Endurance and Resistance Exercise: Acute Postprandial Responses and Chronic Training Adaptations

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ABSTRACT OF THE DISSERTATION

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Obesity is linked to lower lipid oxidation and elevations in resting and postprandial triglyceride (TG) concentrations, and is associated with many chronic disease risks including CVD. Exercise is commonly used to overcome such disruptions in lipid dynamics, but the comparison of various exercise modalities and their role in rectifying such metabolic inadequacies is scarce.

Using the ingestion of isotope labeled [U-13C] palmitate, we investigated postprandial TG and fatty acid (FA) metabolism and the contributing hormonal changes from an acute bout of endurance (E) and resistance (R) exercise in obese women. In comparison to a sedentary control condition, we found significantly elevated exogenous and endogenous derived lipid oxidation during the postprandial period in both E and R. Analysis of plasma FA and TG concentration revealed significant attenuations in endogenously derived TG, and elevations in exogenously derived plasma FA. The only significant change as a function of condition in hormone concentration during the postprandial period was for growth hormone (GH), which was significantly elevated in both E and R in comparison to a sedentary control.

While combining both E and R within the same exercise session in a chronic exercise regimen results in improvements in body composition and fitness, there is still considerable debate as to whether there is a benefit to performing E either before or after R. We investigated the concurrent ordering (E-R, R-E) of 60 min combined E + R during an 8-week intervention to determine potential differences in body composition and physical fitness in inactive women. We found that combined E and R significantly increased aerobic capacity, upper and lower body strength, as well as FFM regardless of the order they were performed.

In summary, compared to a sedentary control, a pre-meal bout of exercise enhances the postprandial rise in growth hormone in obese women. This is associated with enhanced whole body fatty acid oxidation and reduced appearance of only endogenously derived TG in the bloodstream. These results were unaffected by type of exercise (E or R). In a separate study of combined E and R, the order of exercise had no impact on fitness parameters and both groups improved over an 8-week intervention. Collectively, these data suggest that E and R have equivalent and beneficial effects on postprandial fat trafficking and physical fitness in untrained women.

Dedication

I would like to dedicate this dissertation to my loving family. To my parents, who have inspired and helped me become the man that I am today. Without your love and encouragement all these years I would not know what it means to be blessed. It is my hope that my children appreciate me half as much as I do you.

To my dear wife, Edyta, who has stuck by me through these many years whether they were frustrating, stressful, or destined to take forever. You have inspired me every day to pour my heart and soul into my work. Your love, kindness, and compassion has made me thank God that I have been so lucky to have found someone as wonderful and beautiful as you to share my life with. Thank you.

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Abbreviations

10RM	10 repetition maximum
ACSM	American college of sports medicine
AHA	American heart association
AT	Anaerobic threshold
BMI	Body mass index
C	Control
CHD	Coronary heart disease
CHO	Carbohydrate
CR	Calorie restricted
CVD	Cardiovascular disease
E	Endurance exercise
EE	Energy expenditure
EEE	Energy Expenditure of exercise
EER	Estimated energy requirement
ES	Effect size
FA	Fatty acid
FFM	Fat-free mass
GH	Growth hormone
IDC	Indirect calorimetry
IE	Isotopic enrichment
IOM	Institute of medicine
IRMS	Isotope ratio mass spectrometry
FFM	Lean body mass
LC/MS	Liquid chromatography/mass spectroscopy
LPL	Lipoprotein lipase
PAL	Physical activity level
R	Resistance training
RER	Respiratory exchange ratio
RQ	Respiratory quotient
T2D	Type 2 diabetes mellitus
TG	Triglyceride
TLC	Thin layer chromatography
UUN	Urinary urea nitrogen
VCO2	Carbon dioxide production
VLDL	Very-low density lipoprotein
VO2	Oxygen consumption
WHO	World health organization

Chapter 1.

Introduction: Background and Significance

Obesity, lipid metabolism and health

The accumulation of body fat is mainly caused by the intake of calories beyond what the body metabolizes for fuel, thus storing the excess calories as fat, specifically triglycerides (TG). Overweight and Obesity are defined as a condition in which a person has excessive weight and fat accumulation in the body, with a body mass index (BMI) of 25-29 kg/m^2 and $\geq 30kg/m^2$, respectively (22). For the general population, it has been agreed upon by the World Health Organization (WHO) to use BMI as the classification of overweight and obese individuals (95). There are many health risks either directly or indirectly associated with being overweight or obese, including hypertension, type 2 diabetes mellitus, hyperlipidemia, coronary heart disease (CHD), insulin resistance, stroke, sleep apnea, gallstones, cancer, and even reduced life expectancy (55, 148, 192). In addition, physical inactivity is positively correlated with BMI, and both physical inactivity and BMI are directly linked with increased risk of morbidity and mortality and various chronic disease risks (18, 101, 145).

Reducing one's body weight, specifically body fat, within an overweight or obese population, has been demonstrated to significantly improve health (3, 6, 17, 75, 192). Weight loss that is demonstrated to be beneficial to one's health is referring primarily to the loss of TG, the body's storage form of fat (3). The majority of these TGs are what comprise adipose tissue within the body. The oxidation of the fatty acid (FA) chains in TG is the only appreciable way, physiologically, to reduce the TGs stored within the body. Studying the oxidation of FAs in the fasted or postprandial (after a meal) state allows researchers the opportunity to identify similarities or differences in the handling of these lipids among various groups of people, specifically obese versus lean individuals. It

has previously been shown that as body fat increases the ability to oxidize fat (i.e., g/min), is reduced (103). Similarly, a reduction in lipid oxidation has been associated with an increased risk in fat gain (27, 201). This means that obese individuals are at a disadvantage for losing body fat, as they have been shown to have a lower rate of lipid oxidation when compared to a lean counterpart (89, 103, 176). Thyfault et al. found an inverse correlation between BMI and palmitate (a saturated fat) oxidation (176). The more weight gained, the harder it seems to be to oxidize fat in order to lose the excess weight. In addition to the reduced lipid oxidation, obesity has also been correlated with an elevation in postprandial lipemia (elevated plasma TG excursion) (41, 120). Elevations in postprandial TG are associated with an increased risk for cardiovascular disease (CVD) (11, 58, 116, 137). To alter the oxidation rate of FAs, it is imperative that we utilize methods that may alter the body's metabolism. Interventions that may lead to a favorable postprandial FA oxidation and a reduction in postprandial excursion of TG will help promote fat loss and therefore improve one's health. One such method or intervention that has been employed is exercise.

Endurance exercise and resistance training

As early as 400 B.C, scholars such as Hippocrates wrote about and recommended exercise due to its health benefits (78). Research has continued to support the benefits of exercise including a reduction in relative risk for all-cause mortality, CHD, diabetes, hypertension, LDL cholesterol and TG, and improved insulin sensitivity and body composition (15, 74, 164). Current recommendations by the American Heart Association, the American College of Sports Medicine, and the Surgeon General's Report include

exercise as part of their overall strategy to reduce the risk of chronic diseases (5). The Institute of Medicine (IOM) even includes exercise in their dietary macronutrient intake recommendations for management of adiposity (91).

Much of the exercise research has studied endurance exercise (E) of moderate or vigorous intensity, which is reflected in an oxygen consumption (VO_2) of 40-60% VO_{2peak} and >60% VO_{2peak}, respectively (5). VO_{2peak} is the maximal rate, often expressed as mL/kg/min or L/min, of oxygen consumption recorded during a graded exercise test (84). Many of the exercise intensities used are based on the recommendations by major health and medical associations. For example, the American Heart Association (AHA) and the American College of Sports Medicine (ACSM) advise healthy adults under 65 years of age to exercise at moderate intensity for 30 minutes per day, five days a week or at vigorous intensity for 20 minutes per day, three days per week. They also recommend doing eight to 10 strength-training exercises for eight to twelve repetitions of each exercise, two to three times per week (5). For an improvement in health, the Institute of Medicine (IOM) recommends 60 minutes of E per day (91). Additional exercise may be needed to prevent weight gain, for weight loss, or to maintain weight loss. These physical activity recommendations are intended to maintain health and reduce the risk for developing chronic diseases. The research studying E commonly follows the recommended doses of exercise mentioned above as they may be more translational and practical.

Typical exercise recommendations are based on chronic exercise programs. While using chronic E for a loss of body fat has shown much promise, there tends to be a disparity among genders with multiple studies indicating significant body fat losses in

men, but less pronounced results in women (10, 44, 48, 49). A recent review notes that men appear to have greater weight loss in a specified time period when compared to women (49). For example, Donnelly et al. showed an exercise program caused a significant decrease (-5.2kg) in body weight in previously sedentary overweight men (48). Within the same study, age and BMI matched females completed the same E program and saw no decrease in weight, but they did see similar improvements in aerobic capacity. One explanation suggested was an absolute caloric expenditure difference: although the relative intensity achieved was the same for both men and women, men simply had more mass (kg) and therefore expended more total calories (kcal) within the same time period (48). The women were able to maintain their weight, fat mass, and BMI, which proved beneficial considering the control group gained 2.2kg of fat over the 16 months (48). The E may have been useful for preventative purposes rather than as a weight loss treatment per se. Despres et al. also studied the effectiveness of E on changes in fat mass and the alteration of lipolysis (44), but showed no significant changes in lipolysis in the women, even with the increased energy expenditure from exercise. However, there was a significant decrease in body fat percentage for the males (44). Given the health risks associated with excess body fat, the need to find a type of activity that will effectively help promote fat loss, especially in women, is crucial.

Resistance training (R) has often been found to decrease body fat to a degree equal to that of endurance training while simultaneously improving lean body mass (FFM) (185). FFM is characterized as total body mass minus all extractable fat, except essential fat that is required for normal functioning (129). R involves moving an external weight in order to strengthen a muscle or muscle group to be able to overcome the

resistance of that weight (129). As the muscles grow in strength, they are able to overcome a larger amount of external weight. In a 2-year study of overweight women, a R group significantly increased upper and lower body strength compared to a non-exercising control (159). In conjunction with caloric restriction (CR), Geliebter et al. compared the effects of R on body composition, against a CR plus aerobic group or CR only group. All three groups had significant weight loss (-7.8kg, -9.5, -9.6kg), but only the R group had attenuated FFM loss (60). Along with E, many traditional weight loss programs result in a loss of total fat, (~70% of total weight lost is from fat mass), with FFM being lost as well (60, 191). Some of the main improvements achieved in a R program are strength and the maintenance or increase in FFM. Dolezal et al. compared R to E and saw that an increase in FFM within the R group was related to a concomitant increase in BMR (47). The aerobic group, however, saw no change in FFM. Aside from FFM, R has often been promoted for its positive impact on a variety of health outcomes including insulin sensitivity, glucose metabolism, blood pressure, heart disease, and blood lipids (90, 92, 122, 133). In a R program with both males and females, significant improvements were seen in total cholesterol (TC), low-density lipoproteins (LDL), and TC to high-density lipoprotein (HDL) ratios (68, 149).

The chronic effects of either E or R typically include adaptations that are the result of transient responses after each individual exercise session. For example, after a 6-month E or R training program with consistent weight maintenance, Poehlman et al. demonstrated that E increased aerobic capacity significantly and R resulted in increased FFM, yet neither group had significant differences in daily total energy expenditure or respiratory exchange ratio (RER), which is a ratio of the CO_2 (mL) produced to the O_2

consumed (mL). The closer the ratio is to 0.70, the higher the percentage of oxidized lipids. As the ratio approaches 1.0 the body is shifting towards exclusive carbohydrate oxidation. A key component of this study is that the metabolic measurements were taken 72 hours after the last exercise bout (147). This indicates the potential importance of looking at the immediate effects that exercise has on metabolism (83, 124, 125). Acute effects may provide insight into the mechanisms behind weight loss or body composition changes, especially with regards to the oxidation of fat and effectiveness at reducing the excursion of postprandial TG.

Plasma TG, postprandial lipemia and lipid oxidation

Research has demonstrated a sustained hypotriglyceridemic effect lasting anywhere from several hours to several days following an acute bout of exercise (82, 175, 178, 179). As previously mentioned, hypertriglyceridemia is correlated with an increased risk of cardiovascular disease, so the ability to help attenuate a sustained rise in plasma TG is beneficial (11, 58, 137, 142). Considering that a person's resting metabolism accounts for a larger percentage of total daily energy expenditure than does the actual bout of exercise, the post-exercise alteration of resting metabolism is of great importance. As well, most individuals are in a postprandial state during a majority of their waking hours, so the ability to reduce the associated rise in plasma triglycerides is of value. This postprandial period lasts throughout the digestion, absorption, and elimination of dieatary contents. The ability to lower postprandial TG is enhanced by a prior acute bout of E (65, 66, 83, 99, 100, 127, 178, 179, 198, 199). This reduction in postprandial TG concentration is often concomitantly matched with an elevated lipid oxidation (40, 65,

80, 83, 126, 144, 178, 179). Henderson et al. indicated that fat oxidation was significantly elevated during 3 hours post-exercise in both males and females. However, it was only the males that had a significant elevation in lipid oxidation at 21 hours post-exercise (80). Even during the 3 hours post-exercise, the males had a higher lipid oxidation than the females. This warrants further investigation of the effects of E on post-exercise lipid metabolism in women.

An acute bout of R also has the ability to reduce postprandial lipemia (167, 197, 200). Given the similar improvement in lipid concentration and oxidation after a prior bout of either E or R, several studies have sought to compare the differences in magnitude between the two exercises (125, 144). The design of these studies had participants matching each E bout with the energy expenditure equivalence of the R bout. The studies' results indicate that even though the exercise bouts were energetically equal, only R was effective in reducing the post-exercise TG concentration, thus leading the authors to conclude that R is a more potent type of exercise. Given the low total caloric energy expenditure demand of R, and the higher caloric demands of E, this may have put E at a disadvantage in portraying the true impact of a more typical bout of E. As well, while the R prescribed in these two studies was similar to that recommended by current health agencies, the E used was not. This warrants further comparison of E and R on lipid dynamics.

Stable isotope tracers

To study fat metabolism, researchers need a variety of methods to analyze the dynamics of the fat pool within the body. Among these methods is the use of stable

isotope tracers to measure whole body lipid metabolism. The use of different isotope tracers has been around for many years and has proven to be very reliable and accurate for measurement of FA kinetics (193, 194). This methodology offers the advantage of being less invasive than arterial-venous (a-v) sampling (artery catheterization) or the administration of radioactive elements (162), while still retaining validity for the investigation of whole body fat metabolism (36). One use of stable isotope FAs allows investigators the ability to differentiate plasma FAs collected as well as trace the isotope FAs as they make their way throughout the body and ultimately end up being stored or oxidized. This is possible because isotopes are either slightly lighter or heavier than the normal elements found in the FAs, as they have a different number of neutrons. Two stable isotope FAs that are most commonly used, [^{13}C] oleate and [^{13}C] palmitate, are given to a subject orally or intravenously. Oleate and palmitate are among the most common unsaturated and saturated FAs, respectively, consumed in the American diet (1). The orally consumed tracer FAs make their way into circulation and behave with no substantial impact or disruption of unlabeled lipid. The purpose of using such tracers is the ability to "trace" and identify the dynamic fate of the dietary lipid. As labeled FAs make their way into circulation and begin to become oxidized, they will be released and show up in carbon dioxide. Through the collection of breath in conjunction with indirect calorimetry (IDC) and corresponding total fat oxidation rates, one is able to quantitatively calculate the contribution of dietary fat towards total lipid oxidation. As blood samples are taken, and with the use of thin layer chromatography (TLC), labeled TGs and FAs are isolated and quantified through liquid chromatography-mass spectrometry (LC/MS) (80, 143). Among its other uses, LC/MS allows investigators the opportunity to collectively

separate, isolate, and quantify various lipids through a process of ion separation and mass detection by measurement of the mass:charge ratio of variously charged particles (146). Given the increased CVD risk associated with lower lipid oxidation and obesity, one major advantage of this method is the ability to determine if the fat being oxidized is derived exogenously (dietary meal) or endogenously (within the body; stored and mobilized FAs). This trafficking of dietary fat has importance as chylomicron remnants have been linked with atherogenicity of lipoproteins (37).

