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A metabolic profile of escalating density training

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A METABOLIC PROFILE OF ESCALATING DENSITY TRAINING

by

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ABSTRACT

Objective: The purpose of this study was to compare the acute physiological, perceptual, and enjoyment responses between a single bout of escalating density training (EDT) and traditional resistance training (TRAD).

Methods: Twelve physically active males (n = 6) and females (n = 6) (age: 21.4 ± 3.0 years; weight: 69.8 ± 7.9 kg; height: 172.9 ± 12.4 cm; maximal oxygen consumption (VO_2max): 44.7 ± 9.2 ml · kg^{-1} · min^{-1}) performed both EDT and TRAD. During the EDT trial, participants performed chest and leg press exercises in a cyclical fashion for 15 minutes with limited rest. For the TRAD trial, the same exercises were performed for sets of up to 8 repetitions until volume was matched from the EDT trial. Oxygen consumption (VO_2) and heart rate (HR) were measured before, during, and after exercise. Blood lactate (BLa) was measured pre- and post-exercise. Creatine kinase (CK) was

measured pre- and 48 hours post-exercise. Rating of perceived exertion (RPE), physical activity enjoyment (PACES), and oxygen consumption were measured post-exercise.
Results: Oxygen consumption relative to VO_2max was higher ($p < 0.001$) during EDT (56.2 ± 6.8%) compared to TRAD (23.7 ± 4.7%). Heart rate relative to HRmax was higher ($p = 0.021$) for EDT (78.9 ± 7.9%) compared to TRAD (53.0 ± 15.8%), $p = 0.021$. There was no significant difference in total exercise energy expenditure between EDT (929.2 ± 245.9 kJ) compared to TRAD (1267.7 ± 592.5 kJ), $p = 0.181$. Compared to TRAD, BLa was higher ($p < 0.05$) 5- and 10-min post-exercise for EDT. Creatine kinase was significantly greater ($p = 0.002$) following EDT (205.6 ± 111.2 IU/L) compared to TRAD. Average RPE achieved was higher ($p < 0.001$) during EDT (8.8 ± 0.8) compared to TRAD (5.5 ± 1.9). PACES was similar for EDT and TRAD ($p = 0.176$).
Conclusion: Our results indicate that EDT may be an effective alternative to TRAD for strength and cardiorespiratory adaptations. Future research should be done to investigate the long-term physiological adaptations to EDT.

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CHAPTER I: Introduction

Resistance training (RT), defined as a modality of exercise that involves the contraction of muscles against an external load, is a well-established effective method for developing muscular fitness (20). Health benefits associated with RT include increased resting metabolic rate, improved glucose metabolism, improved bone mineral density, decreased gastrointestinal transit time, and improved cardiorespiratory fitness (10, 34–36). Since RT may translate directly to athletic performance, RT programs are also an integral part of a total strength and conditioning program. For example, explosive muscular power and rate of force development are essential for performance in most sports, such as basketball, rugby, football, baseball, etc. (6). Furthermore, RT may be performed to improve aesthetics (i.e., bodybuilding) or reduce injury risk (i.e., strengthening of joints, muscles, tendons, bones, and ligaments) (7,10,21). The effectiveness of carefully planned RT programs as a method of improving aesthetics, overall health, and sports performance has been accepted on the basis of the scientific literature (4,11,21,32,33,35,38). If the proper systematic and scientific approach is applied, significant benefits (as previously mentioned) may be gained from RT programs. This approach is based on key RT characteristics such as volume, intensity, frequency, and exercise selection (4,36).

Typically, RT sessions are performed 2-4 times per week during which exercises of each major muscle group are targeted for 2-4 sets with 8-10 exercises for 3-12 repetitions with 2-5 minute inter-set rest intervals (RI) between each exercise (1). If a warm-up, stretching, and a cooldown are included, RT sessions may exceed an hour in length. Consequently, several time-saving techniques such as supersets (15,32), drop-sets (4,9), and circuits (13,14), are utilized by coaches, trainers, and practitioners. Of interest, superset training, performing two or more exercises in succession with an abbreviated or no RI (15,24), significantly decreases the time spent at rest, allowing for a greater density (amount of work performed within a given time period), than traditional RT (TRAD). Supersets can be performed using two exercises in an alternating fashion, targeting the same agonist muscle group (i.e., leg press and squat) or performing antagonistic muscle actions (i.e., bench press and barbell row) (24). This type of training leads to significantly higher training volume (31) and has been found to be more time-efficient than TRAD (8,31,37). Furthermore, physiological responses (i.e., blood lactate [BLa], creatine kinase [CK], heart rate [HR], oxygen consumption [VO_2], and excess post-exercise oxygen consumption) are significantly greater following a bout of superset RT compared to TRAD (19,27,29,37). Accordingly, these findings suggest that superset RT may be a time efficient alternative to TRAD.

Escalating density training (EDT), a relatively new, but popular form of superset training, was developed in order to increase muscular hypertrophy and enhance cardiovascular fitness in a time-efficient manner (34). Unlike TRAD, where volume load (sets x repetitions x weight) is manipulated, the primary variable manipulated with EDT is training density. Moreover, with EDT, alternating sets of two types of exercises (i.e., agonist-antagonist, or upper-lower) are performed for a pre-arranged number of repetitions per set (i.e., 5) for as many sets as possible within a given amount of time (i.e., 10 minutes) without predetermined RIs. As the workout progresses, the number of repetitions performed per set will decrease but the absolute external load (i.e., 150 lbs.) remains the same throughout. At the end of the workout, total density (i.e., number of repetitions within the given time) will be calculated. During a subsequent workout, the goal is to perform more work within the same time frame, thus increasing or escalating the density within the same time frame.

Currently, no evidence exists demonstrating the acute or chronic physiological responses following EDT. However, training styles that are similar to EDT have shown to elicit a physiological response that is favorable to cardiometabolic adaptations. For example, Weakley et al. demonstrated that superset RT resulted in greater metabolic stress (i.e., BLa) and muscle damage (i.e., CK) when compared to volume-matched TRAD in resistance-trained males (37). In another study, Realzola et al. found that performing supersets with antagonistic pairing resulted in a significantly higher BLa concentration, HR, VO_2, and ratings of perceived exertion (RPE) when compared to TRAD (29). These findings suggest an overall greater metabolic cost for superset training as compared to TRAD (29). Although speculative hypotheses can be made comparing these two similar techniques, research investigating the acute physiological responses to EDT is warranted.

Purpose of Study

The purpose of the current study was to compare the physiological (CK, VO_2, BLa, HR) and perceptual responses (enjoyment and RPE) of EDT compared to TRAD.

Hypotheses

The following hypotheses will be tested in this study:

Hypothesis 1: The EDT session will have a greater relative oxygen consumption compared to the volume-matched TRAD session.

Rationale: Decreased RI times between exercises have been shown to be a key contributor to cardiorespiratory responses during RT (19). Moreover, research suggests that when resistance exercises are performed in a super-setting fashion, oxygen consumption is greater for supersets when compared to volume-matched TRAD (19,29).

Hypothesis 2: Blood lactate concentrations will be significantly greater following EDT compared to TRAD.

Rationale: Previous research investigating superset RT has demonstrated increased BLa concentration, which implies that workouts with increased density are more metabolically demanding than TRAD (29,37). Moreover, the length of RI duration between sets directly affects phosphocreatine resynthesis, proton buffering, and removal of metabolic byproducts (i.e., blood lactate) (28).

Hypothesis 3: Average HR will be significantly higher for EDT compared to TRAD.

Rationale: Previous research suggests superset RT elicits a greater physiological stress (i.e., heart rate) compared to TRAD (29).

Hypothesis 4: Serum CK will be significantly greater following EDT compared TRAD.

Rationale: Skeletal muscle damage increases circulating CK within the blood (3). Previous research has shown that superset RT elicits greater muscular damage and is more likely to increase CK compared to TRAD (37).

Hypothesis 5: Ratings of perceived exertion will be significantly higher during EDT compared to TRAD.

Rationale: Previous findings suggest that as training efficiency increased, there are associated increases in RPE (2,16,37).

Hypothesis 6: There will be no difference between exercise enjoyment between EDT and TRAD sessions.

Rationale: Previous findings demonstrate no difference in enjoyment between superset RT and TRAD (2).

Scope of the Study

Twelve healthy, active males (n= 6) and females (n= 6) between the ages of 18 and 45 who regularly partake in both resistance and endurance training completed two different RT protocols to compare the physiological (VO_2, HR, BLa, and CK) and perceptual (RPE and enjoyment) response between EDT and TRAD protocols. Only individuals who were actively engaged in regular RT ($\geq$ 2-days/week for $\geq$ 12 months) and satisfied the American College of Sports Medicine's recommendations for physical activity ($\geq$150 minutes of moderate or $\geq$75 minutes of vigorous exercise per week) were included in the study. To eliminate the learning effect of EDT, participants were familiarized twice before performing the experimental trials. Following each experimental trial, participants remained seated for 20 minutes of gas collection for estimation of post-exercise energy expenditure. Blood lactate measurements were collected pre-, 5-minutes post, and 10-minutes post-exercise using a portable blood lactate analyzer. Participants were asked their RPE using the 0–10 OMNI RPE scale (22) immediately post-exercise and 20-minutes post-exercise. Enjoyment ratings for the entirety of each exercise protocol were 20 minutes after exercise (17) using a Physical Activity Enjoyment seven-point bipolar Scale (PACES) (25,30).

Assumptions

The following assumptions were identified in this study:

1. Each participant performed his/her ten-repetition maximum testing to the best of their ability to yield an appropriate percent ten-repetition maximum value during both exercise protocols.

2. All participants understood the exercise restrictions of the study (i.e., avoid performing vigorous exercise ≥ 24 hours, refrain from caffeine consumption ≥ 4 hours, and arrive fasted for ≥ 1 hours before each trial) and reliably adhered to these guidelines honestly.
3. All participants maintained their normal diet throughout the duration of the study, and food intake between experimental trials was consistent.
4. Participants accurately reported their previous and current RT status.
5. Participants maintained the same lifestyle routine throughout the duration of their involvement in the study, especially as it pertained to their RT habits.
6. All equipment used in the study was in good working order, including the HR monitor, lactate analyzer, and metabolic cart.

Limitations

The following limitations were identified in this study:

1. The study sample consisted of healthy, physically active women and men between the ages of 18-45 years who participate in regular resistance and cardiovascular exercise. Therefore, the results of this study should be applied to populations with different ages and training statuses with caution.
2. Both protocols in the current study were performed using machine chest press and leg press for safety and convenience. Performing free-weight exercises close to failure may have increased the likelihood of injury. In the real world exercise setting, it is likely that lifters will use a variety of exercises (i.e., back squat, belt squat, lat-pull down, biceps curls, triceps extensions) when performing a session of EDT.

