 min, 10 min and 20 min post-exercise) following the CWIT compared to the TRIIT protocol. Both protocols were considered enjoyable according to the PAES. **Conclusions**: Performing HIIT prior to CWT elicits higher metabolic perturbation in comparison to the integration of HIIT with mini-circuits. CWIT also required greater energy requirements during and after the protocol compared to TRIIT. This may be useful for fitness trainers when determining how to implement HIIT into a CWT workout.

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SYMBOLS / ABBREVIATIONS

>: greater than

≤: less than or equal to

<: less than

±: plus or minus

ANOVA: analysis of variance

BLa^-: blood lactate

bpm: beats per minute

cm: centimeters

CWT: circuit weight training

hr: hour

HR: heart rate

kg: kilogram

min: minute

mmol: millimolar

mph: miles per hour

O_2: oxygen

RPE: rating of perceived exertion

s: seconds

SD: standard deviation

V_{max}: maximal velocity

VO_2: oxygen consumption

VO_{2max}: maximal oxygen consumption

wk: week

WR: work rate

yrs: years

“Responses to Two Weight Training Protocols—One with Integrated High-Intensity Interval Training”

Introduction

Circuit weight training (CWT) has been a popular mode of exercise since its inception back in the late 1970s (3, 23). This form of resistance training exercise was created in an attempt to improve the time efficiency of strength training and elicit a cardiovascular response while performing resistance exercise. Traditional strength training programs consists of resistance exercises performed one exercise at a time for a fixed number of sets and repetitions before moving on to the next exercise. In comparison, CWT is defined as a number of carefully selected exercises arranged consecutively and performed cyclically (20). The number of exercises often range from 6 to 12, typically performed for a specified amount of time [15 to 45 seconds (sec)] or repetitions (8 to 20) with limited break between exercises (15 to 30 sec). Intensities ranging from 40% to 60% one-repetition maximum (1-RM) are selected for a majority of CWT protocols.

Since the first research observing CWT, much evidence has been presented to demonstrate the overall effectiveness of this form of exercise for improvements in body composition in terms of both decreases in fat mass and increases in fat-free mass (7, 8, 11, 15, 22), as well as improvements in cardiovascular fitness (4, 6, 13, 16), muscular strength and endurance (5, 6), and to a lesser extent, flexibility (22) in healthy populations. Clinical populations, such as individuals with cardiac disease, diabetes mellitus, and hypertension have also seen improvements in cardiovascular fitness (4, 8, 11, 13), hemoglobin A_{1c} (5, 14), and blood pressure (8) following CWT programs.

Twenty years following the inception of CWT came the development of high-intensity circuit training (HICT), which increased the intensities to greater than 70% from the typical 40% to 60% 1-RM. Alcaraz, Sanchez-Lorente and Blazevich (2) were the first to implement this type of training and did so to determine if high load intensities (rather than high volume) are practical when performed in a circuit format while maintaining a high cardiovascular stimulus. Similar results have been shown following HICT in regard to improvements in cardiovascular fitness (18), muscular strength, endurance and power (17) and body composition (17, 18). Although there is limited research in the area of HICT, contributing investigators have suggested this style to be the most time efficient format of resistance training for eliciting a high cardiovascular output while improving muscular strength, muscle size and power similar to traditional strength training (1, 17). According to Paoli and colleagues, 12 weeks of HICT performed 50 minutes (min)/day, 3 days/week also provides significant reductions in resting diastolic blood pressure, total cholesterol, low-density lipoproteins, and a significant increase in high-density lipoproteins in middle-aged overweight men.

High-intensity interval training (HIIT) is a popular mode of training that has been shown to improve aerobic capacity and other cardiovascular markers in a more time efficient manner and to a higher degree compared to moderate continuous training in both general and clinical populations (9, 10, 21, 24). Interval training refers to alternating between high-intensity work and low- to moderate-intensity active recovery bouts during an exercise session. Exercisers perform a high intensity work bout between 8 sec to 6 min with rest bouts lasting 12 sec to 4 min. This allows the exerciser to perform a greater amount of work during a single session when the work periods are spaced with recovery intervals (12).

Skidmore and colleagues were the first to analyze the integration of CWT with HIIT (CWIT) in the same exercise session and compared this mode of exercise to CWT with moderate aerobic interval training and CWT in isolation (19). The CWT was comprised of three different stations with three different resistance training exercises performed for 3 sets of 10 repetitions at 90% of a measured 13-repetition maximum with 30 sec to complete the lifts and 30 sec of rest between exercises. The HIIT session consisted of three maximal effort 30sec sprints on a cycle ergometer followed by 3 min of easy pedaling. These interval bouts were performed between the resistance exercise stations. The moderate aerobic interval training session was performed for four 2:30 min cycling bouts at 65-75% HRmax between resistance exercise stations. Results showed that subjects performing CWIT had a higher blood lactate response, increased heart rate and higher rating of perceived exertion compared to both CWT with moderate continuous training and isolated CWT.

Although stations consisting of three exercises are a non-traditional format for CWT (typically 6 to 12 exercises), Skidmore and colleagues described the sessions in their study as CWT protocols. In accordance with traditional CWT guidelines, there should be at least six exercises per circuit in order to be declared a CWT study (23). Thus, a topic of interest that has not yet been studied is the comparison of CWT (nine exercises performed consecutively) and Tri-Set (three exercises performed consecutively) training along with the integration of HIIT at the beginning and end of the exercise protocols.

Problem Statement

Limited research has been done examining the integration of CWT and HIIT and its effects on heart rate (HR), blood lactate and rating of perceived exertion (RPE), but there have been no studies that have investigated this integration with the use of a traditional CWT format. Furthermore, differences in energy expenditure, %VO_2max and acute changes in blood pressure and rate pressure product have not been measured following these types of exercise protocols, in order to provide health and fitness professionals with evidence based exercise programming.

Purpose of the Study

The purpose of the current study is to examine the physiological effects (energy expenditure, VO_2, HR, BLa^-, blood pressure and rate pressure product [RPP]) and perception (RPE and enjoyment) of the combination of HIIT exercise with conventional CWT (nine consecutive exercises) compared to HIIT exercise with tri-set (3 three-exercise circuits) training.

Hypotheses

The following hypotheses will be tested in this study:

Hypothesis 1: There will be no difference in average VO_2 between the two protocols.

Hypothesis 2: There will be no difference in average HR values between the two protocols.

Hypothesis 3: There will be no difference in systolic blood pressures (SBP) at any time points (pre, immediate-post [ip], 10-min-post, and 20-min-post) between the protocols.

Hypothesis 4: There will be no difference in diastolic blood pressures (DBP) at any time points (pre-exercise [pre], immediate-post [ip], 10-min-post, and 20-min-post) between the protocols.

Hypothesis 5: There will be no difference in rate pressure product (product of HR and systolic blood pressure) between the protocols.

Hypothesis 6: Blood lactate will not be significantly different for any of the time points (pre, ip, 5-min-post, 10-min-post, 20-min-post) between the TRIIT and the CWIT protocols.

Hypothesis 7: When examining RPE, there will be no difference between the two protocols.

Hypothesis 8: When examining excess post-exercise oxygen consumption (EPOC), there will be no difference between the two protocols.

Scope of the Study

Fourteen healthy, active males between the ages of 18 and 45 years who take part in both regular resistance and cardiovascular training completed two different integrations of circuit weight and high-intensity interval training to compare the physiological (VO_2, HR, BP, BLa^-, EPOC, RPP) and perception (RPE and enjoyment) response between traditional CWT with HIIT and Tri-Set with HIIT protocols. Only participants with 'Good-Excellent' cardiorespiratory fitness, as defined by American College of Sports Medicine (ACSM) (60-94th percentile) were included in the study. In order to eliminate a learning effect and familiarize participants with the exercises, both protocols were first performed without gas and blood analysis in a randomized order. Following the familiarization trial, both protocols were performed a second time in a randomized order. After the conclusion of each protocol, a seated EPOC analysis was performed for twenty minutes. All ventilatory measurements were collected continuously during exercise using a portable metabolic unit. Blood lactate and blood pressure were analyzed pre-exercise, immediately post-exercise, 5-min post (blood lactate only), 10-min post and 20-min post-exercise using a portable lactate analyzer and sphygmomanometer and stethoscope, respectively. Rating of perceived exertion (6-20 scale) and perceived enjoyment (7-point bipolar scale; PAES) was recorded 20 min following completion of the CWIT and TRIIT protocols.

Assumptions

The following assumptions were identified in this study:

1. Prior to each visit, the participant did not perform any exercise for 24 hours, did not ingest caffeine or alcohol for 3 hours and consumed a small meal 2-3 hours prior to the exercise protocol.
2. Each participant performed his one-repetition maximum and VO_{2max} testing to the best of his ability to yield an appropriate percent one-repetition maximum and equate the appropriate $\%VO_2max$ values during both exercise protocols.

Limitations

The following limitations were identified in this study:

1. The study sample consisted of healthy, active men between the ages of 18-45 years who take part in regular resistance and cardiovascular exercise. Therefore, the results of this study may not apply to females, individuals who are sedentary, have chronic disease, and are outside of this age range.
2. Both protocols in the current study were performed using free weight exercises and on a treadmill. Therefore, the results of this study may not be applicable to other modes of resistance and cardiovascular exercise devices.

Significance of the Study

This study compared the differences in physiological and perception responses between CWIT and TRIIT protocols. The popularity of short duration, high-intensity exercise protocols have grown in recent years. If one protocol is more effective than the other, it may indicate the potential of implementing this protocol into the health and fitness setting. Furthermore, recent evidence (Skidmore et al. 2013) suggests a superior ability for tri-set weight training integrated with high-intensity interval training exercise to elicit a greater blood lactate, heart rate and RPE in females compared to the combination of tri-set weight training integrated with aerobic bout exercise. However, it is unknown whether tri-set weight training is superior to that of traditional circuit weight training when integrated with high-intensity interval training. The results of this study will contribute to the field of exercise programming for healthy, active males.

Definition of Terms

The terms in this study have been defined as follows:

Blood lactate (BLa^-): a metabolic byproduct of glycolysis in the absence of oxygen, often used as an indication of exercise intensity

Carbon dioxide production (VCO_2): the rate of carbon dioxide production as a result of metabolic by-product accumulation at the cell

Circuit training (CT): systematically selected body weight exercises arranged sequentially and performed in a rotational order

Circuit weight training (CWT): systematically selected resistance exercises using external load arranged sequentially and performed in a rotational order

High-intensity interval training (HIIT): short bouts of high-intensity exercise [approximately 90% of peak rate of oxygen consumption (VO_{2peak})] interspersed with bouts of low- to moderate-intensity exercise (approximately 60% VO_{2peak}) in a repetitive manner

Oxygen uptake (VO_2): The rate of oxygen consumption and utilization

Maximal oxygen uptake (VO_{2max}): the maximal rate of oxygen consumption and utilization per minute of exercise

Respiratory exchange ratio (RER): The ratio of carbon dioxide produced compared to the amount of oxygen consumed during ventilation, indicative of substrate utilization.

Rating of perceived exertion (RPE): A subjective measurement to indicate individual level of perceived physical exertion.

Rate pressure product (RPP): The product of combining heart rate and systolic blood pressure during a predetermined time point (HR X SBP) to measure workload of the heart.

Tri-Set: Performing three exercises in sequential order in a rotational fashion for a fixed number of sets.

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CHAPTER 2

This chapter presents a review article, entitled “Circuit Weight Training: Acute and Chronic Effects on Healthy and Clinical Populations” which has been submitted for publication in the Journal of Sport and Human Performance. It is authored by Tony Nuñez, Fabiano Amorim, Jeffrey Janot, Christine Mermier, Ralph Rozenek and Len Kravitz.

CHAPTER 2

Circuit Weight Training: Acute and Chronic Effects on Healthy and Clinical Populations

Tony P. Nuñez[1], Fabiano T. Amorim[1], Jeffrey M. Janot[2], Christine M. Mermier[1], Ralph Rozenek[3], and Len Kravitz[1]

[1]*Department of Health, Exercise and Sports Sciences, University of New Mexico, Albuquerque, NM*

[2]*Department of Kinesiology, University of Wisconsin-Eau Claire, Eau Claire, WI*

[3]*Department of Kinesiology, California State University, Long Beach, Long Beach, CA*

Address for Correspondence: Tony P Nunez; tnunez12@gmail.com

ABSTRACT

Circuit weight training (CWT) involves resistance exercise movements performed in a rotational order with light loads (40-60% one-repetition maximum) using limited to no rest between exercises. This type of training has been implemented in programs involving healthy younger and older adults, as well as in programs involving clinical populations (e.g. diabetes mellitus, hypertension, cardiac disease). Acute responses to CWT demonstrate higher levels of oxygen consumption and higher heart rates compared to traditional resistance training at similar intensities. Furthermore, CWT programs are more time efficient compared to traditional resistance training. Results from investigations using this mode of training range from improvements in muscular strength and endurance, flexibility, body composition to health-related enhancements such as resting blood pressure, hemoglobin A_{1C} and aerobic capacity. The time efficiency in which these results are achieved makes circuit weight training an appealing exercise format. The incorporation of aerobic activity into circuits promotes further improvements in markers of cardiovascular health and fitness.

1. Introduction

The development of circuit training by R.E. Morgan and G.T. Adamson at the University of Leeds (26) can be traced back to the early 1950s. In order to maximize time and space in a gymnasium full of physical education students, Morgan and Adamson implemented body weight exercises all students could perform with little to no equipment in a cyclical fashion. One of the earliest books pertaining to circuit training, written by Robert P. Sorani (26), highlighted many formats of circuit training and advantages of this type of resistance training for different populations with various health, sport and performance-related goals. Traditional circuit training is performed using body weight exercises, while circuit weight training (CWT) refers explicitly to externally loaded resistance exercises performed in a rotating format. A CWT format refers to a number of carefully selected exercises arranged sequentially and performed in a rotational order. The number of resistance exercises typically ranges from 6 to 12, and is usually performed for a specified amount of time (15 to 45 sec [s]) or number of repetitions (8 to 20 repetitions) with limited recovery between exercises (15 to 30 s). Intensities ranging from 40% to 60% one-repetition maximum (1-RM) are generally used for the majority of CWT protocols.