The oxidation of fat with the stable isotope label will appear in the expired breath as labeled CO_2 and allows researchers to identify the rate of both endogenous and exogenous FA oxidation under a variety of situations. The use of exercise as a means of directing dietary fat towards oxidation rather than storage has many implications for its overall health and fat loss benefits. Employing the use of tracer methodology, researchers have been able to study the impact of various acute bouts of exercise on lipid oxidation with the contribution of total lipid oxidation separated into either exogenous or endogenous FAs (65, 182-184). In addition to studying the partitioning of dietary and endogenously derived FAs, researching is lacking that also studies the relative tracer-derived contribution and labeling of circulating TG and FFA. As obesity is associated with elevated TG concentrations in response to a meal, the examination of orally fed tracers to concomitantly track both lipid oxidation and plasma TG and FFA concentrations is pertinent.

The physiological changes that occur from either E or R are the result of the adaptations of the body to the stress that each exercise places on it. These changes are different for E and R because the physiological demands of each exercise are different. E

consists of activity that recruits the use of more oxidative muscle fibers with the adaptive goal of improving oxidative metabolism via enhanced mitochondrial and capillary density (129). R primarily requires the use of fast twitch muscle fibers that have less mitochondria, are primarily glycolytic and capable of generating large amounts of force and power (129). Most aerobic training is going to require more oxygen and will rely more heavily on lipid for fuel compared to R, which will rely more proportionately on carbohydrate (129).

Growth hormone and cortisol

Aside from dietary influence, the metabolic shift that occurs during the transition from exercise to post-exercise comes from the varying levels of hormones, including growth hormone and cortisol, which in turn will help determine the RER (140, 195). These metabolic shifts are typically measured during, immediately after, or within a few days of an acute bout of exercise (39, 52, 104, 141, 156, 174, 188, 195). The presence of these hormones typically indicates the body's reaction to the stress placed on it during the exercise and can often reflect changes in lipolysis. The magnitude of hormone secretion in response to the stress of exercise will vary depending on the intensity and duration of the exercise. Typically, as the intensity and duration increases, so does the amount of hormone secreted.

GH is a peptide hormone released from the anterior pituitary that results in elevated lipolysis, increased amino acid uptake, and lower glucose utilization. Higher intensity or longer duration exercise has been correlated with increased GH secretion (188). While GH does promote the release of FAs from stored TG within adipose tissue,

it also promotes the uptake of amino acids and protein synthesis and thus is considered an anabolic hormone (104, 113). Cortisol is a steroid hormone released from the adrenal cortex that results in catabolism of skeletal muscle (24), mobilization of fuels, and elevations in total body lipolysis (45, 46). Cortisol also causes an elevation in blood glucose through peripheral glucose sparing and the concomitant augmentation of hepatic glucose output via gluconeogenesis (102). While the acute effects of cortisol lead to the mobilization of stored fuel to provide metabolic tissues with energy substrates, one result of this is the degradation of skeletal muscle for the mobilization of amino acids. With exercise, cortisol will typically be released at times when other stress related hormones are released (GH and other growth factors), and it is because of this that both GH and cortisol are often measured in conjunction to assess the overall anabolic state (134). Both GH and cortisol have been directly linked with an intensity- and duration-based dose-response (168, 171, 189).

It has been commonly found that obese individuals have lower acute GH responses and increased cortisol responses to exercise (140, 195). Additionally, in a chronically elevated state often seen in obesity, cortisol has been shown to promote the net retention of fat (157). Wong et al. showed increased GH and cortisol secretion immediately post-exercise and up to 60 minutes following an aerobic exercise bout at 67-68% VO_{2peak} (195). Interestingly, they found a blunted GH response and an elevated cortisol response when comparing obese to the lean males. Kanaley et al. compared obese to lean females and looked at 6-hour integrated GH response, which included a 30 minute exercise bout at 70% VO_{2peak} (96). There was a significant increase in the GH response in the lean versus obese subjects. They repeated the 6-hour integrated GH response test in

the obese subjects after a 16-week aerobic training period and saw no change in GH response, even though there was a significant increase in VO_{2peak} (96). Ormsbee et al. have also shown a blunted GH and abdominal adipose tissue lipolytic response in obese versus lean subjects following a R exercise bout at 85% 10RM (140). GH is associated with elevations in lipolysis and subsequent increased FFA, which are directly related to elevations in lipid oxidation and lower RER (71) Both E and R exercise have produced a lower RER for multiple hours following a single exercise bout. Binzen et al. found a significantly lower RER two hours after R (0.75) versus a sedentary condition (0.85) which reflected a significantly elevated lipid oxidation rate after R (16). Marion-Latard et al. saw elevated GH and a lower RER following 60 minutes on a cycle ergometer at 50% VO_{2peak} when compared to a resting control (128).

While both R and E exercise have the ability to increase both GH and cortisol and augment lipolysis, each study has used different populations as well as intensities and durations of exercise. Some research has indicated the need for at least 20 minutes of E at 60-70% VO_{2peak} in order to see a significant GH response (98). Others have used a lower intensity but increased the duration (128). As with E, the response of GH to R varies with a variety of factors including intensity, rest period, and overall exercise volume. Performing 90% of a 10 repetition maximum (10RM) would constitute a higher intensity than only performing at 50% of the 10RM, and there is a linear correlation with increasing intensity and GH release (171). The 10RM is the maximal amount of weight that can be lifted for a given exercise for exactly 10 repetitions. Additionally, shorter rest periods (~1 minute) produce higher GH releases than longer rest periods (~3 minutes) (114). Increased GH levels are also seen after a higher-volume R session versus a lower-

volume session (3 sets versus 1 set) (114). Chronically, elevated GH is important because its presence signals the body to increase lipolysis and amino acid uptake and storage, which supports and can enhance FFM. In addition, GH positively promotes lipolysis and mobilization of FFA, which can aid in the partitioning of those FFA into oxidation and promote increased lipid oxidation. Given the blunted GH response in obese individuals, the potential use of different exercise modalities warrants further investigation.

To date, there exist very few studies looking at the relationship between the acute metabolic and hormonal changes produced by E or R and corresponding changes in lipid dynamics post-exercise. Further insight into a type of activity that can effectively enable women, particularly those who are overweight or obese, to lose fat or oxidize more lipid is crucial. Finding exercises that improve post-exercise lipid metabolism in women would be considered important and could lead to future chronic studies to look at the efficacy of E and R on body composition changes as well as other adaptations.

Combined endurance and resistance training

A person's physical fitness is defined as a series of attributes (e.g., aerobic capacity, muscular strength and endurance, flexibility) that enables them to perform physical activity and improves functional ability (8). In addition to the benefits that both E and R have towards lipid oxidation, plasma TG concentration, and the hormonal responses that may aid in the metabolic partitioning, these types of exercise do differ in their overall adaptations over time. Chronic participation in these two exercise modalities sheds light on the implications each has on body composition as well as changes in

aerobic capacity and strength. While E consists of metabolic adaptations that aim to improve cardiovascular circulation and oxidative metabolism, R chronically leads to increases in FFM and strength. However, when overall health is sought, a combination of E and R within the same exercise session may be the most promising solution in order to reap the benefits of both modalities.

When designing and prescribing an exercise program, the typical goal is to maximize benefit. While the combination of both E and R within the same exercise bout is practical, time efficient, and efficacious, there are data indicating that the combination may also impede the maximal benefits to be gained in comparison to performing each exercise modality alone. In a 12-week study, combining both modes of exercise into one session produced an increase in strength equal to that of an R-only group, and an increase in aerobic capacity equal to that of an E-only group (130). One problem with this study is that the combined group performed the same workout as both R-only and E-only groups, giving the combined group more total work. A 10-week study comparing the effects of E- or R-only to combined training found that R-only produced improvements in BMR and muscular strength, while E-only produced a decrease in body fat with an increase in aerobic capacity. The combined group provided similar benefits, but not always of the same magnitude (47). Nonetheless, the combined training did prove effective. Many of the studies showing an inferior fitness improvement are those comparing R-only to a combined E + R. The increases in strength are not always as great in the combined group as the R-only group (47, 85, 115). The reduction in strength seen after a bout of E has been attributed to a direct link with neuromuscular fatigue and reduced force production (59, 118).

Sequential ordering of combined exercise

While combining R and E into one session has been demonstrated to be effective for increasing strength and endurance, the sequence in which the exercises are performed may also be an important consideration if we hope to maximize benefits. A 12-week exercise intervention by Chtara et al. compared changes in aerobic capacity between an E-only, R-only, and two combined E + R groups. The combined groups differed in the sequence in which the training was performed (i.e., E-R or R-E). Interestingly, it was found that the order in which the combined group performed their exercises had a significant impact on both VO_{2peak} and a 4km time trial test. Performing E before R improved 4km time trial and VO_{2peak} significantly more than the other exercise sequence as well as either modality by itself (33). It was suggested that performing R before E fatigued the muscles that were used during the aerobic bout (33). It was concluded that, when aerobic capacity is the desired outcome, performing E and R in the same session is most beneficial when performing the E component first. However, other studies have shown attenuation in chronic strength gains when performing E prior to R in the same session (29, 138). This is contradictory to the findings of Chtara et. al and the explanation provided was that when E is performed prior to R, there is a diminished ability of the neuromuscular pathway that hinders the ability to recruit the muscle fibers required to perform the strength demanding exercise (118). Lepers et. al showed that moderate to vigorous intensity E resulted in a lower isometric and concentric muscle contraction ability when the R exercise bout is performed directly after the E (118). In agreement with that greater strength gains are seen when R is performed before E, Cadore et al. found a significant increase in strength gained in comparison to a group performing E-R

(29). It was also demonstrated that the increased strength gains were related to an increase in quality of muscle. When strength was compared per unit of muscle mass, there was a qualitative increase in the amount of force generated in the R-E (29). Within this same study, there was no difference in aerobic fitness gains between the exercise sequences (29).

The greater increases in strength gains when R is performed before E make sense when approached from a muscle recruitment standpoint. R requires rapid recruitment of muscle fibers with the ability of generating large amounts of force in a short period of time. Neuromuscular adaptations are amongst the main changes seen when individuals begin a R program (73). Hakkinen et al. describe the possible interference that performing E in conjunction with R plays in strength gains. They indicate that the neural activation for a specific motor unit plays a major role in the training adaptations to a R program, and the addition of a prior E bout may possibly impede the development of that neural activation ability required to elicit superior strength improvements (73). It should be noted, however, that although other studies have found significant improvements in both strength and power (as well as aerobic capacity) using combined E + R (34, 70), they did not necessarily see significant differences as a function of the order in which the modalities were performed. There still exists sparse or even conflicting research on the optimal order of R and E to maximize benefits from a practical program. Given the few studies that exist, coupled with the potential impacts on fitness and health, there is need to determine the effects that E and R have on specific desired outcomes (weight, body composition, strength, aerobic capacity) when combined into the same session but in different orders.

Specific Aims

Specific aim 1: To determine the post exercise lipid metabolism differences between endurance exercise (E), resistance training (R), and a sedentary control (C), in a population of sedentary, obese women. Lipid oxidation and plasma TG and FA composition were analyzed in a postprandial period after a prior bout of exercise. To better understand the postprandial partitioning of dietary FAs, through the investigation of palmitate oxidation, retention, and storage we used [U-13C] labeled palmitate given in a test meal to compare the exogenous and endogenous contributions of lipid towards lipid oxidation and plasma TG and FA concentration in sedentary obese women.

Specific aim 2: To examine the underlying hormonal concentration changes from equal duration E and R throughout a subsequent postprandial period, as compared to a sedentary time-matched control. To better understand the post-exercise effects on the catabolic and anabolic balance through the endocrine hormone response.

Specific Aim 3: To examine the body composition and fitness adaptations as a result of exercise order when E and R are combined into a single session over 8-weeks of chronic training. E and R have different metabolic and physiological demands and reports on the ordering of each exercise on strength gains, aerobic capacity and resultant body composition changes are mixed.

Chapter 2.

Postprandial triglyceride and free fatty acid metabolism in obese women after either endurance or resistance exercise

ABSTRACT

We investigated effects of two exercise modalities on postprandial triglyceride (TG) and free fatty acid (FFA) metabolism. Sedentary, obese women were studied on 3 occasions in randomized order: Endurance exercise for 60 min at 60-65% VO_{2peak} (E), ~60 min high-intensity resistance exercise (R), and a sedentary control trial (C). After exercise, a liquid mixed meal containing [U-^{13}C]palmitate was consumed and subjects were studied over 7 hours. Isotopic enrichment (IE) of plasma TG, plasma FFA, and breath carbon dioxide, compared with meal IE, indicated contribution of dietary fat to each pool. Total and endogenously derived plasma TG content was significantly reduced in both E and R compared to C ($P < 0.05$) with no effect of exercise on circulating exogenous (meal-derived) TG content. Exogenous plasma FFA content was significantly increased following both E and R compared with C ($P < 0.05$), while total and endogenous FFA was elevated only in E ($P < 0.05$) compared with C. Fatty acid oxidation rates were significantly increased after R and E as compared with C ($P < 0.05$) with no difference between the exercise modalities. The results reflect integration of TG and FFA metabolism following exercise. The present results indicate that R and E may be equally effective in reducing plasma TG levels and enhancing lipid oxidation. Importantly, tracer results indicated that the reduction in postprandial lipemia after E and R exercise bouts is not achieved by enhanced clearance of dietary fat, but rather is achieved by reduced circulating abundance of endogenously produced TG.

INTRODUCTION

Inadequate physical activity level (PAL) is associated with the accumulation of excess body fat, which is caused by positive fat balance (91). Obesity has been linked with many disease risks, including cardiovascular disease (CVD) and type 2 diabetes (T2D) (95, 148). Previously it has been reported that obese individuals exhibit a lower capacity for lipid oxidation when compared to their lean counterparts (89, 103, 176). A reduced ability to oxidize lipids could perpetuate propensity for gain and retention of body fat. Fed state plasma TG (postprandial lipemia) is elevated in obesity (41, 120) and is associated with increased CVD risk (11, 58, 116, 137, 169). Exercise can potentially address these metabolic alterations by altering resting metabolism for many hours after each session. People typically take a meal after exercise and are in the absorptive state for a majority of the day, and studies of the effects of exercise on postprandial metabolism are needed to improve understanding of the integration of metabolic processes and for preclinical testing of exercise efficacy.