3. EDT and TRAD trials were not randomized or counterbalanced. EDT trials were performed first for each participant so that volume could be matched during the TRAD trial. This methodology has been used in previous research (19,29).
4. Blood lactate sampling from the ear was used as a proxy measurement of metabolic stress. Other techniques such as isotope tracers and muscle biopsies may provide a more detailed analysis of lactate concentrations within working muscle during exercise, however these procedures are more invasive and therefore less common. Noteworthy, Chwalkbinska- Moneta and colleagues found muscle and blood lactate concentrations to be highly correlated (r = 0.91) (5).

Significance of the Study

In recent years, the interest in time-efficient exercise modalities that improve both cardiorespiratory and muscular fitness has increased globally (23). Superset training, previously defined as performing two or more exercises in succession with an abbreviated or no RI (15,24), has become an increasingly popular method of RT due to its ability to decrease total training duration time (2,18,27,29). Escalating density training is a relatively new, but popular training method that was developed in order to increase muscular hypertrophy and enhance cardiovascular fitness parameters in a time- efficient manner. To date, there is no literature available investigating the acute or chronic physiological responses following EDT. This study is the first to examine the physiological response that EDT elicits. The results of this study will contribute to the field of exercise programming for healthy, physically active individuals. For example, EDT may be used as an alternative for athletes and exercise practitioners seeking a time-efficient exercise program. Moreover, EDT may be used during a periodized RT program to evoke increases in muscular endurance.

Abbreviations

BLa: blood lactate

CK: creatine kinase

CWT: circuit weight training

EDT: escalating density training

HR: heart rate

PACES: physical activity enjoyment scale

RER: respiratory exchange ratio

RPE: rating of perceived exertion

RT: resistance training

TRAD: traditional resistance training

VCO_2: carbon-dioxide production

VO_2: oxygen consumption

VO_{2max}: maximal oxygen consumption

1-RM: one repetition maximum

$\%HR_{max}$: percent of maximal heart rate

$\%VO_{2max}$: percent of maximal oxygen consumption

>: greater than

≤: less than or equal to

≥: greater than or equal to

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CHAPTER II: Literature Review

This chapter presents a review manuscript, entitled "Escalating Density Training: Potential Molecular Mechanisms and Benefits" that will be submitted to the International Journal of Sports Medicine. It is authored by Desmond Millender, Zachary Mang, Jeremy Ducharme, Christine Mermier, Fabiano Amorim, Tony Nunez, Jason Beam, and Len Kravitz. The manuscript follows the formatting and style guidelines of the journal. The references cited are provided at the end of the manuscript.

Escalating Density Training: Potential Molecular Mechanisms and Benefits

Running header: Mechanisms of Escalating Density Training

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Abstract

Lack of time is often cited as a barrier to exercise. Thus, modalities of exercise that improve both muscular fitness and aerobic endurance are of interest. Escalating density training (EDT) is a training paradigm derived from superset resistance training (RT) to increase muscular hypertrophy and improve cardiorespiratory fitness. With EDT, alternating sets of two exercises are performed for as many rounds as possible within a set time with no predetermined rest interval. Moreover, the training characteristics of EDT are similar to high-intensity interval training (HIIT), high-intensity resistance training (HIRT), and variations of traditional resistance training (TRAD), which have demonstrated the ability to significantly increase cardiorespiratory fitness and muscular hypertrophy. Therefore, this review explains the molecular mechanisms of these exercise modalities and provides a case for how EDT may elicit improvements in cardiorespiratory fitness and induce muscular hypertrophy.

Introduction

Traditional resistance training is a well-established and effective method of exercise for developing muscular fitness [1] with numerous benefits for health (e.g., increased resting metabolic rate, improved glucose metabolism, improved bone mineral density, decreased gastrointestinal transit time, and improved cardiorespiratory fitness (CRF)) [2–5] and athletic performance (i.e., increased rate of force development [6]).Traditional resistance training (TRAD) may also reduce the risks for injury via strengthening of joints, muscles, tendons, bones, and ligaments [7–9]. These benefits are determined by manipulation of key characteristics of resistance training (RT) such as the volume, intensity, frequency, and exercise selection performed [10,11]. Traditional resistance training, defined as the completion of 2-4 sets of 8-10 exercises for 3-12 repetitions with 2-5 minute inter-set rest intervals (RI) between each exercise [12], is generally performed 2-4 times per week and can routinely exceed an hour in duration per session. The time required to complete TRAD may limit its application for individuals who cite a lack of time as a barrier to exercise [13], and athletes who may only have a limited amount of time to spend in the weight room. Consequently, several time-saving techniques such as supersets [14,15], circuits [16–18], and rest-pause sets [14,19] have been developed by coaches, trainers, and practitioners to achieve similar if not greater health and performance benefits compared to TRAD.

Superset training, performing two or more exercises in succession with an abbreviated or no RI, significantly decreases the time spent at rest, allowing for a greater training density (amount of work performed within a given time), than TRAD. Supersets can be performed using two exercises in an alternating fashion, targeting the same agonist muscle group (i.e., leg press and squat) or performing antagonistic muscle actions (i.e., bench press and barbell row) [20].

Researchers have shown that superset training has a significantly higher training volume [21] and is more time-efficient than TRAD [21–23]. This is important because training volume has shown to be pivotal for hypertrophy [24].

Escalating density training (EDT), a form of superset training, is a time-efficient workout that increases training density for a given session [25]. Unlike TRAD, where volume load (sets x repetitions x weight) is manipulated, the primary variable manipulated with EDT is training density. With EDT, alternating sets of two types of exercises (agonist-antagonist, or upper-lower) are performed for a prearranged number of repetitions per set (i.e., 5) for as many sets as possible within a given amount of time (i.e., 15 mins) without predetermined RIs. As the workout progresses, the number of repetitions performed per set will decrease. At the end of the workout, total training density (i.e., number of repetitions completed within the given time) will be calculated. This creates the first time interval (referred to as a PR zone) [25]. The goal is to increase the work performed within a PR zone during the next session, thus the term escalating density training. Training density, expressed as the repetitions and sets performed within a given time period, can be manipulated every session or every training block for an entire workout or exercise. Specifically, EDT workouts employ a critical density index (CDI) [25], a method utilized to create a progressive overload. For example, when an individual can improve their PR zone by 20% or more, a load corresponding to 5% of the current lift will be added for each exercise during the next PR zone [25]. Furthermore, effective incorporation of training density may be attained by reducing RI length. These variables induce metabolic and mechanical stress, which are stimuli that result in improved CRF and skeletal muscle size and strength [23,24,26–30]. Although EDT is performed by many individuals seeking to improve parameters of fitness and performance, there is currently no literature investigating how EDT may elicit such responses. Furthermore, there is currently no evidence explaining the proposed mechanisms by which these adaptations may occur. Hence, the purpose of the current review is to briefly explain the mechanisms by which EDT might elicit aerobic adaptations and present a case for how EDT may stimulate a hypertrophic response.

Modalities that Improve Cardiorespiratory Endurance

Lack of time is often cited as a barrier to exercise [13]. Thus, modalities of exercise that improve both muscular fitness and cardiorespiratory endurance are of interest. Recently, high-intensity interval training (HIIT), high-intensity resistance exercise (HIRE) and other types of high-intensity functional exercise have become more popular in recreationally active individuals [31–33]. High-intensity interval training, characterized by intermittent periods (10 seconds to 4 minutes) of vigorous exercise bouts (65-90% maximal oxygen consumption [VO_2max or VO_2peak] or 75-95% of heart rate max [HRmax]) interspersed by periods of active or passive recovery [34,35], is similar to EDT in that both involve performing bouts of high-density exercise in a short amount of time (i.e., 10- ≥30 minutes). Over the past 20 years, numerous studies have investigated the cardiorespiratory changes during high-intensity interval exercise sessions performed at intensities close to VO_2max [35–37]. These studies indicate that high-intensity interval exercise bouts are highly effective in eliciting prolonged times spent at a high percentage of VO_2max (i.e., ≥90% VO_2max) or at a high percentage of HRmax (i.e., ≥90% HRmax) which leads to an increase in physiological stress and subsequent long-term aerobic adaptations. Similar to HIIT, HIRE, often characterized as a subtype of HIIT that involves the performance of numerous multiple-joint exercises at high intensity (i.e., the maximal number of repetitions during a fixed period) with light-to-heavy load (i.e., 20- 80% 1-repetition maximum [1-RM]) in a circuit-type manner [38,39], has also shown to elicit prolonged periods of increased metabolic stress, and thus provide a muscular fitness stimulus, and a sustained heart rate (HR) near HRmax [40]. Furthermore, studies have demonstrated HIRE as an effective modality to improve CRF [41,42]. Due to similar characteristics, EDT may be sub-categorized as HIRE, and therefore elicit similar CRF adaptations. Although mechanisms outlining physiological adaptations responsible for CRF improvements in HIIT are well-understood, mechanisms investigating HIRE are understudied. Thus, the next section will focus on aerobic adaptations demonstrated by HIIT that may potentially be observed with EDT.

Escalating Density Training Aerobic Adaptations

Cardiorespiratory fitness, defined as an individual's VO_2max, reflects the integrated ability of the pulmonary, cardiovascular, and muscular system to transport and utilize oxygen for metabolic processes [43]. Cardiorespiratory fitness has been identified as one of the best predictors of all-cause mortality, cardiovascular disease (CVD), and cardiometabolic disease [44]. Furthermore, increasing CRF is also beneficial for certain sport and recreational activities where exercise is performed over a prolonged period of time (i.e., soccer, racquetball, swimming, cycling, etc.) [45–47]. The physiological adaptations that improve CRF can be best explained by the Fick Equation. Based on this equation, VO_2 is the product of cardiac output and arterial-venous oxygen content difference (a-vO_2 difference). While central adaptations, such as an increase in cardiac output, result in large increases in VO_2max, peripheral adaptations such as an increase in skeletal muscle mitochondrial content have been linked to improvements in CRF [48] and may occur following both resistance and endurance exercise [49].