The primary focus of this current review is to provide an in-depth synopsis of the physiological and metabolic effects of CWT, as well as highlight specific health/fitness benefits resulting from participation in this type of programming. A secondary aim of this article is to detail the various training protocols from published research in order to provide readers with useful programming ideas for specific populations. This review will examine the acute and chronic effects of CWT on cardiopulmonary function, muscular fitness and body composition within the following populations: healthy, clinical and older adults.

2 Healthy Populations

2.1 Acute Cardiopulmonary Function, Muscular Fitness and Performance Outcomes

The concept of circuit training was in its developmental stages when Wilmore and colleagues (29) designed one of the first circuit weight training (CWT) studies examining energy cost. The researchers used 12 pieces of machine/cam-based strength equipment typically found in large commercial fitness settings and rehabilitation facilities. This acute study included 20 men and 20 women between 17 and 36 years of age, who had experience with both CWT and resistance training. Exercises were performed for 30 s followed by 15 s of rest before the next exercise was performed. Results for the 22.5 min circuit for males demonstrated an approximate mean energy expenditure of 200 kcal (±39 kcal), heart rate (HR) of 143 $b \cdot min^{-1}$ (±17 $b \cdot min^{-1}$) (~ 76% HR_{max}), and $\dot{V}O_2$ values of 20 $ml \cdot min^{-1} \cdot kg^{-1}$ (± 2 $ml \cdot min^{-1} \cdot kg^{-1}$) (~ 40% $\dot{V}O_{2max}$). Mean energy expenditure for females was 142 kcal (±22 kcal) with a HR of 148 $b \cdot min^{-1}$ (±11 $b \cdot min^{-1}$) (85.5% HR_{max}), and $\dot{V}O_2$ values of 17 $ml \cdot min^{-1} \cdot kg^{-1}$ (±2 $ml \cdot min^{-1} \cdot kg^{-1}$) (~ 45% $\dot{V}O_{2max}$). The authors concluded that the energy cost of CWT is approximately the equivalent of cycling at 18.5 $km \cdot hr^{-1}$, jogging at 8 $km \cdot hr^{-1}$ or a vigorous game of volleyball. This pioneer study initiated an extensive amount of research in the area of CWT in both the general and clinical populations.

In an effort to investigate the acute effects of different CWT protocols on cardiopulmonary function and energy expenditure, Gordon et al. (13) had 12 active male volunteers (age = 28 ±5 yr) perform two different CWT protocols of similar total duration using hydraulic exercise equipment at self-selected intensities. Results showed that 30 s work periods with 30 s rest periods elicited a significantly higher $\dot{V}O_2$ (23.4 ±3.5 $ml \cdot min^{-1} \cdot kg^{-1}$) and total energy expenditure (TEE) (9.3 ±0.3 $kcal \cdot min^{-1}$) than 20 s work periods with 60 s rest periods ($\dot{V}O_2$ = 20.4 ±2.9 $ml \cdot min^{-1} \cdot kg^{-1}$; TEE = 8.1 ±0.3 $kcal \cdot min^{-1}$). The researchers noted that the HR response to CWT (75% of HR_{max}) was disproportionately elevated as compared to oxygen uptake (40% $\dot{V}O_{2max}$) and thus not an accurate predictor of the energy demands of CWT. These results are consistent with those noted by Fleck and Dean (9), identifying a pressor response to resistance exercise.

Gordon et al. highlighted that heart rate response remained identical during the 60 s and to 30 s rest intervals between exercises despite a noticeable decrease in oxygen uptake during the 60 s rest interval protocol. There was no physiological explanation or hypothesis in regard to the lack of change in HR response between the 30 s and 60 s rest intervals.

In response to the increased use of free weight CWT in group exercise classes in commercial gyms, Beckham and Earnest (3) developed a research design to examine the metabolic cost of these types of CWT classes. Light and moderate resistances were used to mimic the group exercise class structure. The circuit was performed one time utilizing the following exercises: squat, bent over row, bent leg dead lift, modified clean and press, overhead press, behind neck shoulder press, front shoulder raise and lateral shoulder raise. The number of repetitions performed was not specified. Instead, exercises were performed for a specified amount of time that differed between all exercises ranging between 1 and 4 min. Due to the low intensity loads used during the exercise protocols, $\%\dot{V}O_{2max}$ (28.7 – 31.9% for women; 24.0 – 29.4% for men) was significantly lower than CWT oxygen consumption values reported by Wilmore et al. (44.9 – 46.8% for women; 40.2 – 45.0% for men) (29). Beckham and Earnest proposed that the light to moderate resistance used during group exercise CWT classes was not a sufficient challenge to produce an aerobic response indicative of cardiovascular improvement. For a favorable aerobic response during CWT, Beckham and Earnest suggested training at higher intensities than those used during their study.

In an attempt to determine the optimal volume needed for CWT in order to elicit a cardiovascular response, Gotshalk, Berger and Kraemer (14) examined the oxygen uptake in response to CWT performed at a randomized starting point, but with exercises performed in the same order. Eleven male participants (20 ±2 yr) performed 10 exercises (bench press, leg press, latissimus pull down, seated shoulder press, biceps curl, triceps extension, knee extension, upright row, and seated back row) for 10 repetitions at 40% 1-RM. The protocol was completed for 4.6 circuits and oxygen uptake was analyzed throughout the entire session. Data were collected during the first six exercises to determine the extent of physiological response upon initiation of the protocol, preceded by four full circuits (4.6 circuits in total). After completing 1.6 rounds of the circuit, participants elicited a $\%\dot{V}O_{2max} \geq 50\%$ and had a $\%HR_{max} > 70\%$ both of which remained at these levels for the remainder of the circuit rounds. Comparatively, the researchers determined that exercising at an intensity of 50% $\dot{V}O_{2max}$ produced a greater HR response during CWT (mean HR ~165 $b \cdot min^{-1}$) compared to treadmill running (mean HR ~150 $b \cdot min^{-1}$). It was concluded that CWT was a suitable alternative modality for developing both strength and aerobic capacity, when performed with an intensity of at least 40% 1-RM with a volume of 4.6 rounds of 10 repetitions using 10 exercises.

Monteiro and colleagues (21) examined the acute differences in aerobic response and energy expenditure in trained and untrained men (n=10; age = 26.5 ±4.5 yr) and women (n=15; age = 24.5 ±6.5 yr) using either CWT or CWT combined with aerobic exercise. The CWT session consisted of the following exercises: squat, push-up, right leg lunge with biceps curl, bent over row, left leg lunge with biceps curl, upright row with squat, wide stance squat with shoulder press. One set of each exercise was performed for as many repetitions as possible within a time period of 60 s. Women used 2 kg weights for upper extremity exercises and 4 kg weights for the lower-body exercises, while the men used 4 kg and 6 kg weights for upper- and lower-body exercises, respectively. The combined CWT and aerobic activity session consisted of the same exercises at the same loads, but included 30 s of running at 60% HR_{max} instead of taking 10 to 15 s of rest between exercises. A significantly higher $\dot{V}O_2$ response for both men and women was observed during the combined CWT and aerobic exercise (women = 20.8 ml· min^{-1}·kg^{-1}; men = 23.8 ml· min^{-1}·kg^{-1}) when compared to the CWT session (women = 17.5 ml· min^{-1}·kg^{-1}; men = 20.4 ml· min^{-1}·kg^{-1}). Energy expenditure was significantly higher during the combined CWT and aerobic exercise (women = 6.3 kcal·min^{-}1 for; men = 8.3 kcal·min^{-1}) compared to the CWT session (women = 5.1 kcal·min^{-1} for; men = 7.3 kcal·min^{-1}).

Most CWT studies have used relatively low intensities in their protocols. To determine the effect of higher intensities, Alcaraz, Sánchez-Lorente, and Blazevich (2) investigated the difference in physical performance and heart rate response between standard weight training (SWT) and CWT in 10 trained men (26 ±1.5 yr) using intensities ranging between 60 – 100% 1RM. The SWT session consisted of 5 sets of bench press with 3 min of rest between sets performed to volitional fatigue, while the CWT session completed 5 sets of bench press along with two lower body exercises (leg extension, ankle extension) with 35 s rest between exercises and 3 min rest between circuits. Participants were split into two groups and randomly assigned to the SWT or CWT protocol for the first session and switched to the opposite protocol the following session. There were no significant differences in exercise performance as measured by maximum and average bar velocity and power, and the number of repetitions performed on the bench press between the CWT and SWT protocols. These results indicated that strength training can be performed in a circuit fashion without diminishing exercise performance in the primary lift (bench press). However, the CWT group did elicit statistically higher average HRs (mean = 137 b·min^{-1}) for the entire workout compared to the SWT group (mean = 130 b·min^{-1}). This was likely due to the HR being able to recover more readily during the SWT protocol compared to the CWT protocol. A major limitation of the study was the two protocols were very unbalanced in terms of the amount of work performed: one exercise for the SWT and three exercises for the CWT.

One of the more recent articles examining the acute effects of CWT comes from Skidmore et al. (25). Researchers examined three different training protocols using 11 recreationally active women (mean age = 34.0 ±5.5 yr) as participants; traditional circuit training (TRAD), aerobic circuit training (ACWT), and circuit training mixed with interval training (CWIT). All protocols were composed of the same three mini-circuit stations: Station A: triceps bench dip, hip bridge, prone plank; Station B: standing biceps curl, dumbbell (DB) squat, pushup; Station C: Standing DB lateral raise, DB split squat right leg, DB split squat left leg, standing DB bent-over row. Stations A, B and C were performed for 3 continuous circuits with 13 repetitions for each exercise (each set performed in 30 sec). Loads were determined from a 13-RM test for each exercise for all protocols (i.e., TRAD, ACWT, CWIT). During the TRAD session, participants performed each station (i.e., A, B, C) for 30 s of work with 30 s of rest between exercises. The ACWT session involved the same stations as the TRAD protocol and also included four 2:30 min submaximal aerobic bouts on the cycle ergometer (55-65 rev·min^{-1} at 65-75% HR_{max}) alternated with the three mini-circuit stations. The CWIT workout was similar to the ACWT routine, and differed only in the performance of the cycling bout.

Participants completed three 30 s maximal effort sprint intervals [resistance set at 0.055-percent of body weight (in kg)] on the cycle ergometer followed by a 3-min active rest period on the cycle ergometer before proceeding to the next resistance exercise station. Blood lactate concentrations ([bLa]) were significantly higher at the completion of the CWIT (mean [bLa] = 6.7 $mmol \cdot L^{-1}$) protocol compared to the TRAD (2.3 $mmol \cdot L^{-1}$) and ACWT (4.8 $mmol \cdot L^{-1}$) protocols. Estimated $\%HR_{max}$ was also significantly higher in the CWIT protocol compared to TRAD and ACWT protocols. Lastly, rating of perceived exertion was significantly higher following the CWIT protocol compared to both the TRAD and ACWT sessions.

In summary, research has shown that an acute bout of CWT can elicit sufficient cardiovascular stress in the general population (13, 14, 21, 29). However, loads must be sufficient (≥40% 1-RM) to allow for an aerobic response indicative of cardiovascular fitness improvements, as noted by Beckham and Earnest (3). Heart rate response tends to be disproportionally elevated compared to $\dot{V}O_2$ during CWT (14, 28) and is consisted with the findings of Fleck and Dean (10) for HR responses during dynamic resistance training. Combining CWT with aerobic activity may be the most effective way of eliciting the greatest aerobic responses during an acute bout (21, 25). Furthermore, CWT does not cause a decrement in muscular strength and power when compared to a traditional single-exercise strength protocol (2).

2.2 Chronic Cardiopulmonary Function, Muscular Fitness, Body Composition, Health and Performance Outcomes

Wilmore and colleagues (28) followed up their first acute response study (29) with a 10-week CWT program using both men and women (specific characteristics of participants not reported). Changes in body composition, HR, maximal aerobic capacity ($\dot{V}O_{2max}$), flexibility and muscular strength were measured. The participants (age range not reported) performed the training 3 days/week for 10 weeks. Circuit exercises included bench press, sit-up, leg press, latissimus pull down, low back extension, shoulder press, knee extension, biceps curl, hamstring curl, and upright row. The circuit was performed three times for 30 s per exercise at 40 to 55% 1-RM. Each exercise was performed for as many repetitions as possible during the 30s work period. Results showed significant increases in lean body mass (1.7% for men and 1.3% for women) and treadmill time to exhaustion (24.2% for men, 23.8% for women) for both men and women. Significant increases in muscular strength in all exercises occurred in women (see Table 1). Men also had significant increases in muscular strength for shoulder press, biceps curl, latissimus pull down, and hamstring curl (see Table 1). Women demonstrated improvements in $\dot{V}O_{2max}$ (3.8%) and flexibility (1.1%), and a significant decrease (1.8%) in body fat percentage. However, the men showed no significant change in any of these variables. Wilmore et al. concluded that CWT is an efficient mode of exercise for improvements in body composition, muscular strength and endurance time to exhaustion.

Gettman et al. (11) followed up the Wilmore et al. (28) study with a 20-week CWT versus running program evaluating differences in strength, aerobic capacity, and body composition in 70 male police officers (21 to 35 year of age). The officers were split into three groups; CWT (n = 11), continuous running (RN; n = 16) and sedentary control (C; n = 15). The circuit was performed for 3 days/week for 2 to 3 sets with variable repetitions (10-20 reps) throughout the program. Repetitions progressed from 10 to 20 per set for the first six weeks and then reduced to 15 reps per set for the remaining 14 weeks. The exercises selected were bench press, knee extension, hamstring curl, biceps curl, triceps dip, leg press, sit-up, shoulder press, latissimus pull down and upright row. The running group performed jogging (with some walking) for 3 days/week for 30 minutes, which was maintained at 85% maximum HR range in each session. Study results showed that CWT did not elicit significant improvements in $\dot{V}O_{2max}$, which was consistent with the findings of Wilmore and colleagues (28) for males. There were no significant differences between the CWT and control group for lean body weight or fat mass. However, CWT participants experienced a significant increase in leg press strength (30.2%), $\dot{V}O_{2max}$ (2.9%), and treadmill time to exhaustion (8.9%) compared to the control group. Running group participants saw significant improvements from pre- to post-test in $\dot{V}O_{2max}$ (12.7%), treadmill time to exhaustion (28.9%), fat mass (-14.1%), leg press strength (26.1%) and bench press strength (12.7%). However, only $\dot{V}O_{2max}$ and treadmill time to exhaustion in the running group were significantly greater than the CWT group at the post-test.