Benefits of chronic exercise represent the accumulation of the acute benefits from each individual exercise bout, and chronic exercise can reduce CVD risk (91). An individual exercise bout can increase subsequent resting lipid oxidation (40, 65, 80, 83, 126, 144, 178, 179) and reduce postprandial plasma triglyceride concentration (2, 53, 63, 65, 66, 83, 99, 100, 126, 127, 167, 178, 179, 197-200). Postprandial plasma TG concentration is reduced by a prior acute bout of endurance exercise in men (53, 65, 83, 99, 100, 198, 199) and women (66, 127, 179). A prior single bout of resistance exercise has also shown efficacy for reducing postprandial lipemia in men (167, 197) and women

(200). Attempts have also been made to compare the modalities alongside one another in a single study; in these studies, bouts of E and R were design to match for energy expenditure. When doing so, the R bout was challenging (near the maximum intensity possible during the bout) while the E bout was quite easy, apparently approximately half (or even less) of the intensity that an individual could tolerate well (125, 144). So, not surprisingly, when matched for energy expenditure of exercise (EEE), R appears to be superior to E in its metabolic impacts on plasma TG metabolism and lipid oxidation (125, 144). E inherently entails a high EEE while R, though physiologically stressful in other ways, does not lead to high EEE when performed for a similar duration as E exercise. Matching EEE addresses an interesting biological question, but we believe that this study design does not optimize the translational nature of the resulting data. We sought to compare E and R in the present study in a manner that would be particularly translational and clinically relevant. We studied E and R bouts that were typical of those which may be attempted in an exercise program (matched for duration, each at a challenging intensity, each consistent with current exercise recommendations stating that higher intensities of exercise may carry additional benefits beyond those of lower intensities). In such an experimental design, applying a more challenging E bout could potentially refute the previous results that suggested inferiority of E vs. R.

As discussed above, though potency of E vs. R is still to be considered, generally a prior exercise bout reduces postprandial plasma TG concentration. In studies of post-exercise metabolism, stable isotope tracers can be potentially utilized to label meal FA content in order to track dietary fat and differentiate between exogenous (meal-derived) and endogenous FA contribution to the plasma TG excursion, plasma FFA, and lipid

oxidation. In a small number of studies, fatty acid tracers have been administered in post-exercise meals (65, 182-184), and a subset of this analytical potential was realized as exogenous FA oxidation was measured by isotope labelling of carbon dioxide. However, in light of the potential to also follow these tracers through other fates and pathways, we expanded this methodological approach to study the relative labelling of circulating TG and FFA as well. As obese individuals exhibit low lipid oxidation rates under sedentary conditions (103, 176) as well as exaggerated responses of plasma TG concentration to a meal (41, 120), we considered it important to study this population in attempts to manipulate lipid metabolism with exercise. To our knowledge this is the first study to use an oral fed tracer to track alterations in lipid oxidation as well as plasma TG and FFA concentrations and labelling after exercise.

Interventions that may lead to a favorable postprandial FA metabolism may assist in weight loss attempt and prevent weight gain as well as reduce CVD risk. Therefore, using the methodology of stable isotope tracers, we studied the effects of a pre-meal exercise bout on postprandial TG and FA metabolism over the course of a day, following time-matched exercise bouts of different modalities and compared the results to a sedentary control. We studied women who are traditionally under-represented as study participants in the exercise literature, and obese individuals because of a similar under-representation as well as a need to alter lipid metabolism in this group. We tested the hypothesis that FA oxidation in both exercise groups would increase during the post-exercise period, compared to the sedentary control. We also hypothesized that either exercise approach would lower plasma TG concentrations during the post-exercise period by reduction in both exogenous and endogenous fat content in circulation.

METHODS

Study Participants. 12 sedentary, premenopausal, obese (BMI > 30) women were recruited from Rutgers University, New Brunswick campus and surrounding community by posted notice. Participants were required to have partaken in less than 1h/wk of physical activity at moderate or higher intensity during the prior three months. Nine subjects were administered isotope tracer, while three were provided unlabeled meals and solely included in IDC analysis. Due to a technical error in labeled meal preparation for one participant, the total sample size was reduced to 8 for the tracer analyses but remained at 12 for IDC. Potential study participants underwent subsequent screening tests if they were disease-free as determined by health history questionnaire and were not taking medications known to affect energy metabolism. Female participants reported regular menstrual cycles (24-32 days); if taking oral contraceptives (OC), they were required to have been on them for at least 6 months, and were instructed to continue taking the OC for the duration of the study. Effects of menstrual cycle phase and OC were expected to be subtle compared to effects of exercise per se (32, 172), and the randomization of trial order was meant to balance any minor effects of menstrual cycle and OC phase on substrate metabolism. The procedures and risks were thoroughly explained to the study participants, and their written, informed consent was obtained. Rutgers University Institutional Review Board approved the study protocol (IRB no. 11-030R).

Screening tests. Fasting blood glucose was tested to confirm that all study participants were non-diabetic (glucose < 125 mg/dL). Study participants underwent a

progressive exercise test to assess aerobic capacity (VO_{2peak}) before beginning the study. The test and experimental trials were performed on a graded high-speed treadmill (Trackmaster, Newton, KS) and the VO_2 and VCO_2 measurements were made using a metabolic cart (Parvo medics TrueOne 2400). A continual progressive protocol was used to determine VO_2peak with an increase in workload at 3-minute intervals until volitional exhaustion (5). Body Composition was determined by measuring body volume via air displacement plethysmography using the BOD POD (Life Measurements Instruments, Concord, CA) as described in previous literature (43). Body composition and aerobic capacity, were tested on the same day. On two separate occasions; 1) each subject was familiarized with the entire resistance training protocol, and 2) administered a 10 repetition maximum test (10 RM) for each exercise (9).

Experimental design. With at least one week between trials, participants were studied under each of 3 conditions, each on separate occasions, assigned in a random order. Subjects were given a test meal 30 min after 1) 60 min of endurance exercise at 60-65% VO_2peak (E), 2) ~60 min of resistance exercise (R), and 3) a time-matched resting condition (C) and studied for a 400 min postprandial period. A study design schematic is shown in Figure 2-1.

Figure 2-1

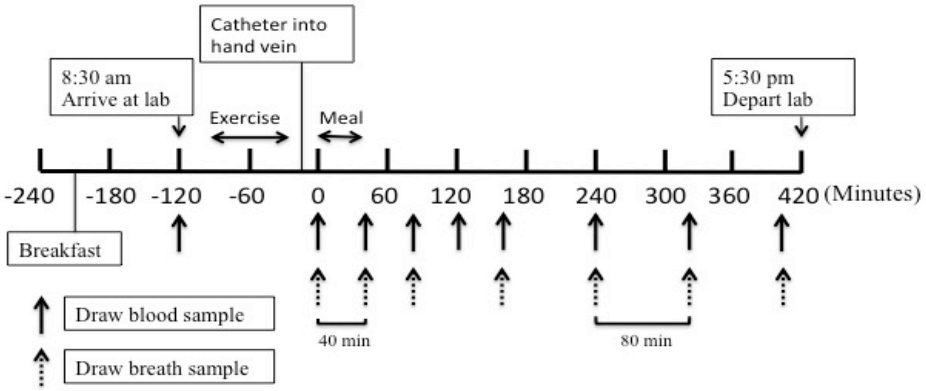


Figure 2-1. Experimental design. Each study participant completed 3 different experimental trials in randomized order, one involving endurance exercise (E), one involving resistance exercise (R), and one with no exercise (C). Minutes, time elapsed since study participant commenced meal consumption. E or R bouts performed from -90 to -30 min, or semi-supine rest during this time period in the C trial.

The day before each trial, study participants were instructed to consume solely their standardized diet and water *ad libitum*, and to abstain from structured physical exercise sessions but to continue typical activities of daily living and were fed for a physical activity level (PAL) of 1.4 according to the current dietary reference intake guidelines of the Institutes of Medicine (IOM) for daily estimated energy requirement (EER) (91). Dietary energy intake was individualized for each study participant (2294.0 ± 81.2 kcal/day) and macronutrient composition was made similar between individuals for carbohydrate (54.3 ± 0.7%), lipid (25.4 ± 0.5%), and protein (20.3 ± 0.4%). On the day of trials, study participants consumed a provided bagel at 7:30am (81.9% carbohydrate, 3.6% fat, 14.5% protein, 249kcal), and arrived at the laboratory at 8:30am. We chose to feed our study participants 1.5 h before exercise in order to increase tolerance of the exercise protocol.

Duration of E was exactly 60 min and the R bout was designed to be approximately 60 min. The intensity for E was 60-65% VO_2peak which in our experience approximates the maximum intensity that can be achieved consistently by sedentary people. The R trial was time-of-day matched and duration-matched, and consisted of 8 whole body exercises, with 3 sets and 10 repetitions of each exercise (Bench press, lat pull down, shoulder press, squat, leg curls, triceps pushdown, biceps curl, lunges) at 90 - 100% 10RM. If 10 repetitions in a given set could not be completed, the weight was reduced in order to complete 10 repetitions on the subsequent set. Prior to exercise, a single-use needle was used for the first blood draw. After the exercise session, study participants stepped off the treadmill and sat into a chair where venous catheters

were placed. The test meal was given 30 min post-exercise after which participants remained seated for the remaining 400 min of the postprandial period quietly reading or watching movies. On the day of the each trial, at the same time of day, a catheter was placed in a hand vein to obtain arterialized blood using the heated hand vein technique. In a previous study (87), blood was simultaneously drawn from the radial artery and from a heated hand vein, and there were no differences between blood sampling sites for glucose, glycerol, or palmitate isotopic enrichment (IE). The catheter was kept patent throughout the study day using a 0.9% saline solution. Water was consumed *ad libitum* during recovery but, aside from the test meal, study participants consumed no other beverages and no food until the 400 min postprandial measurement period ended. Study participants were transported in a wheelchair for trips to the restroom. During each trial, urine was collected and aliquots were taken and stored at -80°C for subsequent analysis of creatinine and urinary urea nitrogen (UUN).

To study the partitioning of dietary FA's post-exercise, [U-^{13}C]palmitate (Cambridge Isotope Laboratories, Andover, MA) was administered in a liquid test meal. 30-min after the termination of exercise, the post-exercise blood drawn and first indirect calorimetry (IDC) measurements were taken. Blood samples for the analysis of TG and FA concentration and palmitate isotopic enrichment (IE) were collected in tubes containing EDTA. At each breath sampling time point, pulmonary gas exchange was determined for assessment of metabolic rate and energy substrate partitioning and an aliquot of expired breath was collected in evacuated exetainer tubes for subsequent determination of $^{13}CO_2$ IE by isotope ratio mass spectrometry (IRMS).

The liquid test meal consisted of Boost Plus (Nestlé HealthCare Nutrition, Fremont, MI, USA) and evaporated milk, and was administered immediately following the post-exercise breath draw, which was 30-min after cessation of exercise. The test meal provided 20 kcal per kg fat-free mass (FFM) (46.2 ± 1.1% of EER). The palmitate isotopic tracer dose of 5mg per kg FFM was added to the test meal, which was heated to 90°C to ensure even mixing of the tracer into the test meal. The macronutrient composition of the drink was: 47.8% carbohydrate, 36.1% fat, and 16.1% protein (1076.4 ± 62.7 kcal), and the average total volume was 599.5 ±34.9 mL. In order to provide consistency participants were asked to consume the entire drink within 20 minutes. The sides of the container were scraped and that small remaining quantity also consumed. In an attempt to mimic non-laboratory conditions, we matched meal size between trials. The common finding has been that an acute bout of exercise does not increase subsequent hunger or ad libitum energy intake throughout the rest of the day (19, 20, 26, 88, 105-109, 123). To describe this phenomenon, previously the association between energy expenditure and energy intake has been described as being only a loose coupling (19).

Urine collection. Upon completion of exercise, subjects were wheeled to the restroom to void their bladder. This first urinary void was discarded such that UUN would be from the post-exercise period, and all subsequent voids were collected for the final analysis of nitrogen excretion and creatinine concentration. All urine collections from a trial over the 400 min postprandial period were pooled. At the end of the collection period, the urine volume was assessed, and an aliquot saved for subsequent analysis.

Calculation of energy and substrate oxidation. The last five minutes of each 10-minute breath measurement were used from pulmonary gas exchange to calculate rates of energy expenditure (EE), carbohydrate oxidation, and lipid oxidation (57). In the substrate oxidation calculations, we utilized non-protein RER values for each time point that we derived from RER and timed UUN excretion, assuming that percentage of resting metabolic rate fuelled by protein was consistent across the entire post-meal period. Assuming that each gram of UUN represents oxidation of 6.25 g protein (57), non-protein RER was calculated from RER. EE, carbohydrate oxidation, and lipid oxidation were calculated as kcal/min or kcal/kgFFM/min, and results from statistical analysis were similar between these two manners of expressing the data. In addition to data expressed at each individual time point, post-exercise averages (and those in the control trial at corresponding time-of-day) were calculated as area-under-the-curve multiplied by duration (i.e., time-weighted average), and incremental concentrations were calculated as time-weighted average minus pre-exercise baseline values.

Laboratory analyses. Glucose concentration was analysed enzymatically (Sigma-Aldrich, Saint Louis, MO) in plasma using a glucose oxidase and peroxidase reagent. Urine was analyzed for UUN content using an enzymatic urea nitrogen kit, which employs the Bethelot reaction (Stanbio labs, Boerne, TX). Timed UUN output was calculated as (nitrogen content x urine volume)/time interval, reported as g/min, and was used to correct substrate oxidation for protein oxidation. Creatinine concentration in urine was analyzed using a calorimetric assay using the Jaffe reaction (Oxford Biomedical Research, Oxford, MI). Assuming creatinine excretion is relatively constant

throughout the day, the UUN results were normalized to urinary creatinine concentration to derive a proxy index of protein oxidation.

Isolation of lipids. Following addition of known amounts of triheptadecanoin and heptadecanoic acid as internal standards, 0.5 mL of plasma for TG and FFA analysis was extracted with 4 ml of 30:70 heptane/isopropanol (v/v) and subsequently mixed with 2 ml 0.003M sulphuric acid. The organic layer was removed and then dried under N_2 gas, and the TG and FFA were isolated by thin layer chromatography (TLC) as previously described (80, 180). Standard lanes in TLC contained oleic acid and triolein and were visualized with iodine. The TG and FFA spots were scraped and extracted, and dried under nitrogen gas. FA's were re-suspended in 150 μL of 90% acetonitrile w/ 0.5 mM ammonium acetate. TG's underwent saponification using a 0.25M KOH in 90% ethanol solution and heated for 45 min at 80 degrees centigrade. Next, to extract the released FAs, we added 0.6mL 1M HCL and 4 mL hexane, mixed thoroughly and then centrifuged to separate phases and subsequently transferred the top layer (hexane). The sample was then dried under N_2 gas and the remaining lipid was re-suspended in 1.5 mL of 90% acetonitrile w/ 0.5mM ammonium acetate. Samples were then analysed by liquid chromatography/mass spectrometry (LC/MS) (Varian Inc, Walnut Creek, CA). For analysis of the liquid test meal, 10 μL of the test meal shake was combined with a known amount of heptadecanoic acid (internal standard). The mixture underwent saponification as described above and the organic phase of the subsequent hexane extraction was dried under nitrogen gas. Samples were then re-suspended in 90% acetonitrile w/ 0.5 mM ammonium acetate and analysed by LC/MS by the same method as employed for plasma samples.