Mitochondria are unique organelles that are capable of adapting to altered metabolic demands like nutrient deprivation, or stressors such as oxidative stress, deoxyribonucleic acid damage, and endoplasmic reticulum stress [50]. Through processes of biogenesis and fusion, newly formed mitochondria are adjoined to neighboring organelles to increase their capacity for adenosine triphosphate synthesis, the sharing of metabolites, and calcium (Ca^{2+}) handling [51]. Furthermore, mitochondria are essential for endurance performance due to their function, content, and density being highly correlated with VO_2max [52–54] and time-trial cardiorespiratory performances [55,56]. For example, an increased mitochondrial content promotes a greater reliance on fat oxidation and a proportional decrease in carbohydrate oxidation [57]. Consequently, exercise training lessens glycogen depletion and lactate production at a given exercise intensity [58], allowing individuals to exercise for a longer duration and greater percentages of individual VO_2max [59].

Performance of endurance exercise training promotes mitochondrial content and biogenesis [51,52,60–62]. Moreover, molecular signals such as Ca^{2+}, 5' adenosine monophosphate (AMP) and reactive oxygen species (ROS) increase during and post-exercise leading to the activation of mitochondrial biogenesis [63]. Specifically, exercise induces increases in transcriptional coactivator, peroxisome proliferator-activated receptor γ coactivator (PGC)-1α (1,2,9), which is a key regulator of mitochondrial biogenesis (5). Similar to endurance exercise, a single session of high-intensity exercise elevates cytosolic concentrations of several metabolites (i.e., lactate, AMP, adenosine diphosphate [ADP]) which initiates a cascade of signaling events in numerous pathways, leading to the upregulated expression of genes encoding proteins for mitochondrial biogenesis [64]. There is a proportional increase in ATP turnover with exercise intensity which relies on carbohydrate oxidation and glycogen utilization [35]. Thus, the greater the intensity, the greater the increase in intracellular lactate, AMP, ADP, expression of PGC-1α, and phosphorylation of AMPK [35]. Moreover, HIIT may also induce skeletal muscle mitochondrial biogenesis by a mechanism involving silent information regulator T1 (SIRT1)

[65]. Activated by AMPK, lactate, and nicotinamide adenine dinucleotide (NAD), SIRT1 is a NAD-dependent type III deacetylase which has been suggested to be a positive regulator of PGC-1α activation [66]. Accordingly, Canto et al. [67] found that acute exercise activates SIRT1-mediated deacetylation of PGC- 1α, which increases the expression of PGC-1α and mitochondrial gene transcription. In line with these findings, Gurd et al. [65] found that SIRT1 activity was accompanied with an increase in PGC-1a and mitochondrial enzymes following 6 weeks of HIIT, which resulted in an 11% increase in VO_2max. Additionally, Burgomaster et al. [68] showed similar increases in PGC1-α in participants who performed several weeks of HIIT compared to those who performed traditional endurance exercise. Similarly, Little et al. [69] demonstrated an increase in PGC-1α protein content, which coincided with elevated mRNA expression of several mitochondrial genes, following an acute bout of HIIT.

Previously, it has been demonstrated that high-load and low-load RT may increase mitochondrial protein synthesis [70,71]. Moreover, Lim et al. [72] suggest low-load, high-volume RT to failure may enhance mitochondrial biogenesis. These authors compared the effects of three volume-matched RT intensities (i.e. 30% 1RM, 80% 1RM to failure, and 30% 1RM to failure) on mitochondrial volume and remodeling markers following 10 weeks [72]. No changes in mitochondrial volume markers were observed, however robust alterations in these markers occurred in the 30% 1-RM to failure group. Additionally, markers of mitochondrial remodeling were increased for the 30% 1-RM to failure group, suggesting increased mitochondrial biogenesis [72]. In agreement with Lim and colleagues, several studies demonstrate high volume RT likely has a greater impact in increasing mitochondrial biogenesis compared to high-load RT [73–75]. This may be due to high-volume RT eliciting greater metabolic perturbations [76,77], potentially signaling activation of pathways leading to mitochondrial biogenesis [78]. Thus, given the similarities between training characteristics of EDT and high-volume RT, utilization of EDT may elicit metabolic stress for subsequent adaptations in skeletal muscle oxidative capacity.

In addition to improvements to skeletal muscle oxidative capacity, other endurance adaptations such as increased resting glycogen content, reduced rate of glycogen utilization and lactate production, increased capacity for whole-body and skeletal muscle lipid oxidation and enhanced peripheral vascular structure and function have been documented after several weeks of HIIT [79,80]. Secretion of pro-angiogenic vascular endothelial growth factor (VEGF) promotes angiogenesis or the formation of new blood vessels [81]. Furthermore, VEGF is one of the most central angiogenic factors in skeletal muscle capillary growth [82]. One of the underlying mechanisms for the secretion of VEGF is the accumulation of lactate within skeletal muscle [83,84]. Another mechanism is the multiple-fold increase in blood flow during exercise which results in increased shear stress and upregulation of VEGF [52,85,86]. Although HIIT results in increased skeletal muscle blood flow and elevations in circulating blood lactate, subsequent elevations in VEGF have not shown to be a potent stimulus for angiogenesis and capillary growth. For example, Hoier et al. [82] reported increased VEGF following 4 weeks of HIIT [82]. However, these elevations in VEGF were not a strong enough angiogenic stimulus to induce capillary growth [82]. Similarly, a study by Jensen et al. [87] demonstrated that four weeks of HIIT induced endothelial cell proliferation and enhanced capillarization, however, VEGF was not found to be altered during training. It has been previously reported that a combination of contractile activity, functional hyperemia, hypoxia, and metabolic stress promotes an upregulation of angiogenic factors [87]. Additionally, some previous RT programs [88] found an increase in muscle angiogenesis, showing an increase in vascular endothelial growth factor and capillary-to-fiber ratio (78). Thus, we speculate that EDT may similarly improve peripheral adaptations that are responsible for promoting endurance.

Regarding central adaptations, there is a paucity of data regarding the effects of HIIT on maximum stroke volume, cardiac output, and blood volume. Recent studies suggesting central adaptations following HIIT demonstrated increases in cardiac output and stroke volume with little changes in blood and plasma volume [59,89]. For example, Astorino et al. [90] investigated the changes in VO_2max and cardiac output in response to a 6-week periodized HIIT protocol [90]. The findings of this study suggest that significant increases in stroke volume and cardiac output occur in response to HIIT. Additionally, a recent review of 45 studies suggested that stroke volume and cardiac output provide moderate contributions with VO_2max increases associated with HIIT [89]. Furthermore, this review suggested hematocrit, blood volume, and plasma volume provide little contribution to changes in VO_2max [89]. Contrarily, Macpherson et al. [91] demonstrated increased VO_2max following 6- weeks of HIIT without coinciding increases in cardiac output. Similar to Macpherson and colleagues, Jacobs et al. [92] demonstrated improvements in VO_2max without a change in cardiac output following HIIT. These authors suggested changes in VO_2max are due to increases in skeletal muscle mitochondrial content and function [92].

In summary, HIIT provides a powerful stimulus for eliciting improvements in VO_2max. We theorize that EDT may provide a comparable stimulus to HIIT during and following exercise allowing for physiological aerobic adaptations that improve CRF. This hypothesis is based on the training similarities (i.e., increased training density and decreased rest interval duration) between EDT and HIIT. As previously mentioned, HIIT elevates cytosolic concentrations of metabolites (i.e., lactate, ADP, and AMP), free radicals (i.e., ROS), and calcium which serve as a signal leading to mitochondrial biogenesis. Though speculative, pathways that are upregulated with HIIT may similarly be upregulated with EDT as previous studies have demonstrated increases in metabolic and oxidative stress following superset [23,26,49], circuit weight training sessions [93], and HIRE [40]. Moreover, it has been suggested that when repetitions are performed with low loads (i.e. 30% 1- RM) to momentary muscle failure, protein markers for mitochondrial biogenesis and mitochondrial capacity are increased [72]. To truly determine the physiological adaptations that improve endurance performance, future studies should investigate the acute and long-term responses following EDT.

Escalating Density Training Hypertrophic Adaptations

Exercise-induced muscular hypertrophy is primarily caused by mechanical tension, muscle damage, and metabolic stress [94]. Mechanical tension, or the disturbance of skeletal muscle integrity (i.e., cytokines, stretch-activated channels, and focal adhesion kinases), causes mechano-chemically transduced responses in myofibers and satellite cells that activate downstream processes and pathways such as protein kinase B (AKT)/ mammalian target of rapamycin (mTOR), which acutely activate protein translation, eventually leading to long-term skeletal muscle hypertrophy [11,95–98]. Progressive mechanical tension overload is attained by increasing RT intensity (36). There are several techniques that can be utilized with RT to increase intensity and promote mechanical tension (i.e., circuits, tempo-training, and supersets) [19,49,99,100]. With EDT, this is implemented by manipulation of the CDI and PR zones [25]. For example, to create a progressively overloading stimulus, all sets and reps are performed in a predetermined 15-minute PR zone. During each PR zone, exercises are performed at a load equivalent to 10-RM with the aim of completing as many repetitions as possible (up to 10 repetitions). When a certain percentage (i.e., 20%) of total repetitions can be completed, more weight is added. This method of overload explains the CDI [25].

Manipulation of the CDI with EDT may elicit mechanical tension necessary for RT-induced hypertrophy within skeletal muscle. For example, it has been reported that mechanical tension is greatest with heavy loads and fewer repetitions [101]. Mechanical tension is known to modulate the activity of the Jun N-terminal kinase (JNK) signaling cascade. Activation of JNK acts as a positive regulator of hypertrophic adaptations within skeletal muscle [102]. Moreover, exercise-induced JNK has been linked to a rapid rise in mRNA of transcription factors that modulate cell proliferation and DNA repair [103,104]. When the CDI is manipulated, more weight is added, and generally fewer repetitions are performed during an EDT session potentially increasing the degree of mechanical tension.

Damage to muscle tissue, specifically tears within the z-disk, sarcolemma, basal lamina, connective tissue, or contractile elements, from RT are accompanied with the accumulation of creatine kinase (CK), lactate dehydrogenase, myoglobin, and several other proteins within the blood [105,106]. The response to this damage signals an inflammatory-like response where neutrophils initiate tissue remodeling via increased recruitment of macrophages and lymphocytes resulting in phagocytosis and differentiation of myoblast and eventually the formation of new myotubes [107]. Further, RT may promote the activation of stretch-activated calcium channels on membranes, leading to the release of cytokines directing satellite cells to migrate the affected fibers [107]. This cascade of events is thought to lead to the release of growth factors that regulate satellite cell proliferation and differentiation [106]. Although research is evolving, it has been suggested that satellite cells release regulatory factors that help with muscular repair and regeneration, and donate their nuclei by fusing to an existing fiber to increase synthesis of new contractile proteins [106,108,108].