Gettman, et al. (12) compared the difference in physiological effects of adding running to a CWT program. The researchers designed a study assessing three different exercise programs over a 12-week training period: CWT with running (RUN-CWT), CWT, and a control. The running was performed for 30 s at an intensity of 60% HR_{max} immediately after each CWT station. A submaximal Bruce protocol test was performed to estimate HR_{max}. Circuit training was performed for 3 days/week using the following exercises: squat, shoulder press, hamstring curl, bench press, leg press, biceps curl, back extension, triceps extension, sit-up, and lateral shoulder raise. Three sets of 12 to 15 repetitions at 40% 1-RM were performed for each exercise. Interestingly, results showed no significant differences between the RUN-CWT and CWT groups for treadmill performance time, $\dot{V}O_{2max}$, and maximum oxygen pulse. Women from the RUN-CWT and CWT groups experienced significant improvements in treadmill time to exhaustion (1.4% and 1.0%, respectively), $\dot{V}O_{2max}$ (5.2% and 4.4%, respectively), O_2 Pulse max (1.4% and 1.1%, respectively), lean body weight (1.0% and 1.9%, respectively), bench press strength (6.0% and 6.0%, respectively) and leg press strength (27.0% and 20.0%, respectively) form pre- to post-test. Women in the CWT group experienced a significant increase in lean body weight (1.9%) compared to the females in the RUN-CWT group (1.0%). Men from the RUN-CWT and CWT groups also experienced significant improvements in treadmill time to exhaustion (1.5% and 1.0%, respectively), $\dot{V}O_{2max}$ (6.6% and 4.8%, respectively), O_2 Pulse max (3.8% and 2.4%, respectively), lean body weight (1.8% and 1.8%, respectively), bench press strength (14.0% and 9.0%, respectively) and leg press strength (41.0% and 31.0%, respectively) from pre- to post-test. Gettman and colleagues concluded that both RUN-CWT and CWT were similarly effective programs for improving aerobic power, muscular strength and body composition.

In order to determine the effects of combined aerobic training and circuit weight training in females, Mosher et al. (23) used a similar design to the Gettman et al. (12) study. Thirty-three college-aged women (age = 20.6 ±1.4 yr) were split into two groups, an aerobic CWT (n = 17) and a non-exercise control group. The aerobic CWT group performed five different modes of aerobic activity three days per week for 12 weeks. The circuit lasted 45 minutes, incorporating 30 activities involving five aerobic stations (treadmill, bicycle ergometer, rowing ergometer, stair climbing, Airdyne bicycle) along with 25 callisthenic or weight training (Station1: twist crunches, leg flexion, shoulder press, agility shuffle and squat thrusts; Station 2: V-sit crunches, mountain climbers, back latissimus pull down, jumping jacks, hip flexors; Station 3: bicycle crunches, 2-feet hops, bench press, step bench, pushups; Station 4: chair crunches, straddle mountain climbers, front latissimus pull down, leg extension, overhead press; Station 5: straddle crunch, leg press, chest row, flutter kicks, flys) stations. Exercise intensity for the aerobic exercise was maintained at 75 to 85% of HR_{max}, determined by a graded exercise test, and the intensity for CWT exercise was between 40 - 50% of each subject's 1-RM. Mosher et al. implemented 3 minute aerobic bouts on five different pieces of cardio equipment interspersed between five 30 s exercise stations. Significant improvements in both $\dot{V}O_{2max}$ (18.2%) and treadmill time to exhaustion (8.0%) occurred in the CWT group. Improvements in muscular strength as were seen in the bench press (20.7%), shoulder press (16.4%), latissimus pull down (13.9%), leg press (22.6%), knee extension (27.1%) and hamstring curl (22.6%). In addition, abdominal endurance improved by 44.5% following the 12-week training program. A key finding from this study was that the CWT protocol elicited improvements in maximal aerobic power as well as muscular strength and endurance in college-aged women.

Alcaraz and colleagues (1) were the first and, to date, are the only researchers to examine the training adaptations between high-intensity circuit training (HICT) and traditional strength training during an 8-week study with 33 healthy men (22.5 ±3.5 yr). Alcaraz et al. defined HICT as the integration of heavy loads (>70% 1-RM) into a CWT format, rather than the typical light loads used in CWT (40 – 60% 1-RM). Two circuits of three exercises each were employed during the study. The volume during the study progressed from 3 sets for each exercise in the first week to 6 sets in the eighth week. Each exercise was performed for 6 repetitions at 85-90% 1-RM (or 100% 6-RM). The first circuit consisted of the following exercises: knee flexion, bench press and ankle extension. The second circuit used latissimus dorsi pull down, squat, and biceps curl. Each exercise was followed by 35 s of rest, and the two circuits were separated by 5 minutes of rest. Participants in the traditional strength training group completed the same exercises for the same volume but did so in a traditional weight training format (completing all sets for one exercise before moving on to the next exercise with 3-min rest between sets). Significant improvements in strength for both the bench press (~13.6%) and squat exercise (~20.0%) occurred in the HICT group, and did not significantly differ from the traditional strength training group (~20.0% and ~21.0% respectively). Furthermore, bench press peak power at 80% of 1-RM was also significantly greater in the post-test compared to pre-test values for the HICT group (10.3%) and did not significantly differ from the traditional strength training group (13.6%). Participants in the HICT group had a significant 1.5 decrease in %-body fat (-8.1%) and a significant increase in lean mass (2.5%). However, participants only had a significant increase in lean mass (2.1%) but did not have a significant decrease in %-body fat.

Shortly following the Alcaraz et al. (1) study, Paoli and colleagues (24) examined physiological adaptations following 12 weeks of HICT, low-intensity circuit training (LICT) and endurance training (ET) in middle-aged overweight men. The researchers recruited 58 participants (61 ±3.3 yr) for the study and were split into one of the three previously stated groups (n = 19, n = 19, n = 20, respectively). The variables examined during the study were body composition (fat mass and lean body mass), blood pressure (systolic and diastolic [DBP]), cholesterol (total, low-density lipoproteins [LDL-c], high-density lipoproteins [HDL-c]), and triglycerides. Participants in the ET group performed aerobic exercise on a cycle ergometer 3 days/week for 40-50 minutes per session at 50% heart rate reserve (HRR). Participants in the LICT group performed 8 min of aerobic exercise on the cycle ergometer at 50% HRR, followed by a circuit style resistance training routine for 3 circuits of four exercises (latissimus pull down, chest press, lateral shoulder raise and leg press) at 15 repetition maximum. Sixty seconds of rest were given between circuit exercises. Participants in the HICT group also performed aerobic exercise on the cycle ergometer, but performed two bouts of 1 minute at 75% HRR and 3 min at 50% HRR. Following the cycle ergometer, the same circuit format was performed; however, unlike the LICT, the HICT performed a “Rest-Pause” lifting style, where participants utilized a 6 RM load for each exercise. The exercise was performed for 6 repetitions at the 6 RM, paused for 20 sec, performed 2 more repetitions at the 6 RM, paused for 20 s and performed 1-2 repetitions at the 6 RM. Results demonstrated significant improvements in the HICT group compared to the LICT and ET groups for all of the following variables: fat mass (-17.5%), lean body mass (4%), DBP (-7%), total cholesterol (-9.5%), HDL-cholesterol (10%), LDL-cholesterol (-16%) and triglycerides (-15%).

A more recent study investigating the adaptations to HICT demonstrated improvements in blood profiles and body composition following as little as 4 weeks of exercise (20). Miller and colleagues recruited 8 obese men (34 ±12.1 yr) to participate in a 4-week HICT program that met three days/week using the following seven exercises: squat, bench press, partial curl-up, dead lift, burpee, bent over row and shoulder press. Exercise loads were selected to allow for 8 to 12 repetitions with minimal rest between exercises and progressed or modified according to this repetition range. Each exercise session lasted for approximately 30 minutes. The following variables were analyzed pre- and post-training: resting HR, systolic and diastolic blood pressure, total cholesterol, triglycerides, HDL-c, LDL-c, blood glucose and insulin, insulin resistance, beta cell function, %-body fat and lean body mass. Following the 4-week HICT program, participants saw significant improvements in in cardiovascular variables such as resting HR (-16.0%) and systolic blood pressure (-5.5%). Participants also demonstrated significant improvements in %-body fat (-1.6% from baseline) but did not significantly increase lean body mass. Fasting blood cholesterol (-10%) and circulating triacylglycerol (-22.4%) also exhibited significant improvements and there were trends for significant improvements in blood insulin (-19.1%; $p = .06$), insulin resistance (-18.9%; $p = .07$) and beta cell function (-18.2%; $p = .06$). This is the first and only study that examined the physiological effects of HICT in an obese population; however, it is important to note that all participants were free of any chronic disease.

In review, although the same improvements in aerobic power are not experienced during CWT as aerobic training, it should be noted that most studies have demonstrated a significant improvement in aerobic power following CWT (11-12, 23). An exception to these findings come from Wilmore and colleagues (28), who did not show significant improvements in $\dot{V}O_{2max}$ in men, but did in women, following a 10-week CWT study.

Improvements in aerobic power tend to be greater when integrating CWT with aerobic exercise stations (between exercises or circuits) (12, 23), which is consistent with studies comparing acute aerobic responses ($\dot{V}O_2$ and HR) between traditional CWT and combined CWT and aerobic exercise (21, 25). Other cardiovascular variables, such as resting HR and blood pressure have also been shown to improvement following HICT in as little as 4 weeks (1, 20). All studies assessing CWT have shown improvements in muscular strength and endurance (11-12, 23, 29) in the general population. Improvements in body composition (increases in lean body mass and decreases in fat mass) in women (23, 28) and men (11, 20) have also been shown following CWT. Furthermore, HICT appears to be the most time efficient way of improving physiological variables (DBP, total cholesterol, HDL-c, LDL-c and triglycerides) associated with risk for cardiovascular disease (24).

---Insert **TABLE 1** about here---

3 Clinical Populations

3.1 Acute Cardiopulmonary Function, Muscular Fitness and Safety Outcomes

Butler et al. (6) examined the CV function and safety in response to an acute bout of CWT in 13 men (57 ±10 yr) with cardiac disease. A crossover design was used to compare the effect of CWT on CV responses to that of walking on a treadmill. Heart rate, blood pressure (BP), and echocardiogram (echo) inspecting segmental left ventricular wall motion were examined. Left ventricular lateral wall motion is associated with ischemia during exercise, thus detriments to the left ventricular lateral wall motion would be indicative of contraindicated exercise. Participants performed two circuits of eight exercises (chest fly, lateral shoulder raise, biceps curl, shoulder press, upright row, chest press, latissimus pull down, triceps extension) for ten repetitions between 40% and 60% 1-RM, with 60 s of rest between exercises. The CWT protocol was compared to 35 minutes of continuous treadmill exercise at 85% HR_{max}. No differences were found for HR between the CWT protocol (33 ±4 $b \cdot min^{-1}$ increase from rest) and the treadmill exercise (39 ±3 $b \cdot min^{-1}$ increase from rest), and there was a higher systolic BP response during the treadmill exercise (149 ±6 mmHg; 37 mmHg increase from rest) compared to the CWT protocol (127 ±6 mmHg; 7 mmHg increase from rest). There was a positive and significant improvement in lateral wall motion during CWT compared to treadmill exercise. Butler and colleagues suggest that CWT may be less demanding on left ventricular myocardial oxygen consumption compared to aerobic exercise performed at 85% HR_{max}. Moreover, no new area of wall-motion abnormalities developed during circuit weight training. However, four left ventricular segments in two patients developed a new wall-motion abnormality during aerobic exercise. Butler et al. concluded that CWT is a safe form of training for patients with cardiac disease.

In another effort to determine the safety of CWT in cardiac patients, DeGroot and colleagues (7, 8) compared two work-to-rest ratios with two intensities; 30s work interval at 40% 1-RM with 30 s of rest; 30s work interval at 40% 1-RM with 60 s of rest; 30 s work interval at 60% 1-RM with 30 s of rest; and a 30 s work interval at 60% 1-RM with 60 s of rest were used to determine the optimal workload in 9 cardiac patients (63 ±7.5 yr) following an acute bout of CWT. Using the same sample, the researchers examined the following variables (which were published in two different studies): energy expenditure, blood lactate and heart rate response. Results showed much lower energy cost (2.98-3.81 kcal·min^{-1}) compared to the previous study by Wilmore et al. (28) who reported an energy cost of ~6.0-9.0 kcal·min^{-1}. This was expected, since cardiac rehabilitation patients start at much lighter resistance exercise loads compared to those general population samples used in previous studies. Furthermore, participants in the DeGroot et al. study had a higher mean age (63.3 yr) compared to all other studies previously cited. Energy expenditure during resistance exercise tends to decrease as we age and can explain the lower energy cost reported during the current study (18). Also, DeGroot and colleagues only had patients perform six exercises (bench press, latissimus pull down, shoulder press, hamstring curl, triceps extension and knee extension) while Wilmore et al. (28) had participants perform 10 exercises. Blood lactate response to the protocols was significantly elevated when using 60% 1-RM (mean [bLa] = ~7.5 mmol·L^{-1}) as compared to 40% 1-RM (mean [bLa] = ~4.7 mmol·L^{-1}). Blood lactate was also significantly greater following 40% 1-RM with 30 s rest (mean [bLa] = ~5.5 mmol·L^{-1}) compared to 40% 1-RM with 60 s rest (mean [bLa] = ~4.5 mmol·L^{-1}). There was no significant difference in mean [bLa] between the 60% 1-RM with 30 s of rest and 60% 1-RM with 60 s of rest protocols (8). The levels of mean [bLa] for all protocols ranged from 4.20 to 8.45 mmol·L^{-1}, and the researchers verified these [bLa] levels to be safe in regard to corresponding exercise intensity for cardiac patients performing CWT.