Mass spectrometry. With minor modification, we employed the liquid chromatography/ mass spectrometry (LC/MS) method of Persson et al (143). Using an Agilent 1200 HPLC system, Ascentis C18 2.1 x 150mm column (Sigma-Aldrich) and Varian 1200L quadruple mass spectrometer with electrospray ionization, FA concentrations and palmitate IE were determined. Mobile phase A (mp-A) was 80% acetonitrile with 0.5mM ammonium acetate, and mobile phase B (mp-B) was 100% acetonitrile with 0.5 mM ammonium acetate. The flow rate was 0.4 mL/min, and FA's were eluted isocratically with 45% mobile phase A and 55% mobile phase B, followed by a column wash at higher organic strength. FA's were identified by retention time and mass-to-charge ratio (m/z). The following ions were selectively monitored in negative mode: Myristate (m/z 227), palmitoleate (m/z 253), palmitate (m/z 255), heptadecanoate (m/z 269), [U-^{13}C]palmitate (m/z 271), α-linolenate (m/z 277), linoleate (m/z 279), oleate (m/z 281), stearate (m/z 283), and arachidonate (m/z 303). Selected ion abundances were compared against external standard curves for calculation of concentration and IE. Aliquots of breath samples were sent to Metabolic Solutions (Nashua, NH, USA) for isotope ratio mass spectrometry (IRMS) measurements of $^{13}CO_2$.

Calculations for isotope data: Percent contribution of dietary fat to plasma TG and FFA was calculated as follows: $IE_{plasma}/IE_{meal}*100$, where IE_{plasma} represents isotopic enrichment of palmitate in either plasma TG or FFA, and IE_{meal} represents isotopic enrichment of meal palmitate. Absolute contents of exogenous (dietary) and endogenous TG and FFA were calculated from this derived percentage and the total concentration of TG and FFA in plasma. Breath $^{13}CO_2$ IEs were corrected for pre-meal baseline IE in each trial. The recovery $^{13}CO_2$ excretion rates were corrected using a bicarbonate retention

factor (81). $^{13}CO_2$ excretion could have been adjusted using a bicarbonate (81) or acetate correction factor (183). Such corrections in studies of post-exercise recovery do not alter the relationship between groups but will simply adjust rates upward from apparent rates indicated by the recovery of ^{13}C-tracer dose in breath CO_2. Bicarbonate retention (81) and acetate retention (183) return to baseline soon after exercise, so we expect the post-exercise $^{13}CO_2$ excretion rates measured in the present study to be proportional to the oxidation rate of the tracer. Furthermore, it has been reported that adiposity does not impact the bicarbonate (93) or acetate (176) correction factor. Oxidation of meal fat was calculated as the corrected percent recovery of [U-^{13}C]palmitate in breath CO_2, divided by 100 to convert percentage to decimal form, multiplied by fat content in the post-exercise meal.

Statistical analyses. Data are presented as mean ± standard error. 2-way comparisons between trials and across time points were made by analysis of variance with repeated measures (RM-ANOVA) with post hoc comparisons using Fisher's Protected Least Significant Difference test. Additionally, 1-way RM-ANOVA was used to compare the average values between trials. Statistical analyses were performed using JMP 10.0 software (SAS Institute Inc., Cary, NC). Statistical significance was set at $\alpha = 0.05$. Coefficient of variation (CV) for glucose, creatinine, and urea was 4.8, 0.4 and 8.9, respectively.

RESULTS

Characteristics of study participants and exercise bouts. Subject characteristics can be found in Table 2-1. All subjects were obese (BMI, 30.0 – 56.7; body fat, 45.4 ± 1.2%). E was time matched with R, and entailed 60 min of walking at an intensity of 61.9 ± 1.0% VO_{2peak}, with a gross exercise energy expenditure (EEE) of 430.8 ± 22.4 kcal. In the R trial, all 3 sets were completed by each study participant and every exercise at an intensity of 88.9 ± 2.3% of 10 RM. Habitual exercise participation was 0.5 ± 0.1 h/wk, indicating sedentary lifestyle status.

Metabolic rate and substrate partitioning. Average post-meal values are reported. During the post-exercise postprandial state, there were no significant trial-by-time interactions. The R trial VO_2 was significantly elevated above C but not statistically different from E (Table 2-2). VCO_2 was not significantly different between trials. In the post-exercise recovery period, RER was significantly lower in E and R in comparison to C (Table 2-2, Figure 2-2). There were significant main effects of trial ($P < 0.0001$) and of time but no time-by-trial interactions for RER. RER value contributions towards energy substrate partition are addressed below. Energy expenditure (EE) was not significantly different among groups when averaged throughout the post exercise time period (NSD). There was a main effect of trial for percentage of energy from fat and from carbohydrate (CHO). E and R groups derived a larger percentage of energy from fat compared with C ($P < 0.05$) and there was no significant difference between E and R (C, 28.76 ± 3.0; E, 37.39 ± 3.0; R,40.39 ± 3.0 %; $P < 0.0001$ for main effect of trial) (Figure 2-2). E and R groups derived a lower percentage of energy from CHO compared with C ($P < 0.05$) and there was no significant difference between E and R (C, 65.65 ± 2.1; E, 56.99 ± 2.1; R,

54.52 ± 2.1 %; P < 0.05 for main effect of trial) (Figure 2-2). There were no significant main effects of trial for percentage of energy derived from protein based on timed UUN (C, 1241.3 ± 333.4; E, 1304.0 ± 375.2; R, 1186.9 ± 406.9 mg/7h; (P > 0.05 for main effect of trial) and the urea-to-creatinine ratio in urine (C, 19.2 ± 4.5; E, 22.5 ± 5.4; R, 17.3 ± 5.6; P > 0.05 for main effect of trial) was not different between trials either. Accordingly, when considered across time during each trial, there was a significant main effect of trial for lipid oxidation (P = 0.0003); post hoc testing indicated significantly increased lipid oxidation (Figure 2-2) in E and R as compared with C with no difference between E and R (C, 0.40 ± 0.05; E, 0.52 ± 0.05; R, 0.58 ± 0.05 kcal/min).

Table 2-1

Age, yr	23.8 ± 1.6
Height, cm	162.7 ± 2.2
Weight, kg	99.4 ± 6.0
BMI, kg/m^2	37.5 ± 2.2
Body fat, %	45.4 ± 1.2
FFM (kg)	53.6 ± 3.1
Fat mass (kg)	45.3 ± 4.0
$\dot{V}O_2$peak, L/min	2.4 ± 0.1
$\dot{V}O_2$peak, mL/kg/min	25.1 ± 1.4
$\dot{V}O_2$peak, mL/kg FFM/min	46.3 ± 2.4

Table 2-1. Characteristics of study participants. Values are means ± SE. n = 12. $\dot{V}O_{2peak}$, peak O_2 consumption; BMI, body mass index; FFM, fat free mass; yr, years.

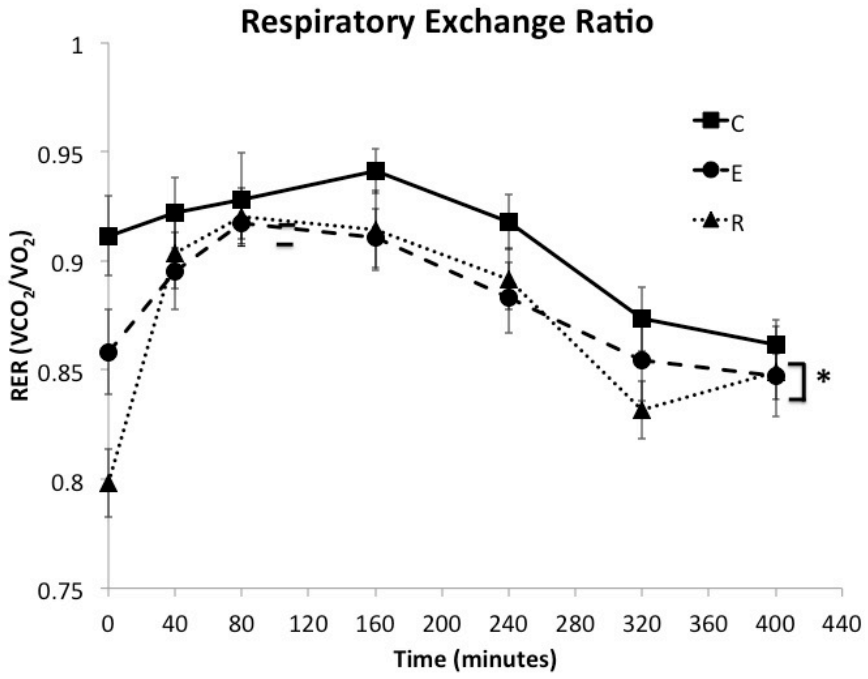
Table 2-2

	C	E	R
$\dot{V}O_2$, L/min	0.26 ± 0.01	0.27 ± 0.01	0.28 ± 0.01 *
$\dot{V}CO_2$, L/min	0.24 ± 0.01	0.24 ± 0.01	0.24 ± 0.01
RER	0.91 ± 0.01	0.88 ± 0.01*	0.87 ± 0.01 *
EE, kcal/min	1.37 ± 0.5	1.40 ± 0.5	1.43 ± 0.5

Table 2-2. Metabolic rate. Values are means ± SE. n = 12. Post-exercise metabolic rate, average of 400 min. $\dot{V}O_2$, oxygen consumption. $\dot{V}CO_2$, carbon dioxide production. RER, respiratory exchange ratio. EE, energy expenditure. * Significantly different from C trial, $P < 0.05$.

Figure 2-2

A


Respiratory Exchange Ratio
1
0.95
0.9
0.85
0.8
0.75
RER (VCO_2/VO_2)
C
E
R
*
0
40
80
120
160
200
240
280
320
360
400
440
Time (minutes)

B

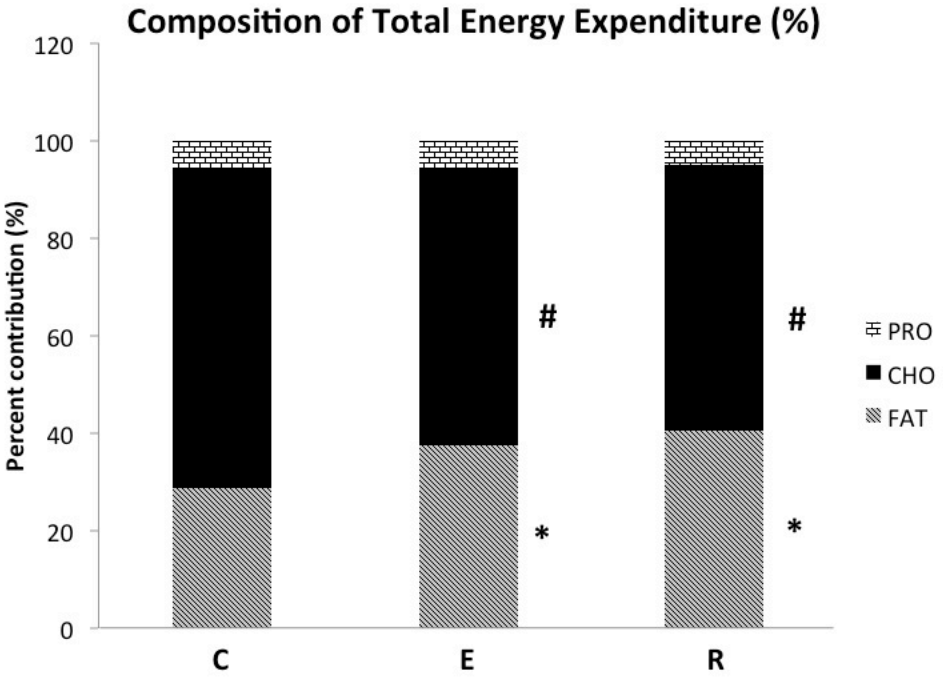

Composition of Total Energy Expenditure (%)
120
100
80
60
40
20
0
Percent contribution (%)
#
#
*
*
PRO
CHO
FAT
C
E
R

Figure 2-2 (cont.)

C

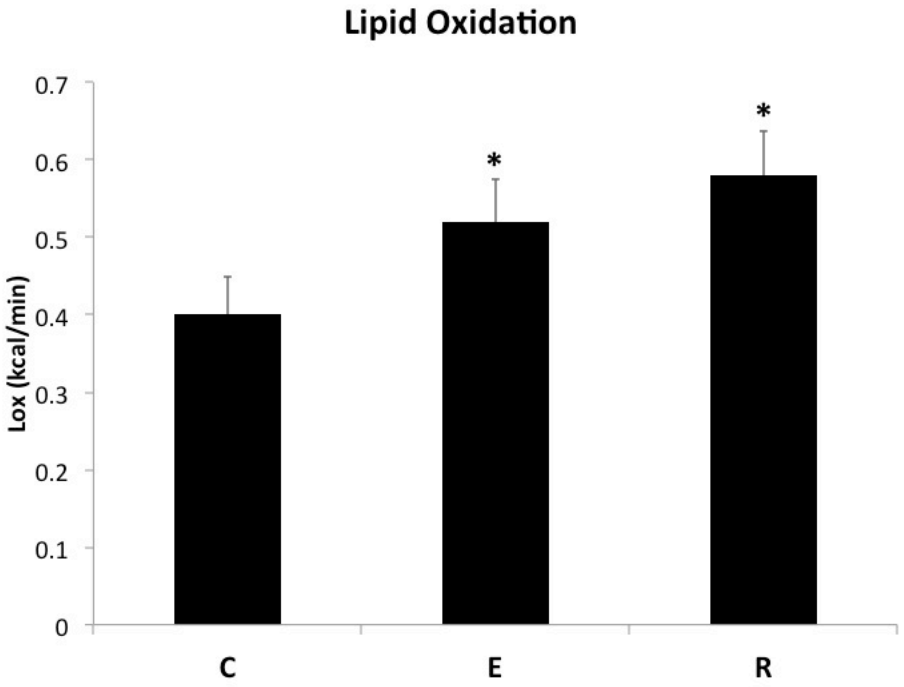
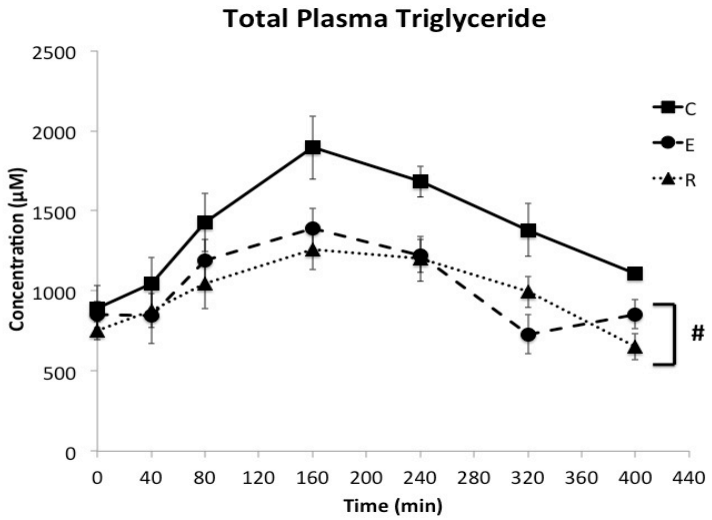


Figure 2-2. Indirect calorimetry and lipid oxidation. Values are means ± SE for average values across entire 400 min postprandial time period or matching time of day in control trial. n = 12. (A) Respiratory Exchange Ratio. RER was significantly lower following both exercise trials throughout the postprandial period. * E and R trials significantly different than C, $P < 0.05$. (B) Energy expenditure distribution. * E and R % energy derived from fat significantly different from C trial, $P < 0.05$. # E and R trials % energy derived from carbohydrate significantly different from C, $P < 0.05$. There was no significant difference between trials for protein. (C) FA oxidation rate. FA oxidation by indirect calorimetry. * Total lipid oxidation in E, R trial significantly different from C trial, $P < 0.05$. Significant differences represent main effects of trial in 2-way ANOVA or group differences in 1-way ANOVA. Main effects of time also observed ($P < 0.05$) but no significant time-by-trial interactions. RER, Respiratory Exchange Ratio. C, Control trial; E, aerobic exercise trial; R, resistance training trial; Lox, lipid oxidation.