Several studies have compared short (i.e., ≤1 minute) vs long (i.e. 3-5 minutes) RI's and their effect on muscle damage [27,29,30,109–111]. A recent study by Senna et al. [30] investigated the effects of volume-equated resistance exercise with two RI lengths (1 and 3 minutes) on inflammatory responses and muscular damage on ten trained men. These authors found greater increases in serum CK from 12 to 24 hours post-exercise in the 1- minute condition compared to the 3-minute condition. These authors also report significant increases in total number of leukocytes, neutrophils, and monocytes within the blood with an increase compared to baseline in pro-inflammatory cytokines (tumor necrosis factor- α, interleukin 1 beta, and granulocyte- macrophage colony-stimulating factor) and anti-inflammatory cytokines (interleukin 5, interleukin 6, and interleukin 10) with the 1-minute RI [30]. Moreover, a study by Mayhew et al. [27] demonstrated higher serum CK following a 1-min RI compared to a 3-min RI. These findings suggest that when volume matched RT is performed with shorter inter-set RI's, there is a greater immune response and damage to the muscle compared to longer RI's [30]. Training characteristics of EDT consist of minimal rest and greater work time. Therefore, similar to aforementioned studies, EDT may elicit a similar response to RT sessions with abbreviated RI's. Thus, performance of EDT may be an alternative to TRAD to elicit skeletal muscle damage for a hypertrophic response.

As previously explained, metabolic stress is responsible for several aerobic adaptations. It has been speculated that metabolic stress also has a significant hypertrophic effect [112,113]. Metabolic stress is a physiological process that manifests as a result of exercise that relies on anaerobic glycolysis for ATP production. Moreover, during exercise there is an accumulation of metabolites (lactate, hydrogen ions, creatine, inorganic phosphate) within muscle fibers [114]. It has been hypothesized that these metabolites mediate cellular swelling which leads to an increase in protein synthesis and decreases proteolysis through activation of the MAPK pathway [113]. Further, a reduction in intracellular oxygen content, or hypoxia, increases the production of ROS which has significant implications on improving skeletal muscle hypertrophy [115]. Moreover, lactate is correlated with myotube hypertrophy and RT hypertrophy [116–118]. Previously, lactate has shown to regulate myogenesis and activate extracellular signal-regulated kinase ½ (ERK 1/2) pathways [116]. The ERK 1/2 cascade is a central signaling pathway that regulates cellular proliferation, differentiation, and survival [119]. Further, metabolic stress, or indicators of metabolic stress (i.e., BLa accumulation), has been posited that it may contribute to hypertrophy by increasing high-threshold motor unit recruitment and activation of more hypertrophy-prone, fast-twitch muscle fibers [120].

Generally, increasing metabolic stress to promote hypertrophy involves performing high volume of repetitions or reducing RI length. This can be achieved by techniques such as superset RT (i.e., performing two or more exercises in succession with an abbreviated or no RI) [14,20]. In a cross-over design study, Kelleher et al. [26] compared the metabolic cost of superset training to TRAD. Ten participants completed a superset protocol consisting of agonist-antagonist grouped exercises and a TRAD protocol. The exercise intensity was 70%1RM. Energy expenditure was significantly greater during superset exercise. Furthermore, excess post-exercise oxygen consumption (EPOC) and blood lactate were significantly greater with superset exercise compared to a volume-matched TRAD session [26]. In a similar study, Realzola et al. [28] compared a superset protocol to a volume-load equated TRAD protocol. The findings of this study also suggest that superset training induces a greater metabolic response as blood lactate, EPOC, percentage of VO_2max, and RPE were significantly greater following superset compared to TRAD RT bouts [28]. Currently, only one longitudinal study has been conducted on superset training using TRAD modalities. In this study, 15 participants performed bench press and bench pulls for eight weeks in a superset vs traditional manner [21]. There were no differences between superset and TRAD for 1RM bench press and bench pull, throw height, peak velocity, and peak power. Interestingly, superset training was completed in half the time required for the TRAD session. This study suggests that superset training is a time-efficient alternative to TRAD [21].

A study by Longo et al. [24] assessed the effects of RI length (i.e., 1 min vs 3 min) in volume-equated RT protocols on muscular strength and quadriceps cross-sectional area. The data from this study suggests that volume-load plays a primary role in hypertrophy than inter-set RI length. Additionally, it has recently been demonstrated that superset training leads to significant increases in muscle mass [22]. As a result of these findings and those demonstrating greater metabolic stress from volume-matched RT bouts with shorter RI's between sets, we suggest that EDT may be an alternative to TRAD for promoting hypertrophy. This hypothesis is centered upon EDT being a form of superset training where resistance exercises are performed in a repetitive fashion. Generally, there are no pre-determined RI's with EDT and the goal is to perform as many repetitions as possible within a given time. The characteristics of this training are similar to that of studies demonstrating greater metabolic stress and similar hypertrophic adaptations with shortened RI's compared to longer RI's [24].

Conclusion

Escalating density training is a popular training method that was developed in order to increase muscular hypertrophy and enhance cardiorespiratory fitness parameters in a time-efficient manner. When RT variables are appropriately manipulated, we propose that EDT may be similar to HIIT for improving cardiorespiratory endurance. As a method to improve muscular strength and hypertrophy, EDT resembles superset RT. Thus, studies investigating HIIT, and superset RT may provide valuable insight into potential mechanisms for possible EDT adaptations. Consequently, incorporating EDT in one's training regimen, may serve to elicit similar adaptations observed following HIIT and superset RT. At this time, no literature investigating the acute or long-term adaptations to EDT exist, warranting more research in this area.

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CHAPTER III: Experimental Study

This chapter presents a complete manuscript that describes the study in traditional journal article form including an abstract, introduction, methods, results, discussion, and references. The manuscript, entitled "A metabolic profile of escalating density training" will be submitted to the Journal of Strength and Conditioning Research. It is authored by Desmond Millender, Chelce Yazzie, Rogelio Realzola, Zachary Mang, Christine Mermier, Fabiano Amorim, Tony Nunez, Jason Beam, and Len Kravitz. The manuscript follows the formatting and style guidelines of the journal and the references cited are provided at the end of the manuscript.

A metabolic profile of escalating density training

Running header: Metabolic cost of escalating density training

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Abstract

Objective: The purpose of this study was to compare the acute physiological, perceptual, and enjoyment responses between a single bout of escalating density training (EDT) and traditional resistance training (TRAD).

Methods: Twelve physically active males (n = 6) and females (n = 6) (age: 21.4 ± 3.0 years; weight: 69.8 ± 7.9 kg; height: 172.9 ± 12.4 cm; maximal oxygen consumption (VO_2max): 44.7 ± 9.2 ml · kg^{-1} · min^{-1}) performed both EDT and TRAD. During the EDT trial, participants performed chest and leg press exercises in a cyclical fashion for 15 minutes with limited rest. For the TRAD trial, the same exercises were performed for sets of up to 8 repetitions until volume was matched from the EDT trial. Oxygen consumption (VO_2) and heart rate (HR) were measured before, during, and after exercise. Blood lactate (BLa) was measured pre- and post-exercise. Creatine kinase (CK) was measured pre- and 48 hours post-exercise. Rating of perceived exertion (RPE), physical activity enjoyment (PACES), and oxygen consumption were measured post-exercise.

Results: Oxygen consumption relative to VO_2max was higher ($p < 0.001$) during EDT (56.2 ± 6.8%) compared to TRAD (23.7 ± 4.7%). Heart rate relative to HRmax was higher ($p = 0.021$) for EDT (78.9 ± 7.9%) compared to TRAD (53.0 ± 15.8%), $p = 0.021$. There was no significant difference in total exercise energy expenditure between EDT (929.2 ± 245.9 kJ) compared to TRAD (1267.7 ± 592.5 kJ), $p = 0.181$. Compared to TRAD, BLa was higher ($p < 0.05$) 5- and 10-min post-exercise for EDT. Creatine kinase was significantly greater ($p = 0.002$) following EDT (205.6 ± 111.2 IU/L) compared to TRAD. Average RPE achieved was higher ($p < 0.001$) during EDT (8.8 ± 0.8) compared to TRAD (5.5 ± 1.9). PACES was similar for EDT and TRAD ($p = 0.176$).

Conclusion: Our results indicate that EDT may be an effective alternative to TRAD for strength and cardiorespiratory adaptations. Future research should be done to investigate the long-term physiological adaptations to EDT.

Introduction

Resistance training (RT), often used interchangeably with terms such as strength training or weight training, is a form of exercise involving the use of an external resistance with the primary goal of increasing muscular strength, endurance, power, hypertrophy, functional ability, and improving overall well-being and cardio-metabolic profile (22,46). These improvements are in response to profound neural adaptations, increases in muscle cross-sectional area, and alterations in connective tissue stiffness (6,24). Traditionally, RT sessions involve the performance of multiple sets of lower- and upper-body exercises with 30 seconds to 5 minutes (min) inter-set recovery intervals (RI). These RI are incorporated into RT sessions to minimize the volume (number of repetitions) and intensity between sets, thus increasing the total duration of the workout. Previously, it was thought that longer RI lengths were required for optimal recovery to maintain intensity and volume-load, resulting in increases in muscular strength and increased hypertrophy. However, recent literature has demonstrated that volume-load, independent of RI length, influences musculoskeletal adaptations (29). Consequently, several time-saving techniques have been examined to alternatively decrease the time needed to complete a RT session (10-12,21,34,38).

Superset training, defined as performing two or more exercises in succession with an abbreviated or no RI, has become an increasingly popular method of time-efficient training for coaches, athletes, and trainers (14,29). This type of training substantially decreases the amount of time spent at rest, allowing for a greater training density (i.e., number of repetitions completed within the given time) compared to traditional resistance training (TRAD) (21). Supersets are generally performed using two exercises in an alternating fashion, targeting the same agonist muscle group (i.e., leg press and squat) or performing antagonistic muscle actions (i.e., bench press and barbell row) (34). This type of training configuration differs from TRAD, such that TRAD requires the same exercise be performed for one or multiple sets before the execution of the next exercise (34). Acute cross-over studies have demonstrated that when a load corresponding to an 8-12 repetition max (RM) is utilized with superset training, total training time is approximately half that of TRAD (31,33). Moreover, increased training density results in higher cardiovascular and metabolic stress (14) and has proven to be an effective method of improving muscular strength and hypertrophy (12,36).