Though not many acute research studies using acute exercise have been done to assess the safety of CWT in clinical patients (6-8), all have determined that loads between 40-60% 1-RM are safe for cardiac rehabilitation patients. These loads are in conjunction with rest intervals between 30 and 60 s, as well as using between six to eight exercises for the circuit. Butler and colleagues (6) also hypothesized that CWT may be more effective for improving lateral wall motion compared to aerobic exercise performed at similar intensities. Energy expenditure is much lower in cardiac rehabilitation patients; however, the main goal of implementing CWT in this population is to improve overall physical fitness (muscular strength, aerobic capacity), making caloric expenditure a secondary concern.

3.2 Chronic Cardiopulmonary Function, Muscular Fitness, Body Composition, Health and Safety Outcomes

Harris and Holly (15) performed a CWT training study in 26 pre-hypertensive males (mean age = 32.1 yr). Ten participants were randomly assigned to the exercise (CWT) group and 16 were assigned to a non-exercise control group. Participants performed CWT 3 days/week for 9 weeks using three groups of exercises: Group 1: biceps curl, triceps extension; Group 2: bench press, abdominal curl, latissimus dorsi pull down, seated back row; Group 3: knee extension, leg press, hamstring curl, calf raise. Exercises were performed for 3 sets of 20 to 25 repetitions at 40% 1-RM. Following 9 wks of CWT, participants improved 1-RM in bench press (12.3%), leg press (53.0%) and increased lean body mass (2.2%). Participants also displayed an increase in $\dot{V}O_{2max}$ during maximal arm ergometry (7.8%). Additionally, volunteers demonstrated a significant decrease in diastolic blood pressure (-4.7%). All outcome measures were significantly improved from pre- to post-test as well as significantly different from the non-exercise control.

Kelemen et al. (17) observed improvements in cardiovascular endurance similar to those found by Harris and Holly (15) following a CWT program in 43 males (55 ±8.5 yr) with known coronary artery disease between the ages of 35 and 70 yr. Patients were randomly assigned to either a CWT (n = 20) or control group (n = 23). Control group patients engaged in a walk/jog mixed with volleyball program, while patients in the CWT group performed the same walk/jog program with CWT. Safety between the two programs was determined by any complications that took place while participating in the study. The CWT program was performed for 3 days/week for 10 weeks and utilized the following exercises: vertical chest fly, biceps curl, shoulder press, high pulley row, low pulley row, bench press, hamstring curl, knee extension, sit-up and leg raises. Each exercise was performed for 2 sets of 10 to 15 repetitions at 40% 1-RM. The walk/jog program was performed after the CWT program (or after volleyball for the control group) at 85% HRmax as determined by a graded exercise test (GXT) on a treadmill. Following the training participants demonstrated improvements in aerobic function (10.8%) based on a timed treadmill walking test, as well as a decrease in body fat (-7.2%). Improvements in strength for chest fly (26.9%), shoulder press (17.0%), hamstring curl (27.0%), knee extension (52.0%), low pulley row (26.6%) and bench press (6.0%) were also observed. The walk/jog combined with volleyball group saw significant improvements in leg curl (19.0%) strength, 0.5% decrease in body fat (-2.3%) and handgrip (1.1%) strength. There was no difference in complications due to exercise for participants in the walk/jog and volleyball nor the CWT group. It was concluded that CWT was a safe and effective intervention in cardiac rehabilitation programs and superior to a walk/jog combined with volleyball program.

Aerobic activity (treadmill running, rowing, cycling, stair climbing, combined arm/leg ergometry) and CWT were used to determine the effectiveness of combining these modalities on cardiorespiratory fitness, body composition, muscular strength, glucose regulation and lipid/cholesterol levels in a group of 10 males with insulin-dependent diabetes mellitus (IDDM) (22) and 11 gender-matched, non-diabetic (ND) controls. Participants trained for 12 weeks using a circuit-style format, five stations with five strength exercises (using 25 different upper and lower body resistance training exercises), and each circuit was preceded with a 3 minute aerobic bout. The researchers reported the IDDM males had significant increases in lean body mass (3.5%), VO_2max (10.5%), average overall muscular strength (23.6%), and HDL-cholesterol levels (11.9%). Significant decreases were reported for fat mass (-5.2%), fasting blood glucose (-5.7%), LDL-cholesterol (-12.1%) and hemoglobin A_{1c} (12.4%), a marker for glycemic regulation. Participants in the ND group demonstrated similar improvements in maximal aerobic capacity (12.0%) and overall muscular strength (23.2%), but did not experience significant improvements in the blood marker variables except for HDL-cholesterol (13.5%). The key finding from this study was that the combined aerobic and strength training circuit style program elicited similar improvements in fitness and greater improvements in glycemic control compared to a ND group performing the same exercise protocol.

Dunstan and colleagues (9) examined the effects of an 8-week CWT program with participants with non-insulin-dependent diabetes mellitus (NIDDM) compared to a non-exercise control group (50.7 ±2.1 yr). Unlike the Mosher et al. (21) study that used apparently healthy participants as a non-exercise control, Dunstan and colleagues used participants with NIDDM as the control (n = 10) to better match the CWT (n = 11) group. Participants performed exercise three non-consecutive days per week for 60 minutes per day using the following 10 exercises: leg extension, bench press, leg curl, dumbbell biceps curl, behind neck pull down, calf raise, dumbbell overhead press, seated row, triceps extension, and abdominal curls. Exercises were performed between 50 and 55% 1-RM for two sets for the first two weeks and three sets for weeks 3 through 8. All participants performed pre- and post- anthropometric measurements, blood pressure, self-blood glucose monitoring (SBGM) and blood analysis (serum glucose, insulin, and hemoglobin A_{1C}). There was no change in mean serum glucose and insulin from baseline in both groups; however, there was a significant increase in total serum insulin area under the OGTT curve from baseline to post-intervention for the non-exercise control group compared to the CWT group (exact values not provided). There was a relative decrease in total serum glucose are under the OGTT curve from baseline to post-intervention for the CWT group compared to an increase in the non-exercise control group (exact values not provided). Self-monitored blood glucose showed a relative maintenance in the CWT group while the non-exercise control experienced a significant increase in SMBG following the 8-week intervention. The results of the study demonstrated that CWT has merit as a suitable form of exercise for the management of NIDDM. Although the findings did not demonstrate significant decreases in all blood analyses (mean serum glucose and insulin) it did negate any deterioration effects of NIDDM.

Ten years later, Kang and colleagues (16) determined that CWT improves glycemic control in females with a similar condition to the sample used by Dunstan and colleagues (9) (type 2 diabetes mellitus; T2DM). Fifteen (51.1 ±1 yr) postmenopausal women completed the 12-week study. Participants were randomized into two groups: walking exercise (WE) or CWT. Both groups performed the same quantity of exercise: 60 minutes, 3 days/week, for 12 weeks. The WE group walked at 60% of HRR while the CWT group combined stair climbing, stationary cycling and 5 resistance exercises (latissimus pull down, abdominal crunch, hamstring curl, knee extension, and biceps curl). All resistance exercises were performed for 3 sets of 12 repetitions and maintained 60% of HRR to match the WE group intensity. The following variables were analyzed pre- and post-exercise: body composition, VO_2max, hemoglobin A_{1C}, insulin, and glucose. Following the training, the CWT group showed a significant decrease in body weight (-2.6%), 2.1% decrease in body fat percentage (-7.7%), increase in muscle mass (7.0%) and an increase in VO_2max (7.9%). Participants in the WE group saw significant improvements in body weight (-2.8%) and a 1.0% decrease in body fat percentage (-3.3%); however, these values were significantly lower than the CWT group. Hemoglobin A_{1C} and fasting blood glucose significantly improved in the CWT group (-8.8% and -5.5%, respectively), while the WE group did not experience a significant change in these markers. However, resting blood insulin significantly improved in both groups, with the WE group (-60.2%) experiencing a more significant improvement compared to the CWT group (-17.9%). It is important to note that resting blood insulin was significantly higher in the WE group compared to the CWT group at baseline (17.04 and 13.45 $\mu U \cdot dl^{-1}$, respectively). Kang and colleagues demonstrated that CWT is suitable for improving blood glucose and insulin, as well as a lifestyle marker, such as hemoglobin A_{1C} after 12 weeks of training. Interestingly, insulin saw greater improvements following a walking program compared to CWT, but may have been due to higher baseline insulin values in the WE group.

Maiorana et al. (18) combined CWT with aerobic activity during an 8-week training study with 13 male (60 ±2 yr) patients suffering from chronic heart failure. Participants were randomized into either an 8-week exercise or non-exercise period. Following the 8 weeks, participants switched into the opposite condition. Participants performed CWT 3 days/week using the following exercises: leg press, left hip extension, right hip extension, chest exercises (not specified), shoulder flexion, seated abdominal crunch, and hamstring curl. Exercise intensity started at 55% 1-RM and increased to 65% 1-RM by week 4, while cycle ergometry and treadmill walking commenced at 60% peak HR and increased to 85% peak HR by week 6. Peak HR was determined by a submaximal GXT on a cycle ergometer. The combination of aerobic training (eight 45-sec bouts on a cycle or treadmill) and CWT (15 reps for 1 to 3 sets depending on tolerance) increased the aerobic response in terms of relative (11.4%) and absolute $\dot{V}O_{2max}$ (10.5%), as well as a significant decrease in HR response after exercising at 60 watts (-11.1%) and 80 watts (-10.7%) during the post-GXT starting at 20 watts and increasing 20 watts every 3 minutes.

Resistance training is essential for maintaining bone mineral density and bone mass especially in post-menopausal women. Thus, Brentano et al. (5) investigated the physiological adaptations to strength and CWT in 28 postmenopausal women (mean age not presented) with bone loss. Participants were divided into three groups; strength training (ST) (n=10), CWT, (n= 9), and control, (n=9). The CWT group performed 24 weeks of training for 3 days/week. Ten exercises (leg press, hip abduction, hip adduction, knee extension, chest fly, reverse fly, biceps curl, triceps extension, sit-up, low back extension) were performed for 2 to 3 sets of 10 to 20 repetitions at 45-60% 1-RM with little to no rest between exercises. The ST group performed the same exercises for 2 to 4 sets of 6 to 20 repetitions at 45-80% 1-RM with 2 minutes rest between sets. For both groups, a new 1-RM test was performed every 8 weeks and matched with the same relative intensity for the exercise. Both the ST and CWT groups improved in $\dot{V}O_{2max}$ (~20.0%), treadmill time to exhaustion (~20.0%) and dynamic upper-body (~30.0%) and lower-body (~35.0%) strength compared to the control. Neither group demonstrated a significant change in bone mineral density (BMD). Brentano and colleagues determined that both CWT and traditional ST improved both strength and cardiovascular fitness in post-menopausal women; however, BMD saw slightly greater improvements (non-significant) in the ST group and, therefore, CWT may not be the most suitable option for improving BMD.

In summary, the evidence suggests that CWT is an effective exercise strategy for combatting many clinical diseases (5, 9, 15-18, 22). Improvements such as decreases in DBP (15), insulin (16), hemoglobin A_{1C} (22), body weight and percent-body fat, as well as increases in functional capacity (5, 15-18, 22) and muscular strength and endurance are experienced in individuals with hypertension, IDDM, and a chronic heart condition following 8 to 12 weeks of CWT. However, eliciting improvements in BMD in post-menopausal women may be best with traditional ST and not CWT (5). Results from studies using participants with NIDDM/T2DM indicate that CWT seems to be a suitable intervention for combatting the negative side effects of the fastest growing disease in the world (9, 16).

---Insert **TABLE 2** about here---

4 Older Adult Populations

4.1 Cardiopulmonary Function, Muscular Fitness, Body Composition, Health and Performance Outcomes of CWT

The only CWT study to our knowledge to use healthy older adults (n=18, 8 men, 10 women; 68 ±5 yr) was done by Takeshima et al. (27). Participants were considered sedentary, but were free of signs and symptoms of disease, and were not taking medications for any cardiovascular, metabolic or pulmonary diseases. Each participant performed a stage GXT on a cycle ergometer in which metabolic gases, HR, RPE and blood lactate were collected every minute during the test. The training exercise protocol consisted of 12 30 s strength exercises integrated with 30 s of aerobic activity (marching with arm movements). Every 4 weeks the researchers progressively overloaded all resistance exercises (resistance dial between 1 and 6; set at “2” for weeks 0-4, “3” for weeks 5-8 and “4” for weeks 9-12) during the 12-week program. Participants in the exercise group were compared to a non-exercise control. Results showed no significant decreases in body mass for either the exercise or sedentary groups. There was a significant decrease in skinfold thickness (-16%) in the exercise group and a non-significant increase in the control group (6.16%). A significant-increase in HDL-cholesterol (10.9 $mg \cdot dL^{-1}$) was also found in the exercise group, but no differences were observed between groups for LDL-cholesterol. The older adults in the exercise group improved in aerobic capacity (29%) determined by $\dot{V}O_2$ at the lactate threshold, as well as peak $\dot{V}O_2$ (15%) during an exercise test.

Bocalini and colleagues (4) examined the effects of 12 weeks of CWT in 69 elderly (67.9 ±9 yr) women, 18 of which were obese as defined by a body mass index (BMI) greater than 30 $kg \cdot m^{-2}$. The participants were split into three distinct groups based on BMI: normal, overweight and obese. All groups had a training and control subgroup. Exercise sessions were performed for 50 minutes per day, three days per week. The following 12 exercises were used: knee flexion, front shoulder raise, lateral shoulder raise, straight-arm latissimus pull down, shoulder rotation, squat, biceps curl, triceps extension, calve raise, push-up, abdominal crunch and hip extension. All exercises were performed for 45 s with 40 s of rest between exercises and intensity was maintained at 70% of the target heart rate [as determined using the Karvonen equation: .70·(maximal HR – resting HR) + resting HR]. Results showed that participants taking part in training in the obesity group had the largest improvements from baseline in body weight (-8.0%), %-body fat (-20.7%), fat mass (-52.6%) and lean body mass (8.6%). Significant improvements also occurred in participants taking part in training in the overweight group for body weight (-4.5%), %-body fat (-10.0%) and fat mass (-15.0%); however, no significant improvements occurred in any anthropometric variables for the normal weight group. We can conclude that CWT is a viable option for decreasing body weight and %-body fat in overweight and obese elderly women, while eliciting improvements in lean body mass.