Metabolite concentrations. The pre-exercise values for all blood measurements were not statistically different ($P > 0.05$). A main effect of time ($P < 0.05$) was observed for all metabolite concentrations reported. Though there was a main effect of time for postprandial glucose excursion time course, there was no main effect of trial or trial-by-time interactions (average post-exercise values: C, 105.7 ± 5.5; E, 106.4 ± 5.7; R, 102.6 ± 5.7 mg/dL, $P > 0.05$). The total plasma TG and incremental plasma TG concentration changes are shown in Figure 2-3. Both exercise conditions exhibited a significant decrease in average total plasma TG (E, 23.4% reduction; R, 27.2% reduction), compared to C (C, 1319 ± 64.9; E, 1010.1 ± 64.9; R, 960.1 ± 64.9 μM, $P < 0.05$). Plasma TG incremental concentration changes for R and E were only approximately half of the C value, and there was a significant main effect for trial with post hoc testing indicating that E and R were significantly different from C but not different from one another (C, 646.5 ± 75.8; E, 332.1 ± 75.8; R, 388.8 ± 75.8 μM, $P < 0.05$ for E and R vs. C) (Figure 2-3). Total FFA concentrations (C, 246.7 ± 21.6; E, 291.8 ± 21.6; R, 237.9 ± 21.6; μM) were significantly elevated in the E group versus R and C (22.6%, 18.3%, $P = 0.015$) (Figure 2-4). There was no statistically significant difference for FFA incremental concentration changes as a function of group.

Figure 2-3

A



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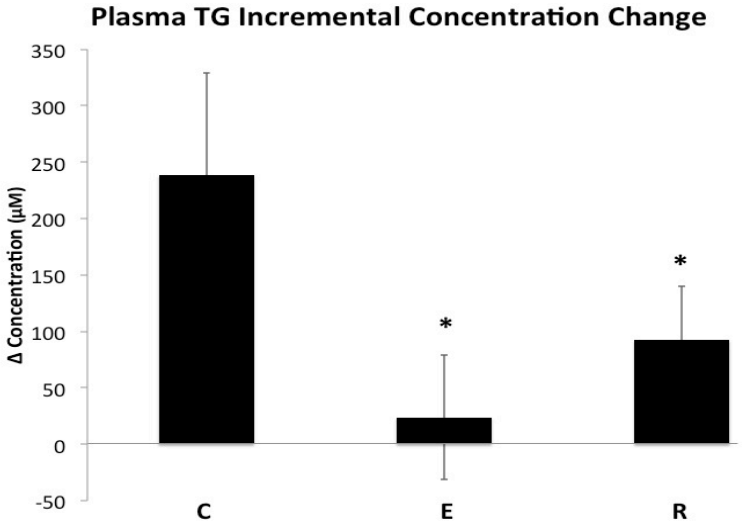
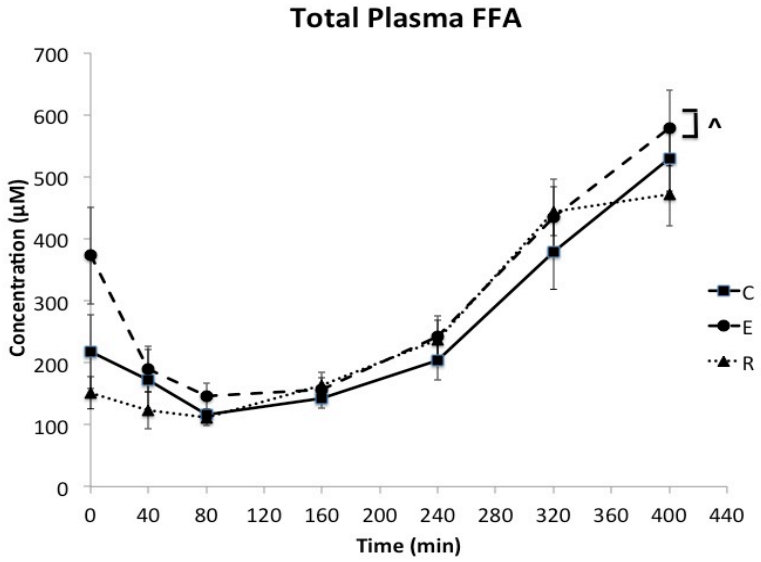


Figure 2-3. TG Metabolite concentrations. Values are means ± SE. n = 8. (A) Plasma TG concentration over time and (B) TG incremental concentration changes from pre-exercise baseline. # E and R trial significantly different from C trial, $P < 0.05$. * TG incremental concentration change in E and R significantly different from C trial, $P < 0.05$. TG, triglyceride; C, Control trial; E, endurance exercise trial; R, resistance exercise trial. Significant differences represent main effects of trial in 2-way ANOVA. Main effects of time also observed ($P < 0.05$) but no significant time-by-trial interactions. Incremental changes by 1-way ANOVA. Time (min), duration elapsed since the commencement of the test meal.

Figure 2-4

A



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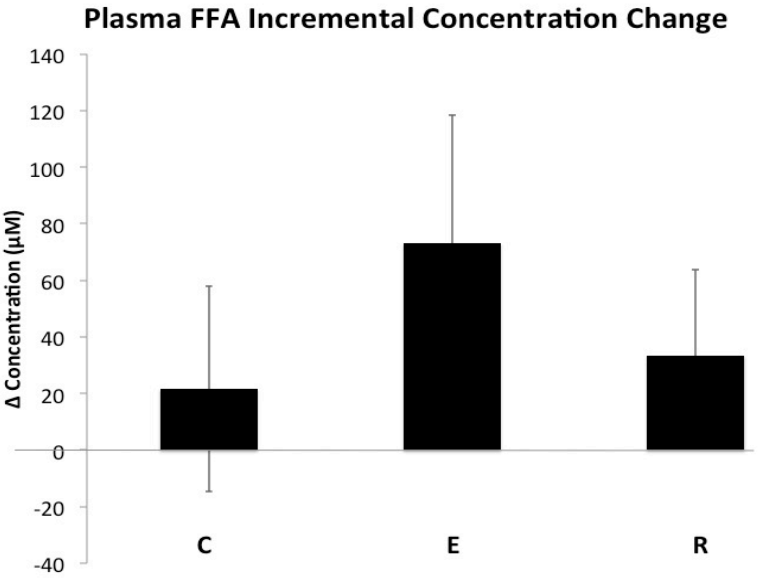
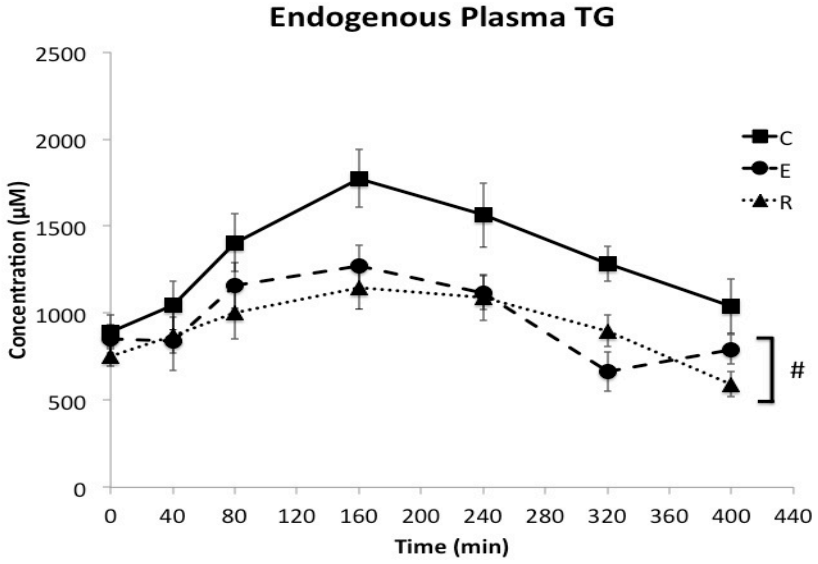


Figure 2-4. FFA Metabolite concentrations. Values are means ± SE. n = 8. (A) Plasma FA concentration over time (B) and FA incremental concentration changes. ^ E trial significantly different from R, C trial, $P < 0.05$. There were no significant main effects of trial for incremental FFA concentration change, $P > 0.05$. C, Control trial; E, endurance exercise trial; R, resistance exercise trial; FFA, free fatty acid. Significant differences represent main effects of trial in 2-way ANOVA. Main effects of time also observed ($P < 0.05$) but no significant time-by-trial interactions. Incremental changes by 1-way ANOVA. Time (min), duration elapsed since the commencement of the test meal.

Fatty acid sources in lipid pools. There was a main effect of trial ($P < 0.05$) and time ($P < 0.05$) and no significant interaction for endogenously derived plasma TG. This circulating TG of endogenous origin (Figure 2-5) was significantly attenuated in the exercise trials (E, 24.0% reduction; R, 28.4% reduction) compared to C ($P < 0.05$) with no significant difference between E and R (C, 1265.5 ± 68.2; E, 962.3 ± 68.2; R, 906.3 ± 68.2 μM). There was a main effect of trial ($P < 0.05$) and time ($P < 0.05$) for endogenously derived plasma FFA concentration. This endogenous FFA was significantly elevated ($P < 0.05$) in E as compared to both C and R (C, 236.2 ± 20.3; E, 274.7 ± 20.3; R, 222.3 ± 20.3 μM) (Figure 2-5). The abundance of exogenous FA in the plasma TG pool had a significant main effect of time ($P < 0.05$), but was not significantly main effect of trial or trial-by-time interaction (Figure 2-6). For exogenously derived plasma FFA concentration, there was a significant main effect of trial ($P < 0.01$) and of time ($P < 0.05$), with no significant time-by-trial interaction. These exogenous FFAs were significantly elevated in both the E and R trials when compared to C, but not significantly different from each other (C, 10.5 ± 2.4; E, 17.1 ± 2.4; R, 15.6 ± 2.4 μM) (Figure 2-6). Breath $^{13}CO_2$ excretion continued to rise during the postprandial period, with a main effect of both time ($P < 0.05$), and trial ($P < 0.05$) and no significant time-by-trial interaction. Post hoc testing indicated that both E and R breath $^{13}CO_2$ excretion and corresponding rates of exogenous FA oxidation were significantly elevated above C (Figure 2-7), with no significant differences between the exercise modalities. Exogenous FA oxidation rates rose continuously throughout the trials to the following final values: C, 3.6 ± 0.5 kcal/h; E, 5.3 ± 0.7 kcal/hr; R, 4.6 ± 0.5 kcal/h. In the 3 subjects that received unlabeled meals (no tracer), we confirmed breath $^{13}CO_2$ excretion rates were negligible.

Figure 2-5

A



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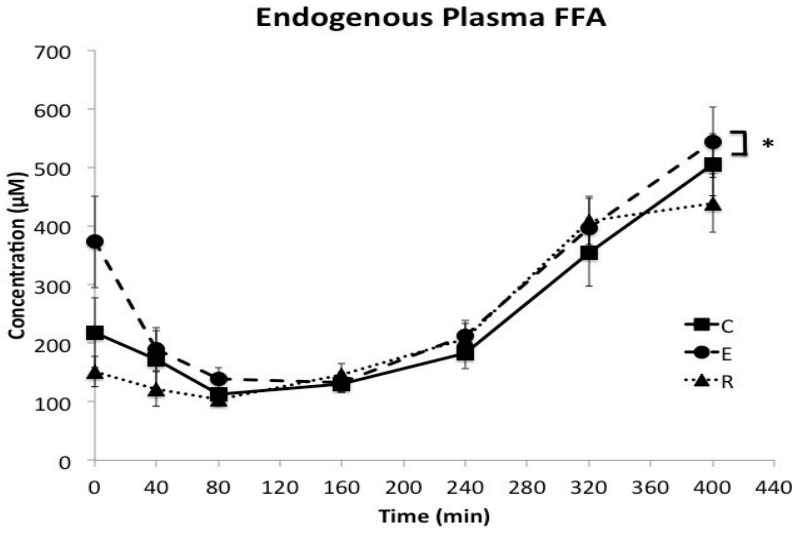
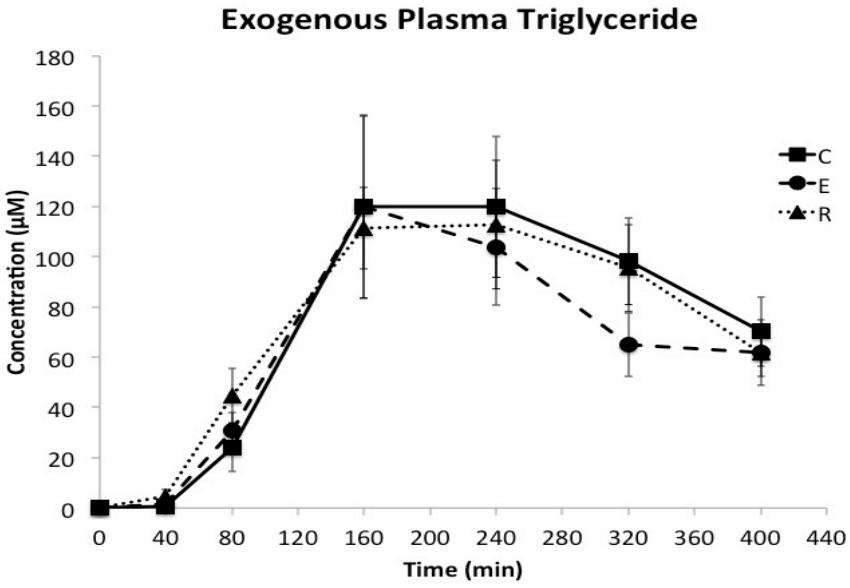


Figure 2-5. Endogenous fatty acid sources in lipid pools. Values are means ± SE; n = 8. (A) Endogenous plasma TG. (B) Endogenous plasma FFA. # E and R trials were significantly different from C trial, $P < 0.05$. * E trial significantly different from C and R trials, $P < 0.05$. TG, triglyceride; FFA, free fatty acid. Analyses by 2-way ANOVA. Significant differences represent main effects of trial in 2-way ANOVA. Main effects of time also observed ($P < 0.05$) but no significant time-by-trial interactions. Symbols are main effects of trial. Time (min), duration elapsed since the commencement of the test meal.