A form of superset training, escalating density training (EDT), is a time-efficient workout that increases training density (i.e., the repetitions and sets performed within a given time period) for a given workout (48). During an EDT workout, alternating sets of two types of exercises (agonist-antagonist, or upper-lower body) are performed for a prearranged number of repetitions (i.e., 5) per set for as many sets as possible within a given amount of time (i.e., 15 min) without predetermined RIs (48). As the workout progresses, the number of repetitions performed per set decreases. At the end of the workout, total training density (i.e., the amount of work performed within a given time frame) is calculated. During a subsequent workout, the goal is to perform more work within the same time frame, thus increasing or escalating the overall training density.

The characteristics of EDT have been proposed to promote physiological changes for improvements in both cardiorespiratory and musculoskeletal fitness (28). To date, no evidence investigating the acute or chronic physiological response of EDT exists. However, similar training styles have shown to elicit a physiological response that is favorable to cardiometabolic adaptations. For example, a recent study by Realzola and colleagues (38) found that performing supersets with antagonistic pairing resulted in significantly higher blood lactate (BLa) concentration, heart rate (HR), oxygen consumption (VO_2), and ratings of perceived exertion

(RPE) when compared to TRAD. These findings suggest an overall greater metabolic cost for superset training as compared to TRAD (38). Interestingly, these authors did not compare any biochemical markers of muscular damage (i.e., creatine kinase). Muscle damage as a result of RT increases the rate of muscle protein synthesis and eventual RT-induced muscular hypertrophy (13,43). Increased levels of muscle proteins, such as creatine kinase (CK), in the blood are widely used as markers of damage (10). Consequently, understanding the musculoskeletal response to EDT is imperative for predictions of long-term adaptations and increases in muscular hypertrophy. Thus, the purpose of the current study was to examine the physiological response and create a metabolic profile for a single bout of EDT. Our secondary purpose was to investigate the perceptual responses (i.e., RPE) and enjoyment of EDT compared to TRAD. We hypothesized that the denser exercise protocol, EDT, would elicit a greater cardiorespiratory (VO_2 and HR), metabolic (BLa), and perceptual response (RPE) than TRAD. We also hypothesized that there would be no difference in enjoyment between protocols, and EDT would result in greater muscle damage (CK).

Methods

Experimental Approach to the Problem

This study used a repeated-measures, cross-over design to compare the metabolic and cardiorespiratory responses of two volume-load equated total-body RT sessions. Experimental trials were separated by ≥ 7 days. Furthermore, the two RT sessions were performed on different days but at a similar time of the day (within 1- to 2-hour difference) to avoid influence of diurnal hormones and circadian rhythm. Participants were asked to avoid performing vigorous exercise ≥ 24 hours, refrain from caffeine consumption ≥ 4 hours, and arrive fasted for ≥ 1 hour before each trial. Measurements obtained for each RT trial included: blood samples for CK and BLa, VO_2, HR, BLa, RPE, and enjoyment via a physical activity enjoyment scale (PACES). Volume-load (sets x reps x load) was calculated during the EDT session and equated during the TRAD session. Previous studies were designed without randomization of the order of exercise sessions in order to equate volume-load during super-set and circuit weight training (24,32,38). The study design and measurement time points are summarized in Figure 1.

Place Figure 1 About Here

Subjects

Participants in the study included fifteen physically active males and females, ages 18-27. However, three withdrew participation due to musculoskeletal injuries unrelated to the study or scheduling conflicts. Oxygen consumption was the main variable of interest used to guide the *a priori* analyses for total sample size using G*Power software (version 3.1.9.7). According to a statistical power analysis with an α-level = 0.05 and 1-β = 0.80, the number of subjects required for a valid analysis was $n = 12$. Participants were considered physically active by meeting both aerobic (≥ 150 min of moderate-intensity or 75 min of vigorous-intensity/week) and strength training (≥ 2 days per week) recommendations (28). Furthermore, all participants were considered resistance trained as their leg press strength-to-body mass ratio met the criteria to be categorized as “well above average” (28) . All participants self-reported being free of cardiovascular, metabolic, viral, kidney, and liver disease with no orthopedic injuries that would prevent them from exercise via health history and physical activity questionnaires. Prior to data collection, each participant gave written informed consent prior to participating. This study was approved by the university’s institution review board.

Anthropometrics

Participants' height (cm) was measured using a stadiometer (Holtain Limited, Crymych, Dyfed, Great Britain) and weight (kg) was recorded using a digital weight scale (MedWeight MS-3900, Itin Scale Company, Brooklyn, NY, USA). Additionally, 3-site skinfold measurements for men (chest, abdomen, and thigh) (22) and women (triceps, suprailiac, and thigh) were measured (23). These values were subsequently used to estimate body density and body fat percentage (%BF) (47). The same researcher conducted all SKF measurements. Anthropometric data are shown in Table 1.

Place Table 1 About Here

VO_2 Max Testing

A maximal oxygen consumption (VO_2max) test was performed on a motorized treadmill (C966i, Precor Inc., Woodinville, WA, USA) while wearing a HR monitor around the chest (Polar HR 600, Polar Electro Inc., Lake Success, NY, USA). Participants wore a nose clip while expired gases were collected using a two-way valve and mouthpiece (Hans Rudolph Inc. Kansas City, MO). Expired gases were continuously measured using breath-by-breath sampling by a metabolic cart (Parvo Medics True One 2,400, Sandy, UT, USA) during the test. The same metabolic cart and procedures were used for EDT and TRAD trials. Prior to testing, the metabolic cart was calibrated in accordance with manufacturer guidelines prior to each exercise session. Each participant then completed a 5-minute warm-up while being instructed to find a find an intensity they could maintain for 30+ minutes. This estimated speed was then used to determine starting speed. All VO_2max tests were performed at a 3% grade while speed was increased by 0.5 mph every minute until participants reached volitional fatigue within 8-12 minutes (53). Maximal oxygen consumption was defined by meeting a minimum of two of the following criteria: respiratory exchange ratio (RER) ≥ 1.1, maximal heart rate within 10 beats of calculated age-predicted HRmax; 208 - (0.7 × age) (49) or RPE ≥ 17 (41), without investigation of plateau. Metabolic data were smoothed using an 11-breath rolling average and the highest data point was recorded as VO_2max (ml · kg^{-1} · min^{-1}) (41). VO_2max results are shown in Table 1.

10-Repetition Maximum Testing and EDT Familiarization

Prior to performing the experimental trials, proper lifting technique and cadence were demonstrated by a research team member who is certified as a strength and conditioning specialist (National Strength and Conditioning Association) and exercise physiologist (American College of Sports Medicine). After observing proper form and descriptions of the leg press (LP) and chest press (CP) exercises, participants performed 5-10 minutes of a self-selected warm-up before executing the first set of exercise with ~50% of their estimated 10-RM for 8-10 repetitions. Following a rest period of 3 minutes, successive sets were performed, and researchers added weight for each set until a successful 10-RM was reached (16,35). All 10-RMs were determined in five attempts. A metronome was used to maintain a repetition cadence of 2:1 (i.e., two seconds eccentric and one-second concentric contraction) during all sets of exercise, and this cadence was used for subsequent RT sessions. 10-RM testing was performed on two days separated by 24-48 hours. The intraclass correlation coefficient for 10-RM was very strong (ICC = 0.96). Familiarization with EDT was performed following 10-RM procedure. During familiarization, participants performed 4 rounds of chest and leg press exercises with a 2:1 cadence for 5 repetitions at a load corresponding to their 10-RM.

EDT protocol

Before the EDT trial began, participants repeated the self-selected 5-10-minute warm-up that was performed prior to 10-RM testing. After this, a heart rate monitor was donned (Polar HR 600, Polar Electro Inc., Lake Success, NY, USA) and participants were fitted with a facemask which was worn for gas analysis. Participants' resting VO_2 was then recorded for 10 minutes for later estimation aerobic energy expenditure. After resting data were recorded, the participants began a 15-minute EDT session during which they completed as many sets of CP and LP as possible. The two exercises were performed in a cyclical fashion and participants were encouraged to rest as little as possible between their sets. Starting exercise (i.e., chest press or leg press) was randomized prior to beginning. Each participant started the session performing five repetitions per set. When they could no longer perform five repetitions, participants performed four repetitions for as many rounds as possible. The drop in repetition number was repeated until the exercise session concluded (i.e., 15 minutes). Rest was not programmed between sets. Repetitions were performed at a load corresponding to 10-RM with a 2:1 cadence. A stopwatch was used to record exercise time and the total duration of each trial. Volume load (sets x reps x load) was calculated during the EDT session and equated during the TRAD session. These data are displayed in Table 1.

TRAD protocol

For the TRAD session, participants completed the same warm-up as during the EDT session. After the warm-up, the heart rate monitor was donned and participants were fitted for a facemask which was worn for gas analysis. Participants' resting metabolic data was then recorded for 10 minutes for estimation of aerobic energy expenditure. After resting data were recorded, CP and LP was then performed for multiple sets of up to 8 repetitions until volume was matched from the EDT session. Starting exercise (i.e., CP or LP) was randomized prior to beginning. Exercises were performed with a 2:1 cadence. Rest interval length between sets was 90 seconds. This was chosen as recent evidence suggests that lifters performing hypertrophy-style training should rest between 60 and 180 seconds (17). Exercise time and total time to complete the TRAD session was measured using a stopwatch.

Blood Analyses, Data Processing, and Calculations

Blood Lactate and Creatine Kinase.

Blood lactate measurements were collected using a handheld lactate meter (Lactate Plus, NOVA Biomedical, Walthman, MA) and strips pre, 5-, and 10-min post-exercise. Researchers sterilized the earlobe with alcohol wipes before puncturing the earlobe to draw blood. Gauze was used to wipe the initial drop of blood away, the ear was gently squeezed, and the second drop of blood was sampled in duplicate and averaged for analysis (18). For CK, blood samples of approximately 10 ml were collected immediately before the warm-up and 48 hours following each experimental trial. Blood samples were placed into vacutainer serum separator tubes (BD, Phoenix, AZ) and centrifuged at 22°C for 15 minutes at 2,200 g (Allegra X-14R Centrifuge, Beckman Coulter, Brea, CA). Serum was then separated into Eppendorf vials, immediately frozen, and stored at -80°C. When all blood samples had been collected and processed, the samples were sent to a commercial laboratory (QuestDirect™, Albuquerque, NM, USA) and analyzed for CK.

Oxygen Consumption and Heart Rate.

Expired gases were continuously measured using breath-by-breath sampling for attainment of metabolic variables (i.e., VO_2, VCO_2) during all exercise trials. The highest 11-breath averaged data point was recorded as VO_2max. For TRAD and EDT, average VO_2 was taken from the 11-breath averaged data and expressed as $\%VO_2max$. Ten minutes of pre-exercise breath-by-breath VO_2 was averaged and reported as the average pre-exercise VO_2. Twenty minutes of post-exercise breath-by-breath VO_2 was averaged for estimations of post-exercise aerobic and anaerobic energy expenditure. Heart rate was monitored continuously during all sessions of exercise and integrated with the metabolic gas analyzer. During the VO_2max test, the highest HR achieved was recorded as HRmax. Heart rate relative to maximal HR (%HRmax) and average HR was calculated for EDT and TRAD protocols.