5 Conclusion and Future Directions

Circuit weight training is a time efficient and effective way of implementing RT programs into healthy and clinical populations. Research indicates that CWT is a safe and effective program for individuals with cardiac disease and other clinical disorders (e.g., hypertension, diabetes mellitus). Improvements in both strength and aerobic capacity ($\dot{V}O_{2max}$) are evident when the appropriate loads are used. Body composition improvements as observed with increases in lean mass and decreases in fat mass are also evident following CWT in general and clinical populations. In clinical populations meaningful decreases in resting blood pressure, heart rate and hemoglobin A_{1c} have been shown. The time efficiency in which results are attained following CWT are advantages as compared to traditional resistance training. Lastly, the ability to integrate various aerobic activities into CWT provides further improvements in markers of cardiovascular health. Although there has been some research investigating the acute response of the integration of CWT and HIIT (CWIT) (25), training studies examining the chronic adaptations between this CWIT and traditional CWT have yet to be performed. An integration of CWT and HIIT may be the most time efficient form of exercise to improve both muscular strength and aerobic capacity.

Practical Applications

The results of this review reveal that CWT is a sufficient means of eliciting an acute aerobic response while maintaining muscular strength, power and endurance. Training studies examining CWT have proven that these acute responses can lead to improvements in aerobic capacity and muscular strength and endurance. Furthermore, decreases in body fat and increases in lean body mass have also been shown following CWT. Utilizing rest periods as “aerobic” stations between circuit exercises may be the most effective way of improving aerobic capacity when implementing CWT into an exercise program.

Circuit weight training is safe for cardiac rehabilitation patients and has proven to be effective for improving blood pressure in borderline hypertensive patients and hemoglobin A_{1C} in individuals with insulin-dependent diabetic mellitus. More recent research in the area of high-intensity circuit training has also proven to be safe for individuals who are obese and have dyslipidemia. The progression of CWT leads to large improvements in total cholesterol, low-density lipoproteins, high-density lipoproteins and triglycerides, as well as improvements in body composition.

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Table 1. Chronic Physiological Benefits of Circuit Weight Training and High-Intensity Circuit Training for Healthy Populations

Investigator(s)	Measured Variable(s)	n	Age, years (mean ± SD)	%-Change
Blood Markers				
Miller et al. (2014)	Total cholesterol Triacylglycerol	8	34.3 ± 12.1	-10.0% -22.4%
Cardiovascular				
Wilmore et al. (1978)	Treadmill time to exhaustion $\dot{V}O_{2max}$	50	NR	23.8 – 24.2% 3.8% for women only
Gettman et al. (1978)	Treadmill time to exhaustion	41	29.7 ± NR	8.9% change
Gettman, Ward, and Hagan (1982)	Treadmill time to exhaustion $\dot{V}O_{2max}$ $MaxO_2Pulse$	77	35.9 ± 5.8	1.0 – 1.5% 4.4 – 6.6% 1.1 – 3.8%
Mosher et al. (1994)	Treadmill time to exhaustion $\dot{V}O_{2max}$	33	20.6 ± 1.4	8.0% 18.2%
Miller et al. (2014)	Resting heart rate Systolic blood pressure	8	34.3 ± 12.1	-16% -5.5%
Muscular Strength and Endurance				
Wilmore et al. (1978)	*Muscular strength*: Shoulder press Bench press Upright row Biceps curl Lat pull down Leg press Hamstring curl	50	NR	 6.9 – 8.8% 14.0% 6.1% 8.1% 10.6 – 20.5% 50.0% 5.6-21.8%
Gettman, Ward, and Hagan (1982)	*Muscular strength*: Bench Press Leg Press	77	35.9 ± 5.8	 6.0 – 14% 20.0 – 41.0%
Mosher et al. (1994)	*Muscular strength*: Bench Press Shoulder Press Lat Pull Down Leg Press Knee Extension Hamstring Curl *Muscular endurance:* Abdominal	33	20.6 ± 1.4	 20.7% 16.4% 13.9% 22.6% 27.1% 22.6% 44.5%
Flexibility				
Wilmore et al. (1978)	Sit-Reach Test	50	NR	1.1% for women only
Body Composition				
Wilmore et al. (1978)	Lean body mass Fat mass	50	NR	1.3 – 1.7% -1.8%
Gettman, Ward, and Hagan (1982)	Lean body mass	77	35.9 ± 5.8	1.8%
Miller et al. (2014)	Percent-body fat	8	34.3 ± 12.1	-1.6%

Abbreviations: Percent-Change from baseline (%-Change); Maximal oxygen consumption ($\dot{V}O_{2max}$); Maximal Oxygen Pulse ($MaxO_2Pulse$); Not Reported (NR)

Table 2. Chronic Physiological Benefits of Circuit Weight Training in Clinical Populations

Investigator(s)	Measured Variable(s)	*n*	Age, years (mean ± SD)	%-Change
Blood Markers				
Kang et al. 2009	HbA_{1C} Resting blood glucose Resting blood insulin	15	51.1 ± 1.0	-8.8% -5.5% -17.9%
Cardiovascular				
Harris and Holly (1987)	$\dot{V}O_{2max}$ Blood Pressure	26	32 ± 5.7	7.8% -4.7%
Kelemen et al. (1986)	Treadmill time to exhaustion	43	55 ± 8.5	10.8%
Maiorana et al. (2000)	$\dot{V}O_{2max}$	13	60 ± 2.0	11.4%
Brentano et al. (2008)	Treadmill time to exhaustion $\dot{V}O_{2max}$			20.0% 20.0%
Kang et al. 2009	$\dot{V}O_{2max}$	15	51.1 ± 1.0	7.9%
Muscular Strength and Endurance				
Harris and Holly (1987)	*Muscular Strength*: Bench Press Leg Press	26	32 ± 5.7	 12.3% 53.0%
Kelemen et al. (1986)	*Muscular Strength*: Bench Press Chest Fly Shoulder Press Hamstring Curl Knee Extension Low Pulley Row	43	55 ± 8.5	 6.0% 26.9% 17.0% 27.0% 52.0% 26.6%
Mosher et al. (1998)	*Muscular Strength*: MVC_7	10	17 ± 1.2	 23.6%
Brentano et al. (2008)	*Muscular Strength*: Upper-body Lower-body	28	NR	 ~30.0% ~35.0%
Body Composition				
Harris and Holly (1987)	Lean body mass	26	32 ± 5.7	2.2%
Kelemen et al. (1986)	Fat mass	43	55 ± 8.5	-7.2%
Mosher et al. (1998)	Lean body mass Fat mass	10	17 ± 1.2	3.5% -5.2%
Kang et al. (2009)	Body weight Percent-body fat Lean body mass	15	51.1 ± 1.0	-2.6% -7.7% 7.0%

Abbreviations: Percent-Change from baseline (%-Change); Maximal oxygen consumption ($\dot{V}O_{2max}$); Average of Seven Maximal Voluntary Contractions (MVC_7); Hemoglobin A_{1C} (HbA_{1C}); Not Reported (NR)

CHAPTER 3

This chapter presents a research manuscript, entitled "Responses to Two Weight Training Protocols—One with Integrated High-Intensity Interval Training". This manuscript is authored by Tony Nuñez, Fabiano Amorim, Nicholas Beltz, Christine Mermier, Terence Moriarty, Roberto Nava, Trisha VanDusseldorp and Len Kravitz. The manuscript follows the formatting and style guidelines of the Journal of Strength and Conditioning Research. References are provided at the end of the chapter. Figures and Tables are provided after the references.

Responses to Two Weight Training Protocols—One with Integrated High-Intensity Interval Training.

Tony P. Nuñez[1,2], Fabiano T. Amorim[1], Nicholas M. Beltz[1,3], Christine M. Mermier[1], Terence A. Moriarty[1], Roberto C. Nava[1], Trisha A. VanDusseldorp[4] and Len Kravitz[1]

[1]Department of Health, Exercise and Sports Sciences, University of New Mexico, Albuquerque, NM

[2]Department of Human Performance and Sport, Metropolitan State University, Denver, CO

[3]Department of Kinesiology, University of Wisconsin-Eau Claire, Eau Claire, WI

[4]Department of Exercise Science and Sport Management, Kennesaw State University, Kennesaw, GA

ABSTRACT

The purpose of this study was to examine the physiological effects (energy expenditure [EE], oxygen consumption [VO_2], heart rate [HR], blood lactate [BLa^-], blood pressure [BP] and excess post-exercise oxygen consumption [EPOC]) and perception (rating of perceived exertion [RPE] and enjoyment) of the sequence order of high-intensity interval (HIIT) with circuit weight training (CWT). Fourteen trained men (25.7 ±4.4 yr) completed two separate resistance exercise protocols matched for time and load. HIIT prior to CWT (CWIT) consisted of six HIIT bouts prior to three rounds of a nine exercise CWT protocol. Mini-CWT with integrated HIIT (TRIIT) consisted of three rounds of three mini-circuits consisting of three exercises with the integration of three HIIT bouts between the first and second mini-circuits and second and third mini-circuits. VO_2, HR and EE were monitored throughout the protocols, while EPOC, BLa^-, RPE and enjoyment were measured post-exercise. Mean values for CWIT and TRIIT were similar ($p>.05$) for VO_2, HR and RPE. EE was significantly higher during the CWIT compared to the TRIIT protocol ($p=.012$), as well as EPOC ($p=.034$). BLa^- was significantly higher at all post-exercise time points (immediately post, 5 min, 10 min and 20 min post-exercise) following the CWIT compared to the TRIIT protocol. Performing HIIT prior to CWT elicits higher metabolic perturbation compared to the integration HIIT with mini-circuits. CWIT also required greater energy requirements during and after the protocol compared to TRIIT. This may be useful for fitness trainers when determining how to implement HIIT into a CWT workout.

INTRODUCTION

Circuit weight training (CWT) has been a popular mode of exercise since its introduction to the fitness industry back in the late 1970s (1, 33). This method of resistance training exercise was created in an attempt to improve the time efficiency of strength training and in some cases, elicit a cardiovascular response while performing resistance exercise (23, 24, 32). Traditional strength training programs consists of resistance exercises performed one exercise at a time to failure or for a fixed number of sets and repetitions before moving on to the next exercise with 60 to 180 seconds (sec) of rest (19). In comparison, CWT is defined as a number of carefully selected exercises arranged consecutively and performed cyclically (29). The number of exercises often range from 6 to 12, typically performed for a specified amount of time (15 to 45 sec) or repetitions (8 to 20) with limited break between exercises (15 to 30 sec). Intensities ranging from 40% to 60% one-repetition maximum (1-RM) are selected for a majority of CWT protocols (12, 13, 33). Much evidence has been presented to demonstrating the overall effectiveness of this form of exercise for improvements in muscular strength and endurance, body composition in terms of both decreases in fat mass and increases in fat-free mass, cardiovascular fitness, and to a lesser extent, flexibility in healthy and clinical populations (7, 12, 23, 24, 32).

High-intensity interval training (HIIT) is a popular mode of training for healthy and clinical populations that has been shown to improve cardiorespiratory capacity and other cardiovascular markers in a time-saving manner and to a higher degree as compared to low- to moderate-intensity continuous training (15, 18, 30, 34). HIIT refers to alternating bouts of high-intensity work with low- to moderate-intensity recovery bouts during an exercise session (26). Exercisers perform a high intensity work bout between 8 sec to 6 minutes (min) with recovery bouts of varying length of time. Conceptually, HIIT allows the exerciser to perform a greater amount of work during a single session when the work periods are spaced with recovery intervals (21).

Skidmore and colleagues (28) were the first to analyze the integration of CWT with HIIT (CWIT) in the same exercise session and compared this mode of exercise to CWT with moderate aerobic interval training (ACWT) and CWT in isolation. However, since there was no difference between the CWT protocols, the comparison was seemingly between the integration of HIIT and moderate aerobic interval training during CWT. The researchers found that the CWIT elicited significantly higher blood lactate, heart rate and ratings of perceived exertion compared to both ACWT and traditional CWT.

The purpose of the current study is to examine the physiological effects (energy expenditure [EE], VO_2, heart rate [HR], blood lactate [BLa^-] and blood pressure [BP]) and perception (rating of perceived exertion [RPE] and enjoyment) of the integration of HIIT exercise with mini-CWT (three exercise cluster) and HIIT prior to conventional CWT (nine consecutive exercises). Since a similar question has yet to be studied, we had no rationale other than to hypothesize there would be no physiological or perception differences between the two protocol approaches.

METHODS

Experimental Approach to the Problem

Fourteen male volunteers served as their own control in a repeated-measure, counterbalanced crossover design, in which subjects performed both HIIT before CWT and a trial integrating HIIT with mini-CWT, separated by at least 72 hours. Trials were precisely equated for total working sets and recovery period durations comprising of 6 sets of 30-sec work followed by 90-sec recovery HIIT and 30-sec work (10 reps at 3-sec per rep) and 30-sec recovery CWT. Before the trials, participants also completed treadmill maximal oxygen consumption (VO_{2max}) and one-repetition maximum (1-RM) testing following established guidelines at the same time of day as the exercise protocols with the same research technician running all tests and trials. A paired t-test was used to analyze mean oxygen consumption (VO_2), heart rate (HR), excess post-exercise oxygen consumption (EPOC) and RPE, while a two-way analysis of variance (ANOVA) was used to assess blood lactate (BLa^-) and blood pressure (BP). A Wilcoxon signed-rank test was used to analyze enjoyment following both protocols. All data collection took place in the human performance laboratory under similar environmental conditions.

Participants

Fourteen college-aged males (age = 25.7 ±4.4 yr) taking part in resistance training at least two days per week and aerobic training at least three days per week for at least 6 months volunteered to participate in this study (see **Table 1**). Prior to beginning to the study, all participants completed a health history/exercise questionnaire to ensure they had no physical limitations and met the minimum requirements for exercise participation. None of the participants had a previous history of musculoskeletal injuries, cardiovascular or pulmonary disease or was on medications during the study. Subjects were fully informed about all testing and exercise protocol procedures and signed a written informed consent and HIPAA authorization prior to testing. The Institutional

Review Board at the University gave approval for the study. Participants were instructed to consume the same meal at the same time period prior to both trials.