Figure 2-6

A



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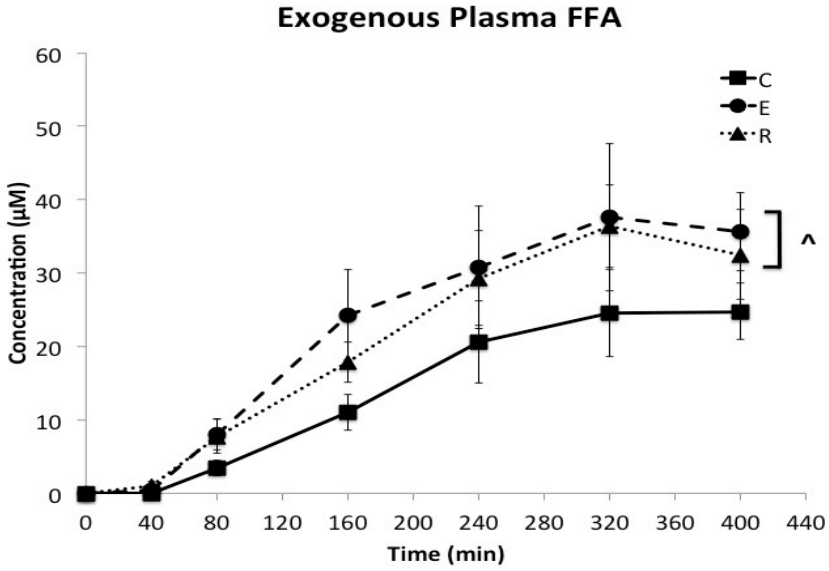


Figure 2-6. Exogenous Fatty acid sources in lipid pools. Values are means ± SE; n = 8. (A) Exogenous FAs in plasma TG. (B) Exogenous plasma FFA. ^ E and R trials significantly different from C trial, $P < 0.05$. TG, triglyceride; FFA, free fatty acid. Analyses by 2-way ANOVA. Significant differences represent main effects of trial in 2-way ANOVA. Main effects of time also observed ($P < 0.05$) but no significant time-by-trial interactions. Symbols are main effects of trial. Time (min), duration elapsed since the commencement of the test meal.

Figure 2-7

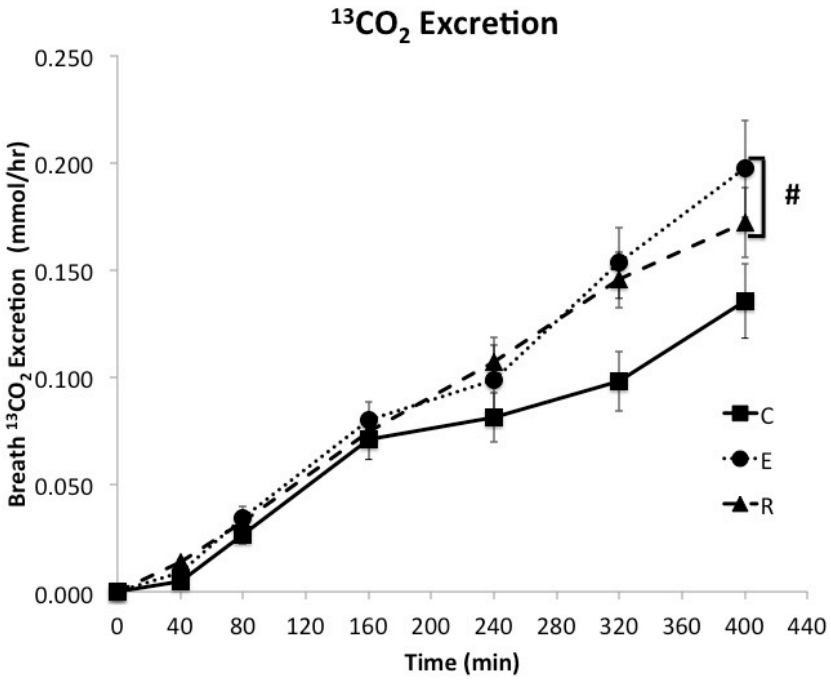


Figure 2-7. $^{13}CO_2$ breath excretion. Values are means ± SE. n = 8. # Significantly different from C trial, $P < 0.05$. Symbols are main effects of trial. Time (min), duration elapsed since the commencement of the test meal.

DISCUSSION

We investigated the effects of two different exercise modalities on postprandial TG and FA metabolism in sedentary, obese women. Our results indicate that a prior session of either E or R significantly attenuates the postprandial lipemic response, concomitantly increasing FA oxidation. We had hypothesized that FA oxidation would be increased after either exercise bout, and this expectation was confirmed by both IDC and tracer methodology. We also hypothesized that prior exercise would reduce postprandial lipemia by a reduction in abundance of both endogenous and exogenous plasma TG, and this second hypothesis was incorrect. We have surprisingly shown that it is only the endogenous TG content that is reduced after exercise in this population with no change in meal-derived TG in circulation. Below we discuss these results in the context of changes in plasma TG concentration with relevance to CVD risk, partitioning and interaction of plasma lipid pools during reduction in postprandial lipemia, and finally we discuss the relevance to the management of obesity and fat balance.

As previously mentioned, an elevated postprandial lipemic response is associated with increased risk for CVD (11, 58, 116, 137). Thus, it is worthwhile to compare different potential interventions for efficacy in lowering postprandial plasma TG excursion. We have compared E to R exercise bouts. A dose effect of exercise volume has been observed for attenuations in plasma TG following E exercise (66, 198). This implies that the response is dependent upon the EEE. This theory for EEE requirement seen with E does not apparently translate over to R which may provide a qualitatively different type of physiological stress. While we did not measure energy expenditure during the R bout, based upon previous work it would seem that the EEE of E might have

been approximately double that of R (125, 144). From this one may predict a greater impact of E in the present study, but as shown the impacts on postprandial lipemia were similar between the two modalities. Previous research has suggested that R may be a more potent form of exercise to reduce plasma TG (125, 144). Studies that have directly compared E to R of similar EEE have used very low-to-low intensity E (~30% VO_{2peak} or perhaps less) (125, 144). Thus, the intensity of E was likely too low in those studies to see significant lipid metabolism effects. In our current study we used a duration-matched approach to the sessions rather than matching for total EEE, which is in agreement with the current E and R recommendations for health and weight maintenance (5, 91). When we compared E to R in a manner consistent with clinical practice and real-world exercise prescription, these intensities of E and R each elicited significant attenuation in postprandial plasma TG concentration. While the previous studies and the data presented in this study support the notion that R may be more potent at reducing plasma TG when impact is normalized to EEE, perhaps the dose-response curves for EEE vs. lipemia are not superimposed because impact of EEE is overlaid upon impacts of other physiological variables that differ between E and R.

The reduction in postprandial TG is typically accompanied by other beneficial changes in lipid metabolism such as an increase in lipid oxidation (65, 83, 144, 178, 179). The present study data are consistent with previous studies that report both E (65, 80, 126, 179) and R (125, 144) increasing lipid oxidation after a previous bout of exercise. An increased risk of weight gain is associated with an elevated RER (161, 201) and lipid oxidation is reduced in obese humans (89, 103, 176) and animal models (13). Our study confirms the ability of a prior bout of either E of R exercise, when of sufficient intensity,

to reduce postprandial RER and thus promote favorable changes to lipid oxidation. The ability to oxidize dietary FAs is negatively correlated with BMI (183), leading to expectation that such ability would be compromised in obesity. Given the health risks associated with obesity and obesity's association with reduced lipid oxidation (89, 103, 148, 176), the results from this study enable obese individuals to use either E or R in order to increase total lipid oxidation. Increasing total lipid oxidation is useful for attaining a negative fat balance, and our present emphasis has been placed on the ability to track dietary fat through metabolic pools and to oxidation.

It has been argued that the trafficking of dietary fat towards either storage or oxidation may play a large role in the physiology of obesity (13). However, very limited data exist to date that describe the role of exercise on the subsequent partitioning of dietary fat (40, 65, 183). Partitioning between oxidation and retention has been assessed, but relative contribution of dietary fat to plasma TG and FFA has not been investigated in the post-exercise state. Gill et al had lean men exercise for 60% VO_{2peak} for 90 min the night before giving them an oral fat tolerance test, labeled with [1,1,1-^{13}C] tripalmitin. They report no significant difference in fasting lipid oxidation between E and C, the morning after, but do report a significant increase in exogenous fat oxidation over the 8-hour postprandial window (65). Perhaps the lack of significant exercise effect on resting lipid oxidation could be explained by the time gap between the end of the exercise bout and the time of resting lipid oxidation measurement, indicating the transient nature of acute exercise. Nevertheless, the E did have a significant effect on the partitioning of dietary fat towards oxidation when compared against C, concomitant with attenuation in plasma TG concentration (65). Other studies have used a similar protocol to this current

study in that they fed an isotopically labeled meal after a prior exercise bout and continually measured exogenous lipid oxidation (182, 183). E of various intensities was compared to a control condition and it was reported that there was a significant partitioning and oxidation of dietary exogenous fat, regardless of the exercise intensity. In a separate study investigators demonstrated significant elevations in postprandial lipid oxidation after a prior bout of E, even when the test meal was given at different time intervals post-exercise (184). These studies confirm the ability of E to significantly alter the substrate oxidation pool in favor of dietary fat. In these studies (182-184), oxidation of dietary ^{13}C-oleate was assessed with ^{13}C-labeling of CO_2 and of ^{2}H-palmitate with ^{2}H-labeling of body water. Interesting, in this case investigators only observed accentuation of oleate oxidation after exercise, not of palmitate oxidation. In our present work, we utilized ^{13}C-labeled palmitate and observed increased oxidation of this label after exercise through labeling of CO_2. Therefore, we did not confirm the findings of Votruba et al. with regard to palmitate retention after exercise, and it is possible that this discrepancy indicates superior sensitivity of ^{13}C-labeling over that of ^{2}H-labeling for detecting the physiological effects of recent exercise. Additionally, our current study is the first we are aware of to compare E to R, and is first to investigate an obese female population with respect to the subsequent partitioning of dietary fat towards oxidation. We report a significant increase in exogenous derived FA oxidation, regardless of exercise modality, when compared against C (Figure 2-5). This exogenous FA oxidation in E confirms previous literature (65, 183) but expands the finding to a new population, and adds the recognition of R as an alternate means of deriving a similarly positive outcome. While other studies have not measured exogenous FA oxidation specifically, our IDC results

confirm the other studies that have seen R increase total lipid oxidation (125, 144) and our tracer findings show that exogenous fat contributes to this increase in lipid oxidation after exercise.

In the current study, we differentiated between exogenous and endogenous sources of plasma TG and FFA, and we discovered that the significant attenuation in total plasma TG came from endogenous TG only, and not from meal-derived TG (Figure 2-4). This could be a result of a reduction in liver derived VLDL-TG secretion, or enhanced VLDL-TG clearance without enhanced chylomicron clearance, or increased contributed of recycled dietary FAs from chylomicrons into VLDL. The contribution of lipid sources to these lipoprotein particles is complex. When investigators are interested in addressing contributions of exogenous and endogenous lipid to circulating TG, there may be a tendency to conceptualize the lipid pools as chylomicrons representing exogenous and VLDL representing only endogenous TG, but this is not entirely accurate. Furthermore, when plasma TG rises after a meal, it may be assumed by some scientists to be the results of rising chylomicron levels, but this is also not accurate. The inter-relationships between these particles is so complex that measuring their concentrations cannot sufficiently answer questions about the sources (dietary vs. endogenous) of circulating plasma TG. After a meal, plasma VLDL-TG can rise to a similar or even greater absolute extent than chylomicron TG (64, 65). Furthermore, a prior exercise bout can reduce both VLDL and chylomicron TG concentrations (64, 65). Making things more complex, during the course of absorbing an isotopically labeled meal, the IE of chylomicron TG changes over time (110, 152), possibly indicating impurity of the isolated plasma fraction, but also likely indicating changing relative contribution of meal fat and perhaps

contribution of fat previously residing in intestinal cells, Further exemplifying the complex nature of these lipid pools, labeled fatty acids from a meal rapidly label the VLDL pool in addition the chylomicron pool (79, 110, 152), so the concentrations of VLDL-TG and chylomicron-TG do not answer questions about the relative contribution of a meal's fat content to postprandial lipemia. Therefore, we derived an approach and a simple calculation to compare the meal IE to IE of plasma TG and FFA, and this directly assessed the contribution of the meal to the plasma TG excursion, and generated surprising and novel data about postprandial lipid metabolism after exercise.

Similar to previous research showing an elevation in total FFA concentration post-exercise using E, (65, 80, 126, 179), we have seen similar total FFA concentration increases after E against C, but no change in total plasma FFA after R. Further analysis revealed a significant rise in exogenous derived FFAs in both exercise groups, but a significant rise in endogenous plasma FFA concentration from E only (Figure 2-4). In the E trial endogenous FFA concentration (Figure 2-4) revealed the significance arises from the probable lipolysis and mobilization of FFAs during the prior E bout. Removal of this immediately post-exercise time point eliminates the statistical significance of endogenous FFA concentration in the E trial. The rise in plasma FFA of exogenous origin after either exercise bout indicates enhanced spillover of dietary FAs (131, 132, 139). This process indicates FAs released by intravascular lipase activity (LPL and/or hepatic lipase) that were not efficiently channeled to direct uptake at the site of lipolysis (131). In the process of spillover, FFAs become systemically available and can ultimately be utilized by tissues that are anatomically distinct from those at which the lipolysis occurred. We observed the increased post-exercise spillover alongside increased oxidation of

exogenous FAs. It is possible that this process promoted oxidation by making labeled fatty acids available to specific tissues that exhibit high rates of fatty acid oxidation such as the liver or others.

In obese individuals there is an accumulation of excess fat storage (76). The ability to oxidize increased amounts of lipid can help rectify and lead to a negative fat balance, which can ultimately lead to a reduction in body fat (76). Elevations in fat oxidation have been demonstrated in the current study in both E and R, with no significant differences between the exercise conditions. The increased lipid oxidation in conjunction with reductions in postprandial lipemia has implications for fat loss and CVD. As we only included female subjects we cannot comment on comparisons to an obese male population. Our results provide obese women with more than one means of increasing lipid oxidation and attenuating the postprandial lipemic response.

In conclusion, we have demonstrated that a prior bout of either E or R attenuated postprandial lipemia by reducing the circulating abundance of endogenously derived plasma TG, and the prior exercise also increased both total FA and exogenous FA oxidation. Our findings in obese women indicate that R provides an at least equivalent effect on postprandial lipemia and fat oxidation as E. When obese women perform the E and R done during the current study, they will have a significantly lower postprandial lipemic response, concomitant with an elevation in fat oxidation. The results exemplify the complex relationship between lipid pools and the ability of lifestyle changes to alter these relationships. Additional preclinical studies comparing potential exercise prescriptions on postprandial lipemia and the trafficking of dietary fat towards oxidation are needed in various populations with both acute and chronic application of the exercise.

Chapter 3.