Estimated Aerobic and Anaerobic Energy Expenditure Calculations

An estimation of the rate of aerobic energy expenditure ($kJ \cdot min^{-1}$) for each subject during each exercise session was calculated using the following formula: [avg VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) during exercise - avg VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) before exercise] x body mass (kg) x 0.001 L x 20.9 kJ. An estimation of the rate of aerobic energy expenditure ($kJ \cdot min^{-1}$) for each subject after each exercise session was calculated using the following formula: [avg VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) after exercise - avg VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) before exercise] x body mass (kg) x 0.001 L x 20.9 kJ. An estimation of the rate of anaerobic energy expenditure ($kJ \cdot min^{-1}$) for each subject during each session was calculated using the following formula: [peak [BLa] ($mmol \cdot L^{-1}$) – resting [BLa] ($mmol \cdot L^{-1}$)] x 0.003 L $O_2 \cdot$ mmol $Lactate^{-1} \cdot$ kg body $weight^{-1}$ x 20.9 kJ (44).

Rating of Perceived Exertion and Physical Activity Enjoyment Scale

Participants were asked their rating of perceived exertion 20 minutes post exercise using the 0–10 OMNI RPE scale (OMNI) (50). Enjoyment ratings were recorded for the entirety of each exercise protocol 20 minutes post exercise (20) using a Physical Activity Enjoyment seven-point bipolar Scale (PACES) (36,39).

Statistical Analyses

We used sex as a covariate to reduce the probability of a Type II error as we didn't have enough power to compare differences between sex. Therefore, one-way repeated measures analysis of covariances (ANCOVAs), with sex as the covariate, were used to identify statistical differences between EDT and TRAD in measurements of session RPE, PACES, average VO_2 (before, during, and after exercise), average HR, %VO_2max, %HRmax, aerobic energy expenditure (before, during, and after exercise), anaerobic energy expenditure during exercise, and total energy expenditure during and after exercise. Mean differences of CK between the EDT and TRAD sessions were analyzed with a 2 (condition) x 2 (time) repeated measures ANCOVA, with sex as the covariate. Mean differences of BLa between the EDT and TRAD sessions were analyzed with a 2 (condition) x 3 (time) repeated measures ANCOVA, with sex as the covariate. The assumption of sphericity was checked using the Mauchly's test of sphericity for the 2 x 3 repeated measures ANCOVA analyses. If this assumption was violated ($p \leq .05$), the Greenhouse-Geisser test was used to test the mean differences. Pairwise comparisons using the Tukey procedure were used to analyze significant interactions from the repeated measures ANCOVAs. If there were no significant interactions, pairwise comparisons using the Bonferroni correction procedure for multiple comparisons were used to analyze significant main effects from the repeated measures ANCOVAs. All pairwise comparisons are reported as mean ± SD and Cohen's *d* effect size (ES). Effect size was calculated using the difference between means divided by the pooled standard deviation. Effect size was interpreted as $0.2 < d < 0.5$ small; $0.5 < d < 0.8$ medium; $d \leq 0.8$ large (9). For all statistical tests, a probability level of $p \leq .05$ denoted statistical significance. All statistical computations were performed using JASP version 0.12.2 software (JASP, Amsterdam, The Netherlands).

Results

VO_2, HR, RPE, and PACES

Figure 2A displays %VO_2max for EDT and TRAD. EDT %VO_2max (56.2 ± 6.8%) was significantly greater compared to TRAD (23.7 ± 4.7%), $p < 0.001$. Average VO_2 was significantly greater for EDT (24.7 ± 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) compared to TRAD (10.4 ± 1.8 $ml \cdot kg^{-1} \cdot min^{-1}$), $p < 0.001$ (see Figure 2B). Average heart rate for EDT (151 ± 12 bpm) was significantly greater than TRAD (110 ± 12 bpm), $p < 0.001$. A significant difference between %HRmax was observed between EDT (78.9 ± 7.9%) and TRAD (53 ± 15.8%), $p = 0.021$ (see Figure 2C). EDT PACES (48 ± 13) was not significantly different than TRAD PACES (67 ± 17), $p = 0.176$. EDT RPE (9 ± 1) was significantly greater than TRAD RPE (6 ± 2), $p < 0.001$.

Place Figure 2 About Here

Aerobic and Anaerobic Energy Expenditure

The average resting rate of aerobic energy expenditure 10 minutes before each session was similar between EDT (6.86 ± 1.88 $kJ \cdot min^{-1}$) and TRAD (7.23 ± 1.89 $kJ \cdot min^{-1\cdot}$), $p = .090$. The average rate of aerobic energy expenditure during EDT (26.99 ± 6.93 $kJ \cdot min^{-1}$) was statistically greater than during TRAD (9.94 ± 8.02 $kJ \cdot min^{-1}$), $p < 0.001$. The average rate of anaerobic energy expenditure during EDT (28.99 ± 13.11 $kJ \cdot min^{-1}$) was statistically greater than during TRAD (19.50 ± 10.03 $kJ \cdot min^{-1}$), $p = 0.005$. There was no significant difference in total exercise energy expenditure (aerobic + anaerobic) between EDT (929.2 ± 245.9 kJ) compared to TRAD (1267.7 ± 592.5 kJ), $p = 0.181$. The average post-exercise energy expenditure for EDT (4.55 ± 1.51 $kJ \cdot min^{-1}$) was statistically greater than TRAD (1.37 ± 2.23 $kJ \cdot min^{-1}$), $p = 0.001$. Lastly, average absolute post-exercise energy expenditure for EDT (90.9 ± 30.3kJ) was significantly greater than TRAD (27.4 ± 44.6 kJ), $p = 0.001$).

Place Table 2 About Here

BLa and Creatine Kinase

There was a significant main effect on condition for BLa, $F (1, 10) = 28.444$, $p < 0.001$, $\eta_p^2 = 0.691$ and time for BLa, $F (1.092, 10.917) = 22.747$, $p < 0.001$, $\eta_p^2 = 0.695$. There was a significant condition x time interaction for BLa, $F (1.217, 12.173) = 13.249$, $p = 0.002$, $\eta_p^2 = 0.570$. There was no significant difference between pre- BLa for EDT (1.0 ± 0.2 mmol/L) and TRAD protocols (0.8 ± 0.2 mmol/L), $p = 0.997$. Table 3 provides an overview of the BLa pairwise comparisons. Mean elevations from baseline to 5- min post in BLa were significantly greater for EDT (7.4 ± 2.7 mmol/L) compared to TRAD (5.2 ± 2.1 mmol/L), $p < 0.001$. Additionally, 10- min post BLa was significantly greater for EDT (6.7 ± 2.7 mmol/L) compared to TRAD (4.4 ± 2.2 mmol/L), $p < 0.001$. There was a statistically significant exercise condition x time interaction for CK, $F (1, 10) = 5.382$, $p = 0.043$, $\eta_p^2 = 0.350$. Table 4 provides an overview of the CK pairwise comparisons. The CK levels after EDT (205.6 ± 111.2 IU/L) were significantly greater than before EDT (123.3 ± 74.9 IU/L), $p = 0.002$. However, the CK levels after TRAD (153.0 ± 92.8 IU/L) were not significantly different than the CK levels before TRAD (124.8 ± 64.9 IU/L), $p = 0.430$. Post EDT CK levels were significantly greater than post TRAD CK levels, $p = 0.037$.

Place Table 3 About Here

Place Table 4 About Here

Discussion

The primary purpose of this study was to provide a metabolic profile of EDT and compare it to the metabolic profile of a volume-load matched session of hypertrophy style training (TRAD). Our secondary purpose was to compare the perceptual responses (i.e., enjoyment and RPE) of EDT and TRAD. We hypothesized that EDT would elicit a greater cardiorespiratory, metabolic, and perceptual response compared to TRAD. This hypothesis was supported, as $\%VO_2max$, %HRmax, average HR, BLa, and RPE were all greater for EDT compared to volume-load matched TRAD. Further, higher aerobic and anaerobic energy expenditure occurred during the EDT trial compared to TRAD. Our second hypothesis was also supported, as there was no difference between enjoyment (PACES) for EDT and TRAD protocols. Additionally, muscle damage (CK) was significantly greater for the EDT compared to TRAD. These findings suggest that EDT may be an effective alternative to TRAD for eliciting increased metabolic demands.

To our knowledge, this is the first study to investigate the physiological response of an acute bout of EDT. Escalating density training has been proposed to elicit a greater physiological demand than TRAD (48). Our study confirms this hypothesis, as %VO_2max was significantly greater with EDT (56.2 ± 6.8%) compared to TRAD (23.7 ± 4.7%). Average VO_2 was greater for EDT (24.7 ± 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) compared to TRAD (10.4 ± 1.8 $ml \cdot kg^{-1} \cdot min^{-1}$). Average HR and %HRmax during EDT were significantly greater than TRAD (Table 2). Based on VO_2 and HR responses, EDT may qualify as a moderate aerobic exercise (28). Only one study has compared VO_2 with superset RT and TRAD. In this study, Realzola and colleagues found that superset RT resulted in an increased VO_2 and HR response compared to TRAD (38). Similarly, other RT modalities (i.e., circuit weight training) have demonstrated the ability to increase VO_2 to percentages that satisfy the ACSM guidelines for improving cardiorespiratory fitness (CRF) (4,8,32). Interestingly, total energy expenditure was significantly greater during EDT compared to TRAD. This is of significance as EDT bouts lasted 15 min where TRAD took 43.2 ± 10.2 min. Moreover, EDT elicited a rate of aerobic energy expenditure of (27.0 ± 6.9 $kJ \cdot min^{-1}$) which was significantly greater than TRAD (10.0 ± 8.0 $kJ \cdot min^{-1}$). These data from the EDT bout are similar to that of more aerobic circuit weight training protocols (3,19).