Testing Procedures

All measurements were completed in the university human performance laboratory. Trials were performed in the following order: (1) VO_{2max} test, (2) 1-RM test, (3) protocol familiarization trial, (4) protocol A/B and (5) protocol B/A (opposite protocol from trial 4). Protocol A and B were counter-balanced so half of the subjects performed protocol A first and the other half performed protocol B first. The VO_{2max} test and 1-RM test were separated by at least 48 hours, 1-RM test and familiarization trial were separated by at least 24 hours and the familiarization trial and both exercise trials were separated by at least 72 hours. Participants were instructed to not participate in any moderate to vigorous exercise 24 hours prior to all trials.

Anthropometric Measurements

Each session took place in the same location under similar environmental conditions and at the same time of day (±2 hour). Height and weight were measured at the beginning of each session. Upon arrival for the first exercise testing trial, body density was estimated using a standardized three-site skinfold (Lange, Beta Technology, Ann Arbor, MI, USA) measured in duplicate (17). The same technician performed the skinfold measurements for all participants. Body fat was then calculated using the appropriate body density equation (27).

Exercise Testing and Screening

Prior to the exercise protocol trials, all participants performed a VO_2max test on a treadmill ergometer (C966i, Precor Inc., Woodinville, WA, USA) on the participant's initial visit (Visit 1; see figure below). The results of the VO_{2max} test determined if the participant was eligible for inclusion in the study (see **Table 1**). If the results determined that the participant was not eligible for the study (less than 'Good' cardiorespiratory fitness according to the ACSM guidelines based on the participant's age), the participant was excluded from any further trials. Max velocity (V_{max}) during the VO_{2max} test was used to determine the running speeds for the subsequent exercise protocols. All VO_{2max} tests were performed at a 3.0% grade (31).

After a minimum of 48 hours following the VO_{2max} test, participants returned to the exercise laboratory for one-repetition maximum testing (1-RM testing)(Visit 2). The following exercises required 1-RM testing for the exercise protocols: squat, bent over barbell row, trapezoid bar dead lift, dumbbell shoulder press, and latissimus pull down. All 1-RM testing followed standardized guidelines previously explained elsewhere (14). Exercise technique, range of motion and repetition duration (3 sec per repetition) were explained and monitored by the same researcher on all exercises for all participants. Repetition duration was cued using a metronome (SQ 50V, Seiko Instruments Inc., Shizuoka, JPN). The 1-RM testing was performed in the same order as the exercise protocols. The 1-RM loads were used to determine each subject's assigned loads during the exercise protocols (see **Table 2**).

Between two and seven days following 1-RM testing, participants returned for a familiarization trial (Visit 3). Two bouts of high-intensity interval training were performed, followed by a round of the CWT protocol. During the familiarization trial, the same researcher observed exercise form and execution to ensure all participants performed all movements with proper listing mechanics. The familiarization was done to ensure volunteers understood the sequence of the CWT protocol and felt comfortable with the exercise loads and sequence. Upon completion of the familiarization trial, participants were randomly assigned to start with one of the two exercise protocols: circuit weight high-intensity interval training (CWIT) or tri-set high-intensity interval training (TRIIT).

Exercise Protocols

CWIT

Upon arrival for the CWIT exercise session, participants were fitted with the mask ($K4b^2$) and HR monitor and one-minute of resting data were collected. During the CWIT protocol, participants performed a 3-min warm-up on the treadmill ergometer at 50% v-VO_2max using the same grade (3.0%) as the VO_2max test. At the end of the warm-up, the participant began the first of the six high-intensity intervals (HIIT). The 'work' portion of the intervals was performed at 105% V_{max} for 30-sec and the 'recovery' portion was performed at 3.0 mph for 90 seconds for all participants. The grade remained at 3.0% for the treadmill intervals. Once all intervals were completed, participants had a 15-sec transition from the treadmill to the first exercise of the circuit. The following exercises were used in the CWIT circuit performed in this order: Squat (Sq), Bent Over Barbell Row (Row), Plank, Dumbbell Shoulder Press (Press), Trap Bar Dead Lift (DL), Abdominal Crunch (Crunch), Kettlebell Sumo Squat (Sumo Sq), Latissimus Pull Down (LPD), and Low Back Extension (LBE). All externally loaded exercises (Sq, Row, Press, DL, Sumo Sq, LPD) were performed for 10 repetitions for 30-sec (3 sec per repetition guided using a metronome). These exercises were done at 50% 1-RM, with 30-sec of rest between exercises with the exception of Sumo Sq, which was performed using a fixed weight for all participants (16 kg) as previously recommended (10). The circuit was performed for 3 rounds with a 30-sec seated rest period between each circuit. The total exercise time (HIIT + CWT) lasted 43.25 min. Excess post-exercise oxygen consumption (EPOC) was collected immediately following the completion of the exercise protocol for 20-min while the participant was sitting quietly. Blood lactate was collected in duplicate immediately post, 5-min, 10-min and 20-min post-exercise, while BP was measured immediately post, 10-min and 20-min post-exercise.

TRIIT

The same exercises, loads, work and rest periods were used during the TRIIT protocol as the CWIT protocol. The TRIIT protocol began with the same warm-up as the CWIT protocol. Immediately following the warm-up, participants transitioned from the treadmill to the starting exercise of the first tri-set. Tri-sets were performed for three rounds (i.e., three mini circuit) and partitioned as follows: (1) Sq, Row, Plank; (2) DL, Press, Crunch; (3) Sumo Sq, LPD, LBE. Three high-intensity interval bouts were performed on the treadmill between the first and second tri-set and between the second and third tri-set. Participants were given 15-sec to transition to the treadmill from the tri-set area and from the treadmill back to the area where the exercises were performed. Total exercise time (Tri-set + HIIT) for the trial was 43.25 min. EPOC, [BLa^-] and BP were collected in the same timeframe and manner as the CWIT protocol.

Metabolic Gas & Heart Rate

Expired gases were continuously measured using breath-by-breath sampling ($K4b^2$, COSMED, Chicago, IL, USA) to obtain metabolic variables (VO_2, EPOC) for the following exercise trials: VO_{2max}, CWIT and TRIIT. The metabolic gas analyzer was calibrated prior to each exercise session in accordance with manufacturer guidelines. Heart rate was monitored continuously using a Polar HR monitor (Polar Electro Inc., Woodbury, NY, USA) which was integrated with the $K4b^2$ device. These HR data were downloaded following the exercise trials.

Ratings of Perceived Exertion & Enjoyment

At 20 min post-exercise for both trials (immediately following EPOC), subjects rated their perceived exertion ($RPE_{6\text{-}20}$)(5) and enjoyment using a physical activity enjoyment seven-point bipolar scale (PAES)(20). Previous literature has determined that a delay between the cessation of exercise and reporting of RPE leads to the most consistent responses (16).

Blood Pressure and Lactate

Blood pressure was measured pre-, immediate post- and 20-min post-exercise for both exercise protocols using a manual blood pressure monitor and stethoscope (Diagnostix 703, ADC, Hauppauge, NY, USA). Blood lactate concentration ([BLa-]) measurements (Lactate Plus, Nova Biomedical, Waltham, WA, USA) were collected pre-, immediate post- [IP], 5-min post-, 10-min post- and 20-min post-exercise. All [Bla^-] samples throughout the study were collected at the ear lobe and obtained in duplicate.

Statistical Analysis

All data are presented as mean ± *SD.* Paired student t-tests were performed to determine differences for average VO_2 and HR between the two protocols. Both VO_2 and HR were averaged over the whole trial. Oxygen consumption data were 11-breath averaged for EPOC. A two-way analysis of variance (ANOVA) with repeated measures was used to determine differences for BLa^- (2 x 5) and BP (2 x 4) between the two protocols for all time points. A Wilcoxon signed ranks test was used to determine differences for RPE and PAES between the protocols. Alpha-level was set to $p \leq 0.05$ for all statistical analyses. Data were analyzed using the statistical package SPSS (Version 20.0, Chicago, IL, USA).

RESULTS

BLa^-

The repeated measures (2 x 5) ANOVA denoted a significant difference between CWIT and TRIIT for BLa^- time, $F(4, 65)=4.619$, $p=.002$. CWIT had significantly higher BLa measurements for IP, 5-, 10- and 20-min post exercise compared to the TRIIT protocol (see **Figure 1**). A Post hoc t-test with a Bonferroni adjustment (alpha-level < 0.005) determined significance occurred between all time points within the TRIIT protocol and all time points in the CWIT protocol, except between the IP and 5-min post time points.

Energy Expenditure and EPOC

There was a significant difference for total energy expenditure (TEE) between the CWIT (mean=494, *SD*=44.82) and TRIIT (mean=475, SD=44.63) protocols; $t(13)=2.94$, $p=.012$. There was a significant difference for EPOC between the CWIT (mean=89.6 ±13.81 kcal) and TRIIT (mean=83.6 ±10.78 kcal) protocols; $t(13)=2.38$, $p=.034$.

VO_2, HR and BP

All mean and standard deviations for VO_2 and HR data can be found in **Table 3**. There was no difference for average VO_2 (VO_{2ave}), percent-VO_{2max} (%VO_{2max}), average HR (HR_{ave}) or percent-HR_{max} (%HR_{max}) between CWIT and TRIIT protocols. Further, there were no protocol by time differences for BP measurements.

RPE and PAES

No difference was found for RPE between protocols. According to the PAES responses, subjects found the CWIT protocol to be more interesting compared to the TRIIT protocol (Z=-2.121, p=0.34). There were no differences between protocols for any other PAES responses.

DISCUSSION

This is the first study design to examine how the implementation of HIIT into a CWT protocol affects VO_2, HR, EE, EPOC, BLa-, BP, RPE and enjoyment responses in well trained males. The main findings from the present study were that BLa^-, TEE and EPOC were higher for the CWIT protocol compared to the TRIIT protocol with both protocols being equated for load and time. Blood lactate measurement allows researchers to evaluate the immediate physiological effects of an exercise protocol (8). Thus, results from the current study indicate that performing HIIT prior to CWT elicits a higher exercise intensity compared to integrating HIIT into a clustered mini-CWT (or Tri-set) protocol. Furthermore, performing HIIT prior to CWT will elicit greater TEE compared to integration of HIIT into mini-CWT bouts.

Blood lactate is primarily used as a marker of exercise intensity. Matching both exercise protocols for time and intensity should led to similar BLa^- responses; however, this was not the case. Accumulation of BLa^- was significantly higher for all post-exercise time points following the CWIT protocol as compared to TRIIT program. This may have occurred due to the potential increased clearance of BLa^- during the integrated HIIT performed in the TRIIT protocol. During the TRIIT protocol, CWT was separated by HIIT, which allowed for the integration of active recovery periods (90 sec walking at 3%

incline) during the workout. These active recovery periods may have led to an improved BLa^- clearance rate during the TRIIT protocol. Previous research has shown that active recovery following high-intensity exercise improves BLa^- clearance compared to passive recovery (2, 22). Unlike the TRIIT protocol, the CWIT protocol consisted of CWT performed for 3 consecutive circuits with an additional 30 sec of passive recovery between circuits. This may have resulted in greater BLa^- accumulation and metabolic perturbation following the CWIT protocol.

Excess post-exercise oxygen consumption is also used as a marker of intensity following anaerobic exercise. EPOC is associated with returning the body back to a homeostatic state (e.g., repletion of muscular energy and decrease in body temperature) which includes the oxidation of BLa^- (6, 11). Since CWIT lead to higher post-exercise BLa^- it could be hypothesized that this would also lead to greater EPOC (28). This was the case in the current study, as the CWIT protocol had higher BLa- and EPOC responses compared to the TRIIT protocol. Although there is no previous research to characterize why this occurred, we hypothesize that the build-up of anaerobic by-products (i.e., BLa^-) following the CWIT protocol may have contributed to a greater EPOC response.

Exercise EE was not significantly different between the two protocols (p=.06) with slightly greater EE during CWIT (442 ±51.5 kcal) compared to TRIIT (421 ±41.2 kcal). Average energy expenditure was greater during both CWIT and TRIIT protocols (10.2 and 9.7 kcal/min, respectively) compared to results from previous resistance training studies (4, 19).

During the CWIT and TRIIT protocols, the percent of VO_2 reserve (%VO_2R) was 57.4% and 56.7%, respectively, while %HR_{max} was 78.5% and 78.4%, respectively.

These $\%VO_2R$ and $\%HR_{max}$ values are similar to those found in previous research evaluating CWT (13, 33). Interestingly, despite differences in BLa^-, TEE and EPOC, there was no difference in $\%VO_2R$ or $\%HR_{max}$ between the two protocols. Although both protocols were predominately anaerobic, the VO_2 and HR responses are indicative of a large cardiorespiratory response. These results suggest that both protocols are suitable exercise modalities for eliciting both an anaerobic and aerobic stimulus. Further research is needed to determine which would be more beneficial for improving markers of aerobic performance. Additionally, future research should also determine which protocol is more effective at improving muscular strength and endurance.

Research has determined that RPE is a suitable subjective measure of intensity during and following both resistance and aerobic exercise (9, 25). Participants in the current study reported the CWIT and TRIIT protocols to be similar in RPE (15.7 ±1.5 and 16.1 ±1.4, respectively), despite having significantly higher BLa-, EPOC and EE during the CWIT protocol. The similarity in RPE between protocols may have been due to both being equated for time and intensity. Both protocols were perceived to be in the 'hard' to 'very hard' range. According to Row and colleagues (25), approximate loads of 50% 1-RM should elicit RPE responses in the 'fairly light' category, while Day et al. (9) reported RPE responses in the 'moderate' to 'somewhat hard' category for similar % 1-RM intensities. However, both of these studies used single set lifts, unlike the multiple set circuit format used in the current study. Limited recovery periods mixed with bouts of HIIT may have led participants to rate the protocols as harder than in previous research. Skidmore and colleagues (28), who also collected session RPE during a mixed CWT and HIIT exercise protocol, reported RPE responses in the 'very hard' to 'maximal' range following 3 sets of integrated HIIT with mini-CWT (three exercises per circuit) for 13 reps at 90% of a 13-RM with 15 sec of rest between exercises.