Postprandial hormone response from prior endurance or resistance exercise in obese women

ABSTRACT

Physiological changes that occur from endurance (E) and resistance training (R) are likely influenced by the metabolic and hormonal response to each individual exercise bout. Some of these hormonal changes appear to be blunted in obese individuals, though it may be that if of sufficient magnitude, or of a specific modality, an acute exercise bout can cause significant hormonal changes in obese people. **PURPOSE**: To compare acute effects of E and R, compared with a resting control (C) upon subsequent hormonal changes in obese women. **METHODS**: Sedentary, obese women (n=12; Body weight = 99.4 ± 6.0 kg; BMI = 37.5 ± 2.2; body fat, 45.4 ± 1.2%) participated in a randomized crossover-design study on 3 occasions: E, R, and C. Subjects completed body composition, 10RM, and VO_2peak tests. E consisted of walking on a treadmill at 60-65% VO_{2peak} for 1-hour. A 1-hour total-body high-intensity R workout consisted of 3 sets of 10 repetitions, 90 s rest for 8 exercises at a load of 90-100% of 10RM. A baseline blood sample was taken 30 min before exercise (0 min) and 30 min post-exercise (120 min). A standardized meal of 20 kcal/kgFFM (CHO-48%, Fat-36%, Protein-16%) was given 30 min post-exercise (120 min) and blood was sampled and assessed at 200, 280, and 520 min in order to assess changes in growth hormone (GH), cortisol, and insulin throughout the postprandial time period. RM ANOVAs were used for statistical analysis. **RESULTS:** There was a main effect of condition for GH ΔAUC, with both R and E significantly different from C (R, 463.0 ± 138.2; E, 243.2 ± 131.6; C, -90.4 ± 157.6 ng/mL, $P<0.02$). There were no main effects of condition for cortisol ΔAUC (C, -4446.6 ± 899.5; E, -6672.0 ± 1130.2; R, -4041.2 ± 874.0, μg/dL, $P > 0.13$), or insulin ΔAUC (C, -4884.7 ± 8985.7; E, -1911.8 ± 9804.5; R, 7333.8 ± 7699.1 pmol/L, $P > 0.39$). There

were no significant time-by-condition interactions for any variables**. CONCLUSIONS**: In obese women, circulating GH concentration is enhanced in the postprandial state following a single bout of either E or R. It appears that the response of GH is more robust than that of cortisol or insulin. As circulating GH has been shown to be reduced in obesity with potential metabolic implications, the present observation could be considered beneficial, particularly alongside the absence of enhanced cortisol level after exercise. Future work may indicate if the endocrine response to E and R can be further enhanced through chronic training in this population.

INTRODUCTION

Endurance exercise (E) and resistance training (R) differ in the specific energetic demands and subsequent metabolic adaptations that result from continued participation in each exercise. E is composed of sustained submaximal intensity exercise, which derives a majority of its energy fuel substrate from lipid, and subsequently causes adaptations that further enhance oxidative metabolism. R consists of high or maximal intensity exercise that predominantly relies on glycolytic and non-oxidative fuel substrates (i.e., phosphocreatine and carbohydrate) to further increase muscular hypertrophy and strength. The different physiological and hormonal changes that occur from either E or R are the result of the adaptations of the body to the stress that each exercise places on it, and the magnitude of hormone secretion in response will vary depending on the intensity, duration, and frequency of the exercise (104, 113). The hormonal response's role via exercise and throughout the post-exercise recovery period in dictating the substrate partitioning varies.

Insulin is a hormone that is central to the regulation of glucose and fatty acids within the circulation. When glucose concentration increases in the body, insulin is released to regulate and return it back within range. Throughout E the release of insulin is lower, with a concomitant increase in fatty acid (FA) release both during and throughout the post-exercise period (80, 104, 181). Elevations in plasma FA are associated with an increased oxidation of fat (71, 153). Limited data exist on the postprandial change in plasma insulin concentration changes from a same-day prior bout of E and R in comparison to a sedentary control. The acute impact of E on the postprandial plasma

insulin concentration has been reported to be not changed (62, 80) or significantly lower (165) in the hours following exercise when compared to a sedentary control. To our knowledge, no studies exist that compared the postprandial insulin concentration response after a prior same day E and R bout in comparison to a sedentary control.

Growth hormone (GH) and cortisol are two hormones that are secreted in various amounts, based on the stress of the body, with a common goal of sparing blood glucose for glycolytic tissues, and increasing lipolysis. While GH does promote the release of FAs from stored TG within adipose tissue (160), it also promotes the uptake of amino acids and protein synthesis, thus is considered an anabolic hormone (9, 196). This makes GH important in the regulation of lean body mass (FFM) and fat. Cortisol is a steroid hormone secreted from the adrenal cortex that, while causing an elevation in blood glucose and release of FAs will also result in breakdown of protein, and thus is considered a catabolic hormone (24, 102). As stated above, the presence of these hormones typically indicates the body's reaction to the stress placed on it during the exercise and can often reflect changes in energy metabolism. The acute stress response of exercise is related to the intensity, duration, and frequency of exercise and a significant GH response has been reported in both E (23, 39, 50, 56) and R (39, 52, 113, 114, 134, 196). When performing E, some research has indicated the need for at least 20 minutes of E at 60-70% VO_{2peak} in order to see a significant GH response (98). Others have used a lower intensity but increased the duration (128). Significant increased cortisol concentrations have also been reported after acute E (94, 97, 104, 171, 195) and R (51, 113, 134). There is a positive association between increased E intensity and cortisol response (94). The response of GH to R varies with a variety of factors including

intensity, rest period, and overall exercise volume (113, 114, 190). Performing 90% of a 10 repetition maximum (10RM) for 10 repetitions would constitute a higher intensity than only performing 50% of the 10RM for 10 repetitions, and there is a linear correlation with increasing intensity and GH release (52, 113, 187).

Current recommendations for exercise are often used in research study design. For an improvement in health the Institute of Medicine (IOM) recommends E 60 minutes per day every day of the week (25). Additional exercise may be needed to prevent weight gain, for weight loss, or to maintain weight loss. The American Heart Association (AHA) and the American College of Sports Medicine (ACSM) (5) advise healthy adults under 65 years of age to exercise at moderate intensity for 30 minutes per day, five days per week or at vigorous intensity for 20 minutes per day, three days per week. They also recommend doing eight to 10 strength-training exercises for 8 to 12 repetitions of each exercise, 2 to 3 times per week (5). These physical activity recommendations are intended to maintain health and reduce the risk for developing chronic diseases. As the various intensities and durations used in a research study have a direct effect on the amount of hormone released in response to exercise, consideration of these differential effects has to be made when designing a study.

Hormonal differences have been reported to exist between lean and obese individuals in both the resting and the post-exercise state (96, 156, 195). It appears that obesity results in suppression of both resting and exercise-induced GH responses. Additionally, obesity is associated with an elevation in resting and exercise-induced cortisol release (96, 181, 195). Perturbations in normal GH and cortisol release have been linked in the etiology of obesity, given the dynamic impact that GH and cortisol have on

blood glucose, FA's and substrate metabolism. The reduction in exercise-induced GH release in obese individuals, however, is not consistent throughout the literature. When compared to a lean counterpart, several studies have reported obese individuals having a suppressed (69, 96, 111, 156, 188, 195) or similar (23, 50) GH response in E. Data are more limited in comparison between obese and lean and the impact of R on GH, but a significant attenuation in GH has been reported in obese individuals performing R (140). Similar disparities exist for the cortisol response from E (62, 72, 195) or R (51, 174).

The majority of a person's waking day is spent in the fed state (postprandial), and exercise is typically followed by a meal. Since obesity is the result of an imbalance between lipid oxidation and lipid storage (76), and the hormonal balance is implicated in the metabolic shift between the various substrate oxidation (i.e., fat and carbohydrate), the acute effects of exercise on the hormonal response post-exercise and in the postprandial state is pertinent. While exercise-induced responses of GH and cortisol have been reported to be disrupted in obese individuals, the current understanding of E and R comparatively warrants further understanding. We studied obese women who are traditionally under-represented as study participants in the exercise literature, and because this group has a need to alter their hormonal response. To our knowledge no study exists that compared the effects of E and R in an obese female population on the resultant post-exercise circulating concentrations of GH, cortisol, and insulin. Given current exercise recommendations, we sought to determine the separate effects of E and R at an intensity and duration that is highly translational and clinically relevant on the GH, cortisol, and insulin response. The purpose of the study was to investigate the acute effects of E and R on the hormonal responses of GH, cortisol, and insulin before and

throughout the post-exercise period in obese women. We hypothesized that both E and R would result in significant increases in both GH and cortisol, with no change in insulin concentration between groups.

METHODS

Study Participants. Twelve sedentary, premenopausal, obese (BMI, 30.0 – 56.7; body fat, 45.4 ± 1.2%) women were recruited from Rutgers University, New Brunswick campus and surrounding community by posted notice. Potential study participants underwent subsequent screening tests if they were disease-free as determined by health history questionnaire and were not taking medications known to affect energy metabolism. Participants were required to be sedentary, having partaken in less than 1 h of moderate physical activity each week for the last 3 months. Due to a technical error in sample preparation for one participant during insulin analysis, the total sample size was reduced to 11 for insulin analyses results and remained at 12 for all other results. Female participants reported regular menstrual cycles (24-32 days); if taking oral contraceptives (OC), they were required to have been on them for at least 6 months, and were instructed to continue taking the OC for the duration of the study. Effects of menstrual cycle phase and OC were expected to be subtle compared to effects of exercise per se (32, 172), and the randomization of trial order was meant to balance any minor effects of menstrual cycle and OC phase on hormonal variation. The procedures and risks were thoroughly explained to the study participants, and their written, informed consent was obtained. Rutgers University Institutional Review Board approved the study protocol (IRB no. 11-030R).

Screening tests. There were three total days of screening, familiarization, and fitness testing. On the first day, fasting blood glucose was tested to confirm that all study participants were non-diabetic (glucose < 125 mg/dL). Body Composition was

determined by measuring body volume via air displacement plethysmography using the BOD POD (Life Measurements Instruments, Concord, CA) as described in previous literature (43). Percent body fat (%BF) was calculated through a two-stage procedure. In addition to %BF, FFM was also calculated. Height and weight were recorded in conjunction with body composition assessment. All subjects were required to fast for at least 3 hours, arrive normally hydrated, and without having exercised prior to the test. Study participants underwent a progressive exercise test to assess aerobic capacity ($V O_{2peak}$) before beginning the study. The test and experimental trials were performed on a graded high-speed treadmill (Trackmaster, Newton, KS) and the VO_2 and VCO_2 measurements were made using the ParvoMedics TrueOne 2400 metabolic cart (ParvoMedics, Sandy, UT). A continual progressive protocol was used to determine $V O_2$peak with an increase in power output at 3-minute intervals until volitional exhaustion (5). Body composition and aerobic capacity, were tested on the same day. On two separate occasions; 1) each subject was familiarized with the entire resistance training protocol, and 2) administered a 10 repetition maximum test (10 RM) for each exercise for strength assessment (9). The 10RM is considered a potentially safer and more reliable form of testing than the 1RM, since the subject pool is unskilled in weight training (7). Subjects warmed up for 3-5 minutes on a stationary bicycle at 50% of their estimated HR_{max} to increase blood flow and prepare for the maximal testing. Weight was increased between sets until precisely 10 repetitions, executed in good form, were attained for each of the exercises. The 10RM was achieved within 4 sets for all subjects (9).

Experimental design. With at least one week between trials, participants were studied under each of 3 conditions, each on separate occasions, assigned in a random

order. Subjects were studied before and after 1) 60 min of E at 60-65% VO_2peak, 2) ~60 min of high-intensity R, and 3) during a time-matched resting control condition (C). Each condition included an identical test meal following either the exercise or quiet rest period. A study design schematic is shown in Figure 3-1. Coefficient of variation (CV) for GH, cortisol, and insulin was 7.9, 5.3, and 3.7, respectively.

Figure 3-1

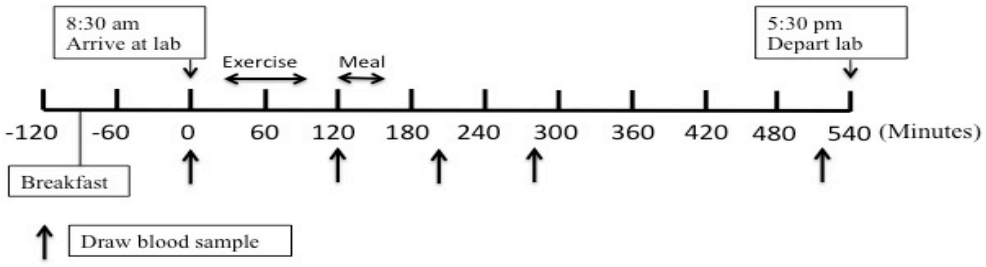


Figure 3-1. Experimental design. Each study participant completed 3 different experimental trials in randomized order, one involving endurance exercise (E), one involving resistance exercise (R), and one with no exercise (C). Minutes, time elapsed since study participant arrived at the laboratory. E or R bouts performed from 30 to 90 min, or semi-supine rest during this time period in the C trial.

The day before each trial, study participants were instructed to consume solely their standardized diet and water *ad libitum*, and to abstain from structured physical exercise sessions but to continue typical activities of daily living. They were fed for a physical activity level (PAL) of 1.4 according to the current dietary reference intake guidelines of the Institutes of Medicine (IOM) for daily estimated energy requirement (EER) (91). Dietary energy intake was individualized for each study participant (2294.0 ± 81.2 kcal/day) and macronutrient composition was made similar between individuals for carbohydrate (54.3 ± 0.7%), lipid (25.4 ± 0.5%), and protein (20.3 ± 0.4%). On the day of trials, study participants consumed a provided bagel at 7:30am (81.9% carbohydrate, 3.6% fat, 14.5% protein, 249kcal), and arrived at the laboratory at 8:30am. We chose to feed our study participants 1.5 h before exercise in order to increase tolerance of the exercise protocol.

Duration of E was exactly 60 min and the R bout was designed to be approximately 60 min. The appropriate intensity for the 60-65% VO_2peak was achieved by using oxygen consumption (VO_2) data from the VO_{2peak} assessments. The R trial was time-of-day and duration-matched, and consisted of 8 whole body exercises, with 3 sets and 10 repetitions of each exercise (Bench press, lat pull down, shoulder press, squat, leg curls, triceps pushdown, biceps curl, lunges) at a load equal to 90-100% 10RM. If 10 repetitions in a given set could not be completed, the weight was to be reduced so that 10 repetitions could be completed. Prior to exercise, a single-use needle was used for the first blood draw from a heated hand vein. After the exercise session, study participants stepped off the treadmill and sat into a chair where they were catheterized, and remained

seated for the remaining 400 min of the postprandial period quietly reading or watching movies. Water was consumed *ad libitum* during recovery but, aside from the test meal, study participants consumed no other beverages and no food until the postprandial measurement period ended. Study participants were transported in a wheelchair for trips to the restroom.

Blood was sampled and assessed 30 min before exercise (0 min), 30 min after exercise (120 min) and for 400 min postprandial (200, 280, and 520 min) in order to assess changes in growth hormone (GH), cortisol, and insulin. The post-exercise meal consisting of Boost Plus (Nestlé HealthCare Nutrition, Fremont, MI, USA) and evaporated milk was administered immediately following the post-exercise blood draw (30 min post-exercise), with the dose scaled to fat-free mass (FFM). The test meal provided 20 kcal per kg FFM (~46% of EER). The macronutrient composition of the drink was: 47.8% carbohydrate, 36.1% fat, and 16.1% protein (1076.4 ± 62.7 kcal), and the average total volume was 599.5 ±34.9 mL. In order to provide consistency participants were asked to consume the entire drink within 20 minutes. The sides of the container were scraped and that small remaining quantity also consumed.