High mechanical work is generally associated with an increased production of energy via anaerobic metabolism (45). Specifically, with high density RT, there is a greater reliance on anaerobic metabolism, resulting in an increase in BLa production and accumulation of hydrogen ions (39,40). In the current study, rate of anaerobic energy expenditure was significantly greater during EDT compared to TRAD. Consequently, BLa was significantly higher 5- and 10-minutes post- exercise (Table 4). Similar results were reported by Kelleher et al. (24) who found a significantly higher concentration of BLa following superset RT compared to TRAD in resistance trained men. These authors propose that increases in BLa are a result of decreased RI duration. Moreover, Realzola et al. (38) found similar increase in BLa in both men and women following an acute bout of superset RT. These increases in metabolic responses (i.e., blood lactate), result in an increased perceived intensity. For example, previous studies investigating superset RT have demonstrated that increases in BLa coincide with increases in ratings of perceived exertion (21,34). Mang and colleagues (32) report similar findings when RT is performed in a circuit type manner compared to TRAD. Similar to these studies, the current study found that session RPE was significantly greater following an acute bout of EDT compared to a volume-matched TRAD session. Interestingly, PACES did not reveal a difference in level of enjoyment between EDT and TRAD. These findings are in agreement with a recent study by Andersen and colleagues (1) which demonstrated no difference in exercise enjoyment between superset and TRAD RT sessions. Since perceived enjoyment is similar between TRAD and time-efficient RT sessions, strength and conditioning professionals should let time availability and preference drive training style.

Serum CK activity was used to assess muscle damage. Creatine kinase is an intramuscular protein that is most noticeable following eccentric muscle actions, or vigorous-muscle damaging exercise (2). Following damaging exercise, there is disruption in the sarcolemma and Z-disks structure and thus, increased membrane permeability (26). The increased membrane permeability allows CK to leak into interstitial fluid, where it then enters circulation via the lymphatic system and is later cleared from the blood by the reticuloendothelial system (2), which justifies the delayed release of CK into circulation. Moreover, it has been suggested that CK peaks around 24-72 hours post exercise (5,9). Thus, the current study investigated differences in CK pre- and 48-hours post exercise. There were no differences between pre-CK values between protocols. For TRAD, there was no significant difference between pre- and post-CK levels. However, EDT elicited significant increases from pre- to 48-hours post-exercise. Furthermore, 48-hour post-exercise CK for EDT was significantly greater than CK following TRAD (Table 4). Previous studies investigating time-efficient RT techniques have shown similar findings (28,41,45). For example, Weakley et al. (51) found that superset RT results in greater CK than TRAD 24 hours post-exercise. Similarly, Mayhew et al. (33) found that short RI (i.e., 1 min) results in greater CK levels 24 hours post-exercise when compared to a volume-equated session of RT with a longer RI (i.e. 3 min). Collectively, the research suggests that time-efficient RT programs, like EDT, result in greater muscle damage than TRAD. This is of significance as muscle damage triggers growth mechanisms that produce an increase in muscle protein synthesis to repair damaged tissue resulting in hypertrophic adaptations (30,31,43).

A limitation to this study is that the sample consisted of healthy, physically active women and men between the ages of 18-45 years who participate in regular resistance and cardiovascular exercise. Therefore, the results of this study should be applied to populations with different ages and training statuses with caution. Since CK values were elevated following EDT, understanding perceived muscle soreness may have provided further explanation of perceptual responses; thus, lack of perceived pain and soreness was a limitation. Further, both protocols in the current study were performed using machine CP and LP for safety and convenience. Performing free-weight exercises close to failure may have increased likelihood of injury. In the real-world setting, it is likely that lifters will use a variety of exercises when performing a session of EDT. Another limitation is that BLa sampling from the ear was used as a proxy measurement of metabolic stress. Other techniques such as isotope tracers and muscle biopsies may provide a more detailed analysis of lactate concentrations within working muscle during exercise, however these procedures are more invasive and therefore less common. Noteworthy, Chwalkbinska-Moneta et al. (7) found muscle and blood lactate concentrations to be highly correlated ($r = 0.91$). Further, the current study examined the BLa response pre- and post-exercise. Future studies should compare BLa response before, during, and after EDT. A final limitation for this study is that EDT and TRAD trials were not randomized or counterbalanced. EDT trials were performed first for each participant so that volume could be matched during the TRAD trial. This methodology has been used in previous research (21,34).

Practical Application

The current study shows that EDT elicits a higher physiological demand compared to volume-load equated TRAD. Further, EDT may provide similar benefits of moderate intensity aerobic exercise to improve CRF. Of note, EDT only took 15 min to complete compared to 43 minutes for TRAD. Thus, EDT may be used as a more time-efficient exercise regimen to elicit increased metabolic demand. Due to increased energy expenditure, EDT may be an effective training method for individuals seeking to increase caloric expenditure and potentially improve body composition. However, more data are needed investigating the long-term effects of EDT.

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Tables and figures

Table 1. Participant characteristics (N= 12).

Characteristic	**All (*n*= 12)**	**Male (*n*=6)**	**Female (*n*= 6)**
Age (years)	21.4 ± 3.0	22 ± 3.8	20.8 ± 2
Weight (kg)	69.8 ± 7.9	74.4 ± 7.3	65.3 ± 6.1
Height (cm)	172.9 ± 12.4	177.8 ± 5.6	163.1 ± 13.5
Body Fat (%)	15.1 ± 6.8	10.2 ± 4.9	20.1 ± 4.1
VO_2max (ml · kg^{-1} · min^{-1})	44.7 ± 9.2	52 ± 6.9	37.4 ± 3.1
HRmax (bpm)	192.0 ± 14	192.5 ±13.7	191 ± 15
Chest Press 10- RM (kg)	60.5 ± 19.2	75.6 ± 12	45.4 ± 11.1
Leg Press 10- RM (kg)	175 ± 21.5	178.9 ± 19.2	171.2 ± 24.9
Chest Press TVL (kg)	3, 485.8 ± 1147.8	3, 975.8 ± 1, 163.3	2, 995.8 ± 984.2
Leg Press TVL (kg)	10, 994.5 ± 2, 422.2	10, 685 ± 984.2	11, 304 ± 3, 421.8

Data are displayed as means ± standard deviation. cm, centimeters; kg, kilograms; BF (%) = body fat percentage; VO2max, maximal oxygen consumption; ml, milliliters; min, minute; HR max, maximal heart rate achieved during exercise test; RM, repetition maximum; TVL, total volume load.

Table 2. Comparisons between EDT and TRAD for average VO2, %VO2max, average HR, %HRmax, average rate of aerobic EE before exercise, average rate of aerobic and anaerobic EE during exercise, average rate of total EE during exercise, total exercise EE, average aerobic EE after exercise, average absolute EE after exercise, RPE, and PACES. N=12.

Dependent Variable	**Condition**	**Mean ± SD**	***F***	***p*-value**	**Effect Size (η_p^2)**
Avg VO_2	EDT	24.7 ± 3.5*	185.720	< 0.001	0.949
($ml \cdot kg^{-1} \cdot min^{-1}$)	TRAD	10.4 ± 1.8			
$\%VO_{2max}$	EDT	56.2 ± 6.8*	157.826	< 0.001	0.940
	TRAD	23.7 ± 4.7			
HR (bpm)	EDT	151 ± 12*	56.426	<0.001	0.849
	TRAD	110 ± 12			
%HRmax	EDT	78.9 ± 7.9*	7.535	0.021	0.430
	TRAD	53.0 ± 15.8			
Pre-Exercise VO_2	EDT	4.7 ± 1.0	3.632	0.086	0.266
($ml \cdot kg^{-1} \cdot min^{-1}$)	TRAD	4.9 ± 1.3			
Pre-Exercise Aerobic	EDT	6.9 ± 1.9	3.523	0.090	0.261
EE ($kJ \cdot min^{-1}$)	TRAD	7.2 ± 1.9			
Exercise Aerobic EE	EDT	27.0 ± 6.9*	25.440	< 0.001	0.718
($kJ \cdot min^{-1}$)	TRAD	10.0 ± 8.0			
Exercise Anaerobic	EDT	28.9 ± 13.1*	12.851	0.005	0.562
EE ($kJ \cdot min^{-1}$)	TRAD	19.5 ± 10.0			

Total Exercise EE	EDT	929.2 ± 245.9	2.069	0.181	0.171
(kJ)	TRAD	1,267.7 ± 592.5			
Post-Exercise	EDT	4.5 ± 1.4*	19.685	0.001	0.663
Aerobic EE ($kJ·min^{-1}$)	TRAD	1.4 ± 2.2			
Absolute	EDT	90.9 ± 30.3*	19.680	0.001	0.663
Post-Exercise EE (kJ)	TRAD	27.4 ± 4.6			
RPE	EDT	8.8 ± 0.8*	37.895	< 0.001	0.791
	TRAD	5.5 ± 1.9			
PACES	EDT	48.1 ± 13.3	2.119	0.176	0.175
	TRAD	66.9 ± 17.3			

Data are displayed as means ± standard deviation. Avg; average; EDT, escalating density training; TRAD, traditional resistance training; VO2, oxygen consumption; ml, milliliters; min, minute; kg, kilogram; %VO2, percentage of maximal oxygen consumption achieved during exercise test; HR, heart rate; %HRmax, percentage of maximal heart rate achieved during exercise test; EE, energy expenditure; kJ, kilojoule; RPE, rating of perceived exertion; PACES, physical activity enjoyment scale. *Significantly different than TRAD, $p < 0 .05$.

Table 3. Blood lactate values before exercise, 5 minutes post-exercise, and 10 minutes post-exercise. N=12

Condition	**Time**	**Mean ± SD (mmol/L)**
EDT	Pre-exercise	1.0 ± 0.2
	Post-exercise 5 min	7.4 ± 2.7*§
	Post-exercise 10 min	6.7 ± 2.7*§
TRAD	Pre-exercise	0.8 ± 0.2
	Post-exercise 5 min	5.2 ± 2.1§
	Post-exercise 10 min	4.4 ± 2.2§

EDT= Escalating density training, TRAD= traditional resistance training, min= minutes.

* Statistically greater than TRAD, $p < 0.05$

§ statistically greater than pre within same condition

Table 4. Creatine kinase levels before and after the EDT and TRAD sessions. N = 12.

Condition	**Time**	**Mean ± SD (UI/L)**
EDT	Pre-exercise CK	123.3 ± 74.9
	Post-exercise CK	205.7 ± 111.2*§
TRAD	Pre-exercise CK	124.8 ± 64.9
	Post-exercise CK	153.0 ± 92.8

EDT= Escalating density training, TRAD= traditional resistance training, min= minutes, CK= creatine kinase.