We quantified ratings of perceived enjoyment using the PAES and observed that subjects perceived the CWIT protocol to be more ‘interesting’ than the TRIIT protocol. It is also important to note that both protocols were rated ‘enjoyable’ and ‘gratifying’ according to the PAES. Furthermore, we must acknowledge that the sample for the current study was an active population who had been taking part in both resistance and aerobic training. More research needs to be done to determine if individuals who are less active or currently sedentary would rate these type of protocols ‘enjoyable’ and ‘gratifying’. Bartlett and colleagues (3) found similar results when comparing HIIT to moderate-intensity continuous running, where individuals taking part in the HIIT more ‘enjoyable’ compared to the moderate-intensity continuous running. This was also a physically active sample and may have led to this positive rating of enjoyment.

In conclusion, the integration of HIIT into a CWT format leads to a significant increase BLa-, EPOC and EE that is indicative of high-intensity exercise. We also conclude that physically active individuals enjoy both the integration of HIIT with CWT and performing HIIT prior to CWT. Based on our findings, performing HIIT prior to CWT elicits higher BLa-, EPOC and EE compared to the integration of HIIT in between mini-CWT clusters. Performing HIIT prior to CWT leads to a larger anaerobic response during training and integrating HIIT may increase anaerobic by-product clearance during mini-CWT exercise protocols. Future research should determine if the integration of HIIT with CWT leads to a different training effect compared to performing HIIT prior to CWT.

PRACTICAL APPLICATION

We compared the physiological and perceptual responses of performing HIIT prior to CWT and integration of HIIT with CWT in active college-aged males. According to our results, CWIT may lead to greater metabolic perturbation, which is indicative of a high-intensity exercise format. Integration of HIIT with CWT lead to a lesser metabolic perturbation post-exercise and burned less calories during and after the exercise protocol compared to HIIT prior to CWT. Due to the higher EE and EPOC found during the CWIT protocol, this may be a preferred program for individuals looking to increase caloric expenditure and, potentially improve body composition in the long run. However, long-term trials still need to be carried out. Furthermore, both protocols were considered enjoyable based on a physical activity enjoyment scale.

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Table 1. Subject Characteristics (*n*=14)

Characteristic	Mean ±*SD*
Height (cm)	173.8 ±5.1
Weight (kg)	77.6 ±5.8
Age (yr)	25.7 ±4.4
Body fat (%)	10.6 ±3.7
VO_{2max}* (ml/kg/min)	47.6 ±4.3
Squat 1-RM* (kg)	134 ±18.5
BB Bent Over Row 1-RM (kg)	84 ±13.7
DB Shoulder Press 1-RM (kg)	29 ±5.6
Trap Bar Dead Lift 1-RM (kg)	157 ±22.7
Lat Pull Down 1-RM (kg)	123 ±21.4

*VO_{2max} = maximal oxygen consumption; 1-RM = one-repetition maximum; BB = barbell; DB = dumbbell

Table 2. Physiological measures of both exercise protocols.

Variable	CWIT		TRIIT	
	Mean ± *SD*		Mean ± *SD*	
VO_{2ave}	25.2 ±1.91		24.8 ±2.12	
$\%VO_{2max}$	53.1 ±4.03		52.5 ±4.96	
HR_{ave}	149.8 ±12.54		149.6 ±16.33	
$\%HR_{max}$	78.5 ±4.82		78.4 ±7.01	
	SBP	DBP	SBP	DBP
BP: Rest	119 ±6.3	79 ±9.1	120 ±8.9	79 ±7.9
BP: IP	130 ±18.6	79 ±14.9	129 ±14.6	81 ±14.6
BP: 10min	111 ±9.1	82 ±7.7	114 ±12.0	83 ±7.7
BP: 20min	108 ±12.1	81 ±8.8	110 ±11.5	82 ±7.4

*BP = blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure; IP = immediately post-exercise; 10min = 10 minutes post-exercise; 20min = 20 minutes post-exercise

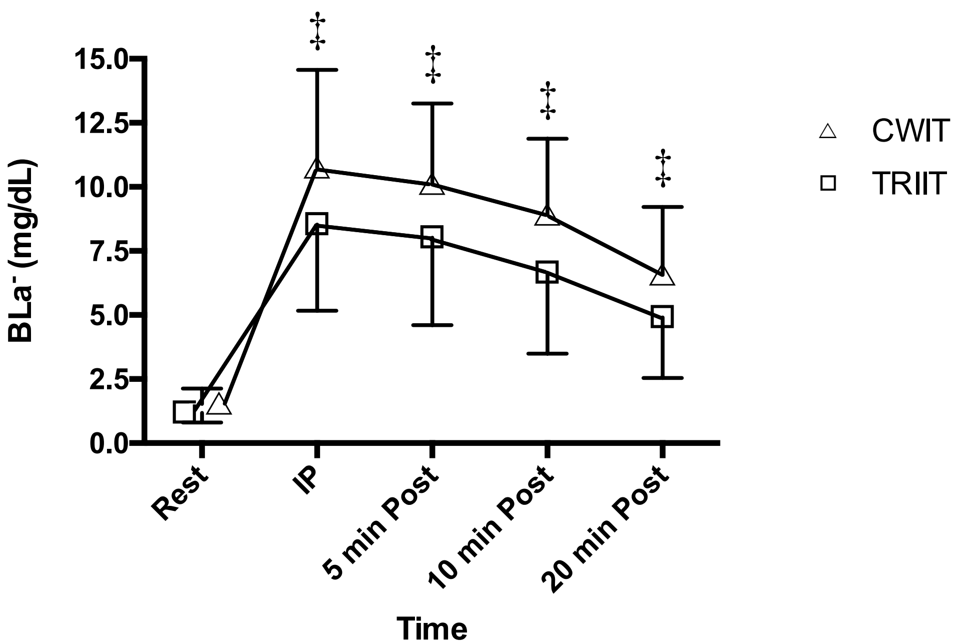

Figure 1. Blood lactate response between CWIT and TRIIT
*Blood lactate (BLa-); immediate post-exercise (IP); 5 minutes post-exercise (5 min Post); 10 minutes post-exercise (10 min Post); 20 minutes post-exercise (20 min Post); High-intensity interval training (HIIT) prior to circuit weight training (CWIT); Integrated HIIT with mini-CWT clusters; ‡ indicates a significant difference (*p*<.05) between protocol time points.

CHAPTER 4

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This research team was the first to examine physiological and metabolic differences between HIIT performed prior to traditional CWT (CWIT) and the integration of HIIT between three three-exercise mini-circuits (TRIIT) in a homogenous group of young, well-trained males. Specifically, we analyzed the following variables to look for differences between the two protocols: 1) average oxygen consumption (VO_2), 2) average heart rate (HR), 3) excess post-exercise oxygen consumption (EPOC), 4) energy expenditure during the exercise trial, 5) blood lactate responses following the exercise trial at immediate, 5-minute, 10-minute and 20-minute post-exercise, 6) blood pressure response following the exercise trials at immediate, 10-minute and 20-minute post-exercise, 7) rate pressure product following the exercise trials at immediate, 10-minute and 20-minute post-exercise, 8) rating of perceived exertion post-exercise, and 8) rating of enjoyment for each workout. The in-preparation review manuscript found in Chapter 2 entitled "Circuit Weight Training: Acute and Chronic Effects on Healthy and Clinical Populations" encompasses all relevant peer-reviewed literature to date examining the acute and chronic effects following CWT in both healthy and clinical populations. This paper demonstrates that responses following a combination of HIIT and CWT may differ depending on the structure of the exercise protocol.

The research manuscript entitled, “Responses to Two Weight Training Protocols—One with Integrated High-Intensity Interval Training” found in Chapter 3 provides evidence that CWIT may be a more physiologically taxing exercise protocol compared to TRIIT in college-aged, well-trained men. Furthermore, the higher energy expenditure during and EPOC following the CWIT protocol provides evidence-based information to trainers that this may be the preferred protocol for individuals wanting to improve body composition and increase caloric expenditure during and after workouts.

Not included in the Chapter 3 manuscript are the results for the rate pressure product responses. There was no difference between protocols for any of the exercise time points for rate pressure product. However, as expected, there was a significant increase in rate pressure product at the immediate post-exercise time point compared to all other post-exercise time points (Pre-exercise, 10 minutes and 20 minutes post-exercise).

Conclusions

The integration of HIIT into a CWT format leads to an increase in blood lactate, EPOC and energy expenditure similar to that of other high-intensity exercise protocols. We also conclude that our sample of physically active males enjoyed both the integration of HIIT with CWT and performing HIIT prior to CWT. Based on our findings, performing HIIT prior to CWT elicits higher blood lactate, EPOC and energy expenditure compared to the integration of HIIT in between mini-CWT clusters. Performing HIIT prior to CWT leads to a larger anaerobic response during training and, therefore, integrating HIIT between mini-CWT exercise protocols may increase anaerobic by-product clearance during mini-CWT exercise protocols. Oxygen consumption, HR and blood pressure did not differ between the two protocols; thus, cardiorespiratory and vascular responses should lead to similar improvements over time.

Recommendations

Several research questions and study ideas have prompted consideration of the following future investigations for study:

1) The current study had a sample of well-trained college-aged men; thus, future research studies could include these protocols with other homogenous samples (age, sex, fitness level, disease state).
2) Training studies examining the benefits of combining HIIT with CWT are needed to determine if there are different chronic adaptations between these protocols.
3) Differentiating between effects associated with traditional CWT and mini-CWT clusters following a training study would also be of interest given the current popularity of this type of programming in the fitness industry.
4) Examining the hypertrophic effect of CWT comparing every exercise performed to maximal voluntary contraction in a high repetition (low load) versus low repetition (high load) would be noteworthy.
5) Examining various peripheral heart action combinations of exercise in a CWT sequence has not been investigated and could open the door to new training applications.
6) Exploring HIIT integrated with CWT with some sport athletes, such as basketball and soccer players, may have some unique athletic performance applications.

APPENDICES

A. Informed Consent

B. Flyer

C. Health History Questionnaire

D. Data Collection Sheets

APPENDIX A.

Acute Responses to Two Weight Training Protocols
Consent to Participate in Research

01/18/2017

Purpose of the study: You are being asked to participate in a research study that is being done by Dr. Len Kravitz and Tony Nuñez, from the Department of Health, Exercise and Sports Sciences. The purpose of this study is to determine the exercise protocol that combines resistance and aerobic training that elicits the greatest caloric expenditure and intensity. You are being asked to take part in this study because you are a male between the ages of 18-45 years and take part in regular resistance training (≥2 days/week, 30 min/day, for at least 6 months) and aerobic training (≥3 days/week, 30 min/day, for at least 6 months). You must meet the criteria for “Good” to “Excellent” fitness based on your age, as well as be considered a healthy individual as determined by a health history questionnaire in order to participate in the study.

This form will explain what to expect when joining the research, as well as the possible risks and benefits of participation. If you have any questions, please ask one of the study researchers.

What you will do in the study:

- You will be asked to visit the Exercise Physiology Lab in Johnson Center at the University of New Mexico, Albuquerque, NM on five separate occasions. Please feel free to ask any questions at any time during the study.
- All visits will be separated by a minimum of 2 days and a maximum of 7 days with all visits completed within a 4-week timeframe.
- Prior to each visit, you will be asked not to perform any exercise 24 hours before the visit, not ingest any caffeine or alcohol 3 hours prior to the visit, and to consume at least 16 ounces of water as well as a small meal 2-3 hours before the visit.
- The first visit will take approximately 90 minutes, second visit will take approximately 75 minutes, third visit will take approximately 60 minutes and fourth and fifth visit will take approximately 90 minutes each.
- During your first visit you will be asked to do the following:
  - Sign this informed consent and a HIPAA form after getting all questions about the study answered.
  - Complete physical activity/health history questionnaire. You will be asked to fill out a questionnaire about your health and that of your immediate family relatives in order to screen for any issues that could cause additional risk to you by being part of the study.
  - Your height and weight will be measured, and percent-body fat will be estimated via skinfold (SKF) measurements. The SKF measurements are done using a skinfold caliper to measure a double layer of skin and underlying (subcutaneous) fat in three locations: chest, stomach and thigh. The sum of the SKF measurements is used to estimate body density (Db). The estimated Db is used to estimate percent-body fat.
  - You will then be asked to perform a maximal oxygen uptake test (VO_2max) on a treadmill for approximately 10 minutes. This test will require you to run on a treadmill with an increasing intensity (controlled by the researcher) until

you cannot continue. You will have a facemask on while performing the test to allow for collection of expired gases. Also, you will be fitted for a heart rate monitor chest strap in order to collect heart rate.
    - Upon completion of the maximal exercise protocol, the facemask will be removed and you will begin a cool-down on the treadmill walking at a speed that is comfortable for you.
    - The maximal speed that you reached during your VO_2max test will be used to determine your speeds for the interval training you will perform during the exercise trials.
- <u>During your second visit the following will occur:</u>
    - Complete one-repetition maximum (1-RM) muscular strength tests for the following 5 exercises in the listed order: squat, bent over barbell row, dead lift, shoulder press and lat pull down.
    - You will be asked to perform 1-RM tests in the following format: for the first set select a light load that is comfortable for 10-12 repetitions followed by a 1-min break; for the second set select a light to moderate load that is comfortable for 5-8 repetitions followed by a 2 min break; continue to decrease repetitions while increasing load until you can only perform one repetition at the given load. This should be achieved within 5 sets.
    - One-repetition maximums will be used to determine the weight used during the exercise trials.
- <u>During your third visit the following will occur:</u>
    - You will be asked to perform a familiarization protocol consisting of the high-intensity intervals and exercise protocols associated with the exercise trials on days 4 and 5. During the familiarization protocol, you will be asked to wear the same facemask used during the VO_2max test. This is to ensure you are comfortable performing the high-intensity intervals and the exercise protocol while wearing the facemask.
    - Only three bouts of high-intensity intervals will be performed (as opposed to 6 during the exercise trials) and one round of the exercise circuit (as opposed to 3 rounds during the exercise trials). No data will be collected during the familiarization trial and is designed for you to get a feel for how the exercise trials will be conducted.
- <u>During the fourth and fifth visit the following will occur:</u>
    - At visit 4- The exercise trial protocol (circuit or tri-set style) that you will be asked to perform will be randomly chosen for you by a flip of a coin.
    - At visit 5- You will perform the exercise trial protocol that was not done on visit 4. For example, if circuit style protocol was performed at visit 4 you will do the tri-set style protocol or vice versa.
    - Before the start of the warm-up, you will be re-familiarized with the procedures of the exercise protocol (including high-intensity intervals and exercise style).
    - Upon completion of the third circuit or third tri-set, you will be asked to sit in a chair while the researchers collect blood lactate. To do this the researcher will collect a drop of blood from your ear 5 times during each exercise protocol trial. This will occur before you begin to exercise, immediately after you finish exercising, 5-minutes post exercise, 10-minutes post exercise and 20-minutes post exercise.
    - During the circuit style protocol, a warm-up will begin on the treadmill at 50-55% of the max speed attained during the VO_2max test.