* Statistically greater than TRAD Post-exercise CK, $p < 0.05$

§ statistically greater than EDT Pre-exercise CK, $p < 0.05$

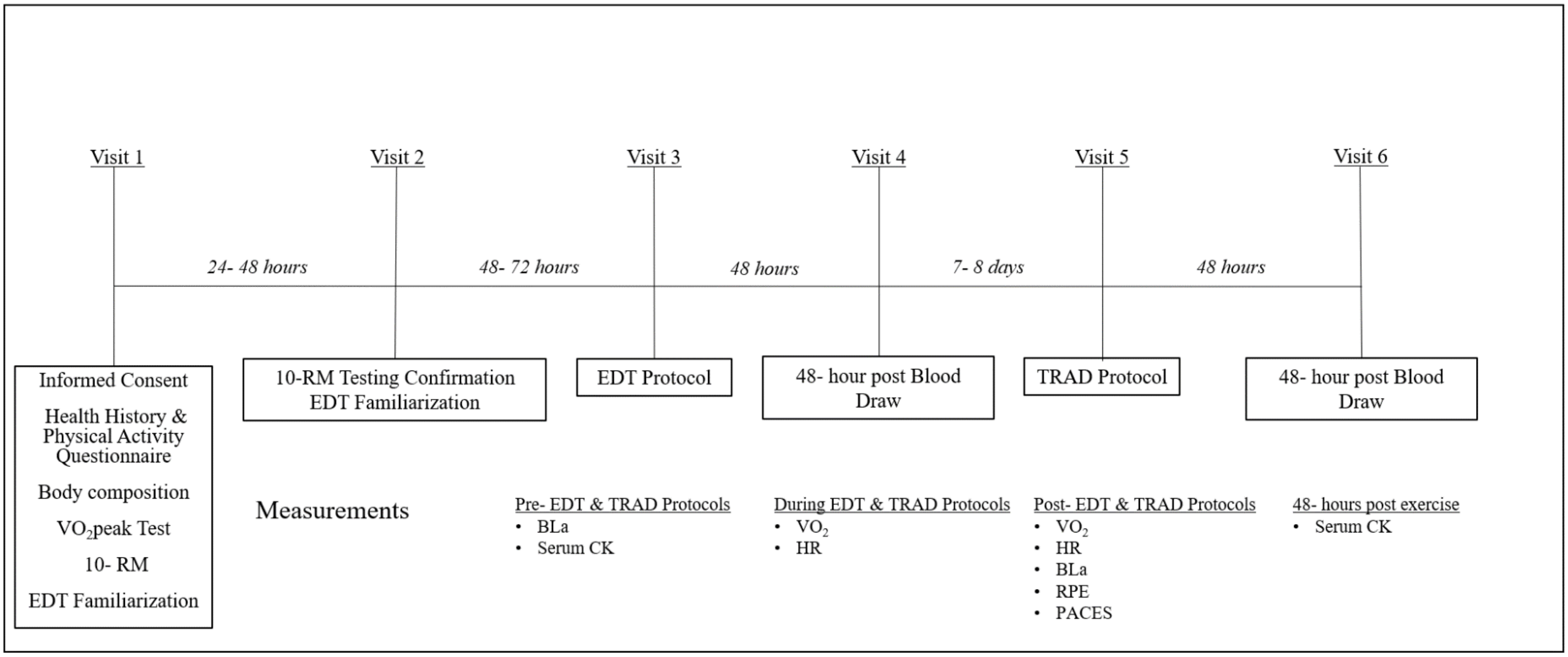

Figure 1. Summary of study design. EDT, escalating density training; RM, repetition maximum; BLa, blood lactate; CK, creatine kinase; TRAD, traditional resistance training protocol; VO_2, oxygen consumption; HR, heart rate; RPE, rating of perceived exertion; PACES, physical activity enjoyment scale.

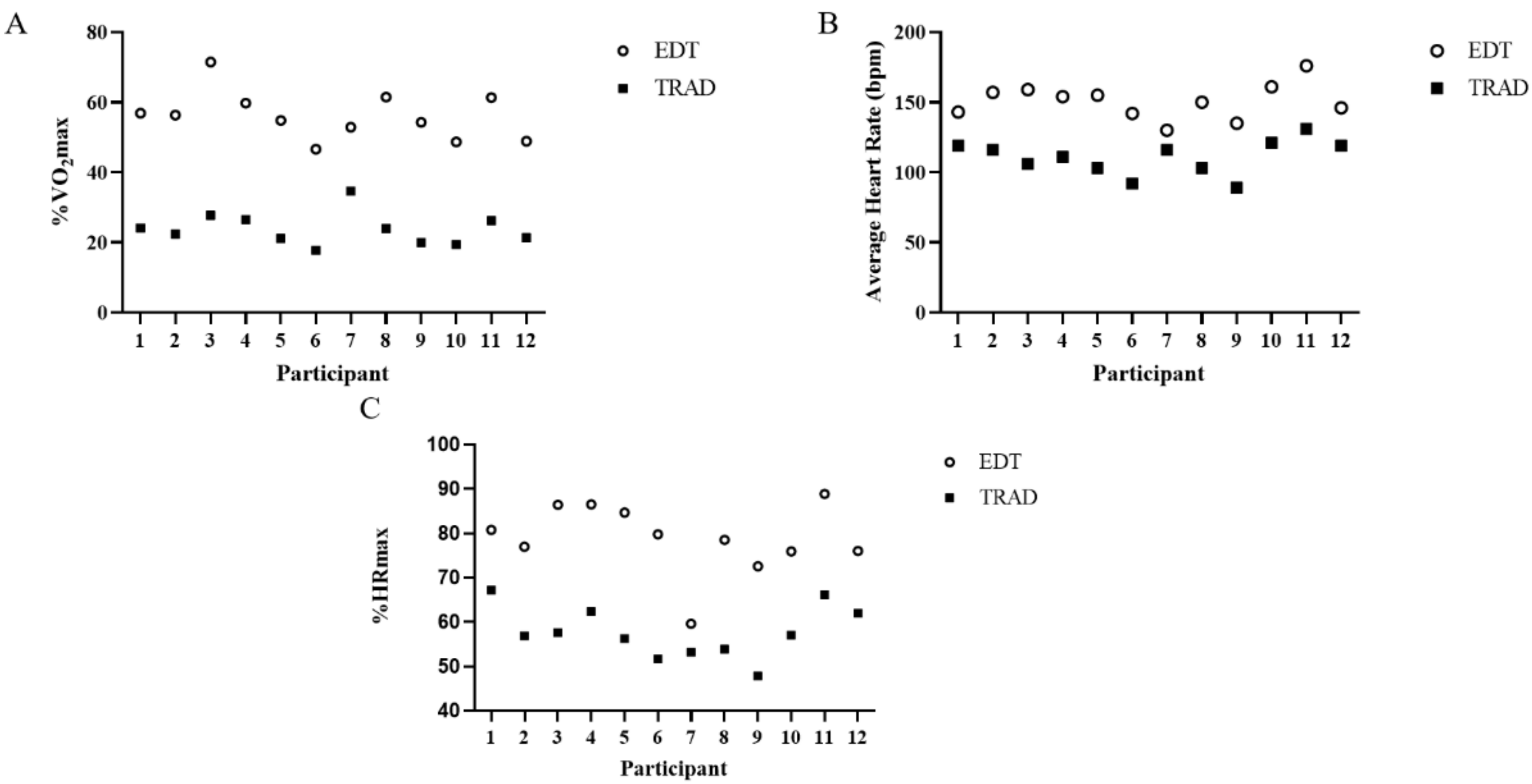

Figure 2. (A) %VO_2max for EDT and TRAD. (B) Average heart rate for EDT and TRAD. (C) %HRmax for EDT and TRAD. EDT, escalating density training; TRAD, traditional resistance training.

CHAPTER IV: Summary, Conclusions, and Recommendations

Summary & Conclusions

Resistance training (RT) is a well-established effective method for developing muscular fitness [1]. Health benefits associated with RT include increased resting metabolic rate, improved glucose metabolism, improved bone mineral density, decreased gastrointestinal transit time, and improved cardiorespiratory fitness [2–5]. Recently, global interest in time-efficient exercise modalities that improve both cardiorespiratory and muscular fitness has increased [6]. As mentioned in Chapter 1, escalating density training (EDT) is a relatively new, but popular training method that was developed in order to increase muscular hypertrophy and enhance cardiovascular fitness parameters in a time-efficient manner. However, there is no literature supporting such hypothesis.

In chapter 2, we present a review entitled "Escalating Density Training: Potential Molecular Mechanisms and Benefits" which encompasses relevant peer-reviewed literature investigating the acute physiological response to high-intensity interval training (HIIT), high-intensity resistance training (HIRT) and traditional resistance training (TRAD) which lead to long-term adaptations that improve measures of cardiorespiratory fitness and muscular strength and hypertrophy. Additionally, chapter 2 reviews the characteristics of EDT and provides a case for how EDT may elicit similar physiologic responses which could potentially lead to long-term adaptations like those observed in the aforementioned training styles.

The research manuscript entitled, "A metabolic profile of escalating density training" found in chapter 3 provides evidence that EDT induces higher physiological demanding exercise compared to TRAD in physically active, resistance-trained men and women. Specifically, we analyzed the following variables to look for differences between the two protocols: 1) average oxygen consumption (VO_2), 2) percent of maximal oxygen consumption (%VO_2max), 3) average heart rate (HR), 4) percent of heart rate max (%HRmax), 5) energy expenditure, 6) rating of perceived exertion (RPE), 7) ratings of enjoyment for each workout, 8) blood lactate, and 9) creatine kinase. EDT elicited a greater response in all physiological measurements without a difference in enjoyment. However, there was a significant difference in RPE, with EDT being perceived as a more intense training modality.

When volume is matched, EDT leads to significantly greater VO_2, %VO_2, HR, %HRmax, aerobic energy expenditure, anaerobic energy expenditure, RPE, BLa, and CK compared to TRAD. Although EDT was more physiologically and perceptually demanding, there was no difference in exercise enjoyment. Thus, while speculative, we conclude that EDT may serve as an alternative to elicit similar if not greater long-term musculoskeletal adaptations. Moreover, EDT may provide a strong enough stimulus to improve cardiorespiratory fitness. More research is needed to corroborate these findings.

Recommendations

Future researchers should replicate our design and provide data for acute physiological responses observed with EDT with various training durations (i.e., 5 vs. 10 min), repetition ranges (i.e. 5, 10, or 15 repetitions), relative intensities (i.e., 5 RM vs. 15 RM), and exercises (push + pull vs. upper + lower). Moreover, acute investigations comparing acute bouts of EDT to HIIT and circuit weight training (CWT) may provide a better understanding for the overall response elicited by EDT. From there, training studies are necessary to see if EDT, HIIT, and CWT elicit similar outcomes for body composition, muscular strength, and measures of aerobic fitness (i.e., VO_2max).

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