- Following the warm-up, you will perform 6 bouts of high-intensity intervals at the start of the protocol in the following format: 105% of the max speed that you reached during the VO_2max test for 30 sec, followed by walking at 3.0 mph for 90 sec.
- Immediately after the 6 high-intensity interval bouts, you will walk to the first exercise of the circuit protocol. The circuit will consist of 9 exercises performed for 3 rounds; all exercises using weight will be performed for 10 repetitions completed in 30 sec, while all unloaded exercises will be performed for 15 repetitions completed in 30 sec. All exercises will be followed by a 30 sec rest/transition period, where you will be asked to walk to the next exercise in the circuit. You will receive an extra 30 sec break between circuit rounds (totaling 60 sec of break between circuit rounds).
- During the tri-set style protocol, the same warm-up on the treadmill will be performed as the circuit style protocol. Following the warm-up, you will go directly to the first exercise of the first tri-set. The tri-sets will consist of three exercises performed sequentially until all exercises are performed for three sets. Tri-sets will be performed with the same weight for the same number of repetitions and within the same 30-sec time frame as the circuit style protocol. You will perform 3 bouts of high-intensity intervals between the first and second tri-sets and the second and third tri-sets. This will total up to the same number of high-intensity interval bouts (6) as the circuit style protocol.
- Upon completion of the last exercise of the third tri-set, you will be asked to sit in a chair while the researchers collect blood lactate in the same manner as described in the circuit style protocol.
- The facemask will remain on while you sit in the chair for the 20 minutes so the researchers can collect gases to analyze post-exercise oxygen consumption (EPOC). This will help the researchers completely quantify the amount of energy utilized during each exercise protocol trial.
- After the 20-minute EPOC, you will be asked to remove the facemask and provide the research team with a rating of perceived exertion (RPE) on a scale of 6-20 for the entirety of the trial.
- At visit 4 you will be asked to schedule your final visit in which you will perform the exercise protocol you did not complete on visit 4. Visit 5 will take place at least 2 days but no more than 7 days after the completion of visit 4.

Participation in this study will take a total of 6 hours and 45 minutes over a period of 5 days. Day 1 will last approximately 90 minutes, Day 2 approximately 75 minutes, Day 3 approximately 60 minutes, Day 4 and 5 approximately 90 minutes each.

- PLEASE NOTE: You may be excluded from the study if you do not meet the cardiorespiratory range of Good to Excellent fitness based on your age group. Please see “Right to withdraw from study” for more information on instances of why you may be withdrawn from the study by the investigators.

Risks: Risks of this research study may include loss of privacy, loss of confidentiality, and inconvenience. There are risks associated with maximal exercise testing including the following: brief feelings of nausea, lightheadedness, muscle cramps, or dizziness during or after completion of exercise. According to the American College of Sports Medicine (1), the risk of a cardiac event in normal healthy individuals during a maximal exercise test is minimal, 0.0006% (6 in 10,000). Experienced personnel will be monitoring heart rate throughout the test and will stop the test if abnormalities are detected. Termination of the exercise test will also occur if the participants ask or if there is a failure of the heart rate or gas monitoring systems. One-repetition maximum testing does incur a small risk among resistance trained individuals (2.4% chance of injury); however, risks are decreased when these 1-RM assessments are supervised by a certified personal fitness trainer. Muscle soreness, muscle strain and/or injury may occur during submaximal exercise. A certified personal trainer will be present to ensure injury during your safety during the exercise protocols.

There is a risk of discomfort when collecting capillary blood as well as a very small risk of infection. Sterile techniques and trained personnel will be used to limit this risk.

Benefits: There will be no direct benefits to the participants. However, it is hoped that information gained from this study will help us understand the best exercise format for integrating aerobic training. You will be given the results of your body fat and VO_2max testing at the end of your participation. Learning these new exercise routines may also help you add more time efficient workouts to your current exercise routine and may lead to improvements in muscular strength and overall fitness. Furthermore, information about your VO_2max and speed at VO_2max will help you better program aerobic exercise on a treadmill for continuous and high-intensity interval training.

Confidentiality of your information: All data will be kept under a lock and key in a filing cabinet located in Johnson Center B147A. There will be no subject identifiers on any data collection forms. Only a subject number will be used. A key matching your name to your participant number will be held in a locked cabinet located in Dr. Kravitz's office (Johnson Center 1160) for the purposes of contacting you for scheduling only. Only the investigators will be able to access your data. We will take measures to protect the security of all your personal information, but we cannot guarantee confidentiality of all study data. The University of New Mexico Institutional Review Board (IRB) that oversees human subject research may be permitted to access your records. Your name will not be used in any published reports about this study.

Payment: You will not be paid for participating in this study.

Right to withdraw from the study: Your participation in this study is completely voluntary. You have the right to choose not to participate or to withdraw your participation at any point in this study without penalty. Any data collected from individuals who withdraw from this study will be destroyed and not used for data analysis; however, your individual results will be available for your viewing prior to its disposal. Also, the investigators also reserve the right to stop the testing due to your discomfort, any abnormalities during exercise, your failure to comply with the exercise testing protocols, or if investigators feel it would be unsafe for you to continue. Instances of failure to comply with the exercise protocols, not completing trials within the allotted time (2-7 days between each), or repeated failure to adhere to exercise form guidelines that may put you at risk of injury. In these cases, the research team may withdraw you from the study. As mentioned previously, you must meet the VO_2max criteria for the study in order to move beyond the exercise testing portion.

If you have any questions, concerns, or complaints about the research study, please contact:

Len Kravitz, Department of Health, Exercise and Sports Sciences, MSC 04-2610, 1 University of New Mexico, Albuquerque, NM 87131.

(505) 277-5151. lkravitz@unm.edu

If you would like to speak with someone other than the research team or have questions regarding your rights as a research participant, please contact the IRB. The IRB is a group of people from UNM and the community who provide independent oversight of safety and ethical issues related to research involving people:

UNM Office of the IRB, (505) 277-2644, irbmaincampus@unm.edu. Website: http://irb.unm.edu/

CONSENT

You are making a decision whether to participate in this study. Your signature below indicates that you have read this form (or the form was read to you) and that all questions have been answered to your satisfaction. By signing this consent form, you are not waiving any of your legal rights as a research participant. A copy of this consent form will be provided to you.

I agree to participate in this study.

______________________________	______________________________
Name of Adult Participant	Signature of Adult Participant

Researcher Signature (to be completed at time of informed consent)

I have explained the research to the participant and answered all of his/her questions. I believe that he/she understands the information described in this consent form and freely consents to participate.

______________________________	______________________________
Name of Research Team Member	Signature of Research Team Member

APPENDIX B.

Participants needed for Research Study

Are you a male, who is a healthy, fit individual who partakes in resistance and aerobic exercise???

The exercise physiology lab will be assessing two exercise training protocols using high-intensity intervals and resistance exercises to determine their effect on caloric expenditure and other physiological responses. This study will involve five different laboratory visits, totaling approximately 7 hours of your time.

Participant requirements:

- 18-45 years old
- Males only
- Free of any illness/medical conditions
- At least 2 days/wk resistance training
- At least 3 days/wk aerobic training

If interested contact: Tony Nuñez tnunez12@unm.edu
Or Dr. Len Kravitz lkravitz@unm.edu

APPENDIX C.

HEALTH HISTORY QUESTIONNAIRE

Name______________________________ Date___/___/___ Phone
(H)____________(W)____________

Date of Birth ___/___/___ Age_________

Email ____

Address
(home)____
____
Street City State
Zip Code

♦♦

MEDICAL HISTORY

Physical injuries:
____

Limitations
____

____ Have you ever had cardiovascular problems? Y N

If YES, please explain:
____

Have you ever had any of the following? Please check all that apply.

Cancer (specify type) ______________________

High blood pressure ______________________

Asthma ______________________

Are you taking any medications, vitamins or dietary supplements now? Y N

If YES, what are they?
____

Are you allergic to latex: Y N

♦♦

LIFESTYLE FACTORS

Do you now or have you ever used tobacco? Y N If yes: type ________________

How long? ______ Quantity____/day Years since quitting______________

How often do you drink the following?

Caffeinated coffee, tea, or soda _______oz./day Hard liquor _______oz./wk. Wine _______oz./week

Beer _______oz./wk.

What do you do for physical activity/exercise now?

____ How often do you perform aerobic exercise? _______ How long per session? ____________________

How often do you perform resistance exercise? _______ How long per session?

____

Estimate your exercise intensity level or exercise heart rate

____

Indicate your current level of emotional stress. High____ Moderate ____ Low____

APPENDIX D.

VO2 Max Data Collection Sheet

Subject #: ____________________ Date: ____________________

Height (cm):__________ Weight (kg):__________ Age (yrs):__________

	Tricep/Chest	SI/Abd	Thigh	Total	BD	BF%
SKF 3 site	/	/	/			

Stage	Time	HR	RPE	Speed
Rest	0 - 1			
1	1 - 2			
2	2 - 3			
3	3 - 4			
4	4 - 5			
5	5 - 6			
6	6 - 7			
7	7 - 8			
8	8 - 9			
9	9 - 10			
10	10 - 11			
11	11 - 12			
12	12 - 13			
	13 - 14			
	14 - 15			
	15 - 16			

HR max (bpm): __________

VO2max (ml/kg/min): __________

Velocity at VO2max (mph): __________ **105%:** __________

50%: __________

One-Repetition Max Testing

Subject #: ____________________ Date: ____________________

Squat:	10-12	5-8	3-5	1-2	**50% 1-RM**	
weight:						(lbs)

Row:	10-12	5-8	3-5	1-2	**50% 1-RM**	
weight:						(lbs)

Sh Press	10-12	5-8	3-5	1-2	**50% 1-RM**	
weight:						(lbs)

Dead Lift	10-12	5-8	3-5	1-2	**50% 1-RM**	
weight:						(lbs)

LPD	10-12	5-8	3-5	1-2	**50% 1-RM**	
weight:						(lbs)

CWIT Data Sheet

Subject #: ________________________ Date: __________

Height (cm): __________ Weight (kg): __________

HIIT WU Speed: 50% __________ HI Speed: 105% __________ LI Speed: 3.0 mph

	1	**2**	**3**	**4**	**5**	**6**
HR (bpm)						

CWIT

	Squat	**Row**	**Plank**	**Sh Press**	**Dead Lift**
wt (lbs):			n/a		
	Crunch	**Sumo Sq**	**LPD**	**LBE**	**Rest**
wt (lbs):	n/a			n/a	
					+ 30 sec

Bla (mg/dl)

Pre: __________

IP: __________

5 min Post: __________

10 min Post: __________

20 min Post: __________

BP (mmHg)

Pre: __________

IP: __________

10 min Post: __________

20 min Post: __________

RPE (6-20)

20 min Post: __________

Polar EE (kcal)

20 min Post: __________

TRIIT Data Sheet

Subject #: ______________________ Date: __________

Height (cm):__________ Weight (kg):__________

WU Speed: 50% HI Speed: 105% LI Speed: 3.0 mph

	Squat	Row	Plank
wt (lbs):			n/a

HIIT	1	2	3
HR (bpm):			

	Sh Press	Dead Lift	Crunch
wt (lbs):			n/a

HIIT	4	5	6
HR (bpm):			

	Sumo Sq	LPD	LBE
wt (lbs):			n/a

Bla (mg/dl)

Pre: __________

IP: __________

5 min Post: __________

10 min Post: __________

20 min Post: __________

RPE (6-20): __________

BP (mmHg)

Pre: __________

IP: __________

10 min Post: __________

20 min Post: __________

Polar EE (kcal)

20 min Post: __________

Subject #: _________ **Physical Activity Enjoyment Survey** Date: _______________

I enjoy it	1	2	3	4	5	6	7	I hate it
I feel bored	1	2	3	4	5	6	7	I feel interested
I dislike it	1	2	3	4	5	6	7	I like it
I find it pleasurable	1	2	3	4	5	6	7	I don't find it pleasurable
I am very absorbed in this activity	1	2	3	4	5	6	7	I am not at all absorbed in this
Its not fun at all	1	2	3	4	5	6	7	It's a lot of fun
I find it energizing	1	2	3	4	5	6	7	I find it tiring
It makes me depressed	1	2	3	4	5	6	7	It makes me happy
It's very pleasant	1	2	3	4	5	6	7	It's very unpleasant
I feel good physically while doing it	1	2	3	4	5	6	7	I feel bad physically while doing it
Its very invigorating	1	2	3	4	5	6	7	It's not at all invigorating
I am very frustrated by it	1	2	3	4	5	6	7	I am not at all frustrated by it
It's very gratify	1	2	3	4	5	6	7	It's not at all gratifying
It's very exhilarating	1	2	3	4	5	6	7	It's not at all exhilarating
It's not at all stimulating	1	2	3	4	5	6	7	It's very stimulating
It gives me a strong sense of accomplishment	1	2	3	4	5	6	7	It doesn't give me a strong sense of accomplishment
It's very refreshing	1	2	3	4	5	6	7	It's not at all refreshing
I felt as though I would rather be doing something else	1	2	3	4	5	6	7	I felt as though there is nothing else I would rather be doing