Laboratory analyses. Blood for insulin, cortisol, and GH were drawn into serum-separator tubes with no additive and allowed to clot for 30 min. Samples were centrifuged at 3000g for 15 minutes to obtain serum and stored at -80°C for analysis. Growth hormone was analyzed using a solid phase enzyme-linked immunosorbent assay (ELISA), which utilizes an anti-HGH antibody for solid phase immobilization and monoclonal anti-HGH antibody in the antibody-enzyme conjugate solution (MP Biomedicals, Solon, Ohio). Insulin was analyzed with a radioimmunoassay (RIA) using

antibody coated polypropylene tubes and ^{125}Iodine (Siemens Medical Solutions Diagnostics, Los Angeles, CA). Cortisol was also analyzed using an RIA with insulin-specific antibody coated tubes and ^{125}Iodine (MP Biomedicals, Orangeburg, NY).

Statistical analyses. Data are presented as mean ± standard error. 2-way comparisons between trials and across time points were made by analysis of variance with repeated measures (RM-ANOVA) with post hoc comparisons using Fisher's Protected Least Significant Difference test. Additionally, RM-ANOVA was used to compare the ΔAUC average values between trials. Effect sizes (ES) were computed using Hedges *g*. Statistical analyses were performed using SPSS v.19 software (SPSS Inc., Chicago). Statistical significance was set at $\alpha = 0.05$.

RESULTS

Characteristics of study participants and exercise bouts. Subject characteristics can be found in Table 3-1. All subjects were obese (BMI, 37.5 ± 2.2; body fat, 45.4 ± 1.2%). E was time matched with R, and included 60 min of walking at an intensity of 61.9 ± 1.0% VO_{2peak}, with a gross exercise energy expenditure (EEE) of 430.8 ± 22.4 kcal.

Table 3-1

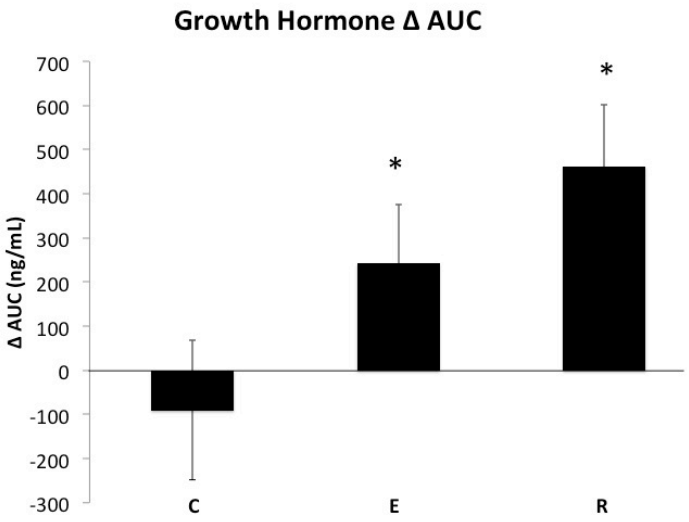
Age, yr	23.8 ± 1.6
Height, cm	162.7 ± 2.2
Weight, kg	99.4 ± 6.0
BMI, kg/m^2	37.5 ± 2.2
Body fat, %	45.4 ± 1.2
FFM (kg)	53.6 ± 3.1
Fat mass (kg)	45.3 ± 4.0
$\dot{V}O_2$peak, L/min	2.4 ± 0.1
$\dot{V}O_2$peak, mL/kg/min	25.1 ± 1.4
$\dot{V}O_2$peak, mL/kg FFM/min	46.3 ± 2.4

Table 3-1. Characteristics of study participants. Values are means ± SE. n = 12. $\dot{V}O_{2peak}$, peak O_2 consumption; BMI, body mass index; FFM, fat free mass; yr, years.

Hormones. There was a main effect of time for GH, cortisol, and insulin ($P < 0.05$). There was a main effect of condition for GH ΔAUC, with both R and E significantly different from C (RT, 463.0 ± 138.2; ET, 243.2 ± 131.6; C, -90.4 ± 157.6 ng/mL, $P<0.02$)(C vs. E, ES = 2.3; C vs. R, ES = 3.7; E vs. R, ES = 1.6) (Figure 3-2). There were no significant time-by-condition interactions for GH ($P > 0.05$) (Figure 3-2). There were no main effects of condition for cortisol ΔAUC (ET, -6672.023 ± 1130.2; RT, -4041.2 ± 874.0; C, -4446.6 ± 899.5 μg/dL, $P > 0.39$)(C vs. E, ES = -2.2; C vs. R, ES = 0.5; E vs. R, 2.6)(Figure 3-3). There were no significant time-by-condition interactions for cortisol ($P > 0.05$) (Figure 3-3). There were no main effects of condition for insulin ΔAUC (ET, -1911.8 ± 9804.5; RT, 7333.8 ± 7699.1; C, -4884.7 ± 8985.7, pmol/L, $P > 0.13$)(C vs. E, ES = 0.3; C vs. R, ES = 1.5; E vs. R, ES = 1.0)(Figure 3-4). There were no significant time-by-condition interactions for insulin ($P > 0.05$) (Figure 3-4).

Figure 3-2

A



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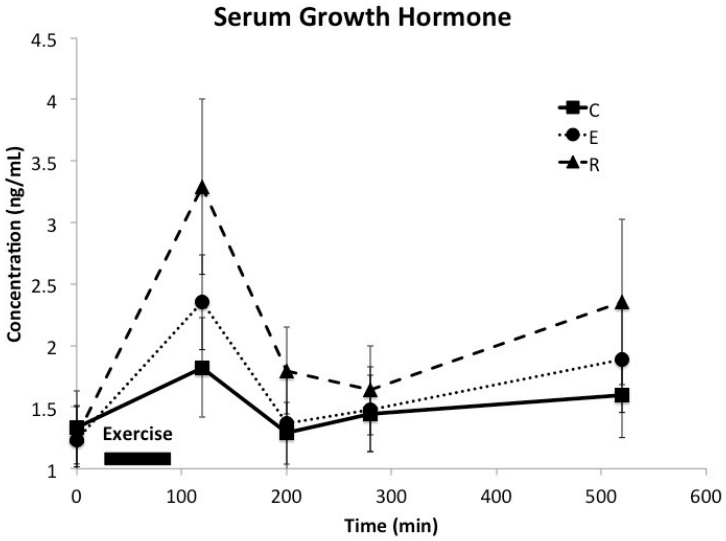
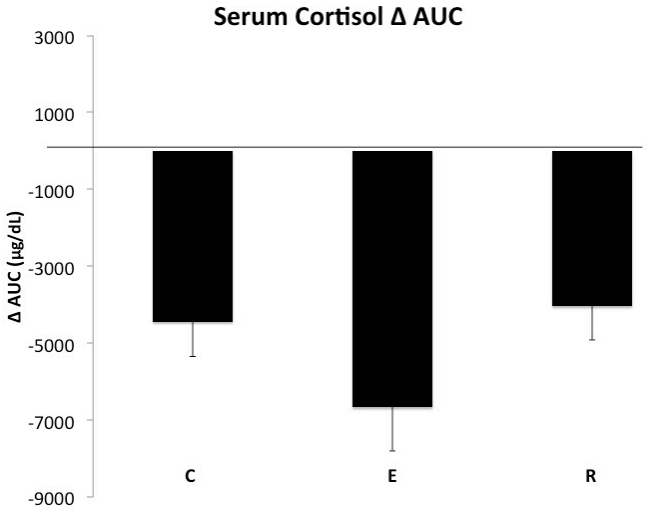


Figure 3-2. Serum GH concentration. Values are means ± SE. n = 12. (A) ΔAUC for GH plasma concentration. *Significantly different from C trial, $P < 0.05$. (B) Plasma GH concentration throughout the entire study day. Symbols are main effects of trial. Time (min), duration elapsed since the commencement of the first blood draw.

Figure 3-3

A



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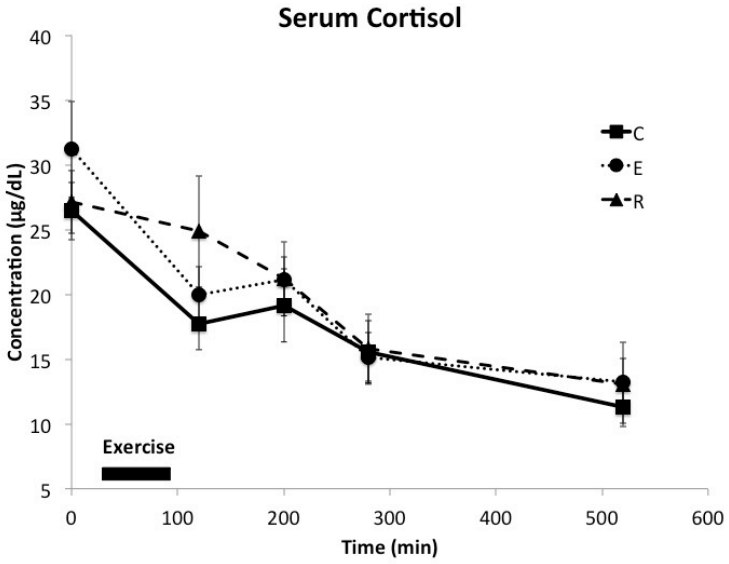
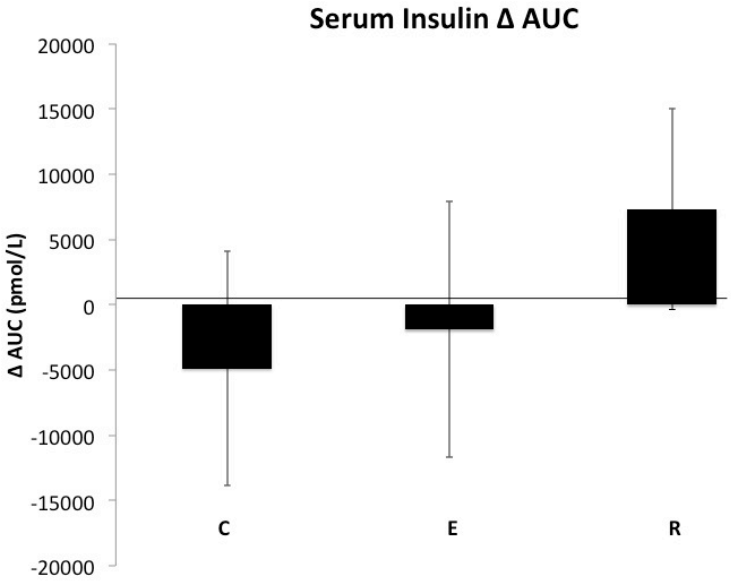


Figure 3-3. Serum cortisol concentration. Values are means ± SE. n = 12. (A) ΔAUC for cortisol plasma concentration. $P > 0.05$. (B) Plasma cortisol concentration throughout the entire study day. Time (min), duration elapsed since the commencement of the first blood draw. No significant differences between trials.

Figure 3-4

A



B

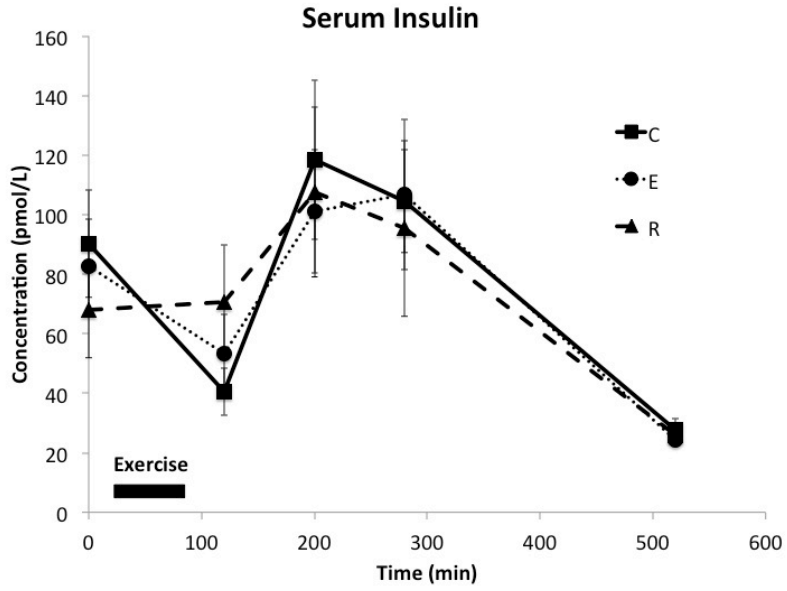


Figure 3-4. Serum insulin concentration. Values are means ± SE. n = 11. (A) ΔAUC for insulin plasma concentration. $P > 0.05$. (B) Plasma insulin concentration throughout the entire study day. Time (min), duration elapsed since the commencement of the first blood draw. No significant differences between trials.

DISCUSSION

The purpose of the study was to investigate the acute effects of E and R on the hormonal responses of GH, cortisol, and insulin before and throughout the post-exercise period in obese females. Our hypothesis that both E and R would cause a significant increase in GH and cortisol above a sedentary control was partly confirmed. There was a significant increase in the incremental GH increase for E and R, but there was no significant change in cortisol compared to C for either exercise group.

As R was of a vigorous intensity, and consisted of a shorter rest period with multiple sets, significant increases in GH above the sedentary control confirms what has been previously found (112, 113, 140). With regards to E, it has been suggested that GH release is related to achievement of a minimal intensity of at least the anaerobic (AT) or lactate threshold (LT) (52, 156). In the current study, the average E intensity (61% VO_{2peak}) corresponded to an average of 79.3% of the AT. This indicates that E, at an intensity below AT, can elicit a significant GH response in obese females. Given the implications that GH has on suppression of peripheral glucose uptake and utilization, the elevation in GH in response to exercise should promote an increase in fat oxidation. There was an increased fat oxidation during recovery from both exercise conditions within the current study (results reported elsewhere). Previous data have indicated the post-exercise shift towards fat oxidation is partially reliant on GH release (150). It should be mentioned that the potential metabolic implications regarding GH responses to E and R may relate to positive and similar changes in fat mass despite the different chronic skeletal muscle adaptations to E and R. E leads to adaptations pertaining to

enhanced oxidative capabilities, which equates to little or no increase in lean mass (115, 136, 155), while R directly stimulates the remodelling of skeletal muscle towards a more hypertrophic state capable of creating large amounts of force and power (115, 136, 155). While there was no statistically significant difference between GH response in E and R, further analysis revealed a large effect size for comparison of ΔAUC.

There were no significant increases in cortisol response for either exercise, which is surprising, given the previous reports of increased cortisol response to both E (104, 112) and R (113, 134). This is also particularly notable because cortisol response is reported to be significantly elevated in response to E in obese compared to lean individuals (195). One possible explanation for our findings could be the timing of the exercise bouts (42). Cortisol release is based on a diurnal pattern and, given the time of day that subjects had their first blood draw (0830 h), it is expected that there would be a somewhat higher cortisol concentration, as has been reported in the morning hours. The baseline cortisol concentrations for all three conditions were the highest of the entire study day. Kanaley et al., found the time of day significantly altered the response of cortisol to exercise, as the morning incremental cortisol response was lower than both afternoon and evening exercise induced cortisol responses (97). This may explain the lack of significance in cortisol responses for either exercise group, compared to C, in the current study. Previous research supports our current finding that E at ~62% VO_{2peak} is not of sufficient magnitude to elicit a significant cortisol response (94). Another explanation for the lack of significant cortisol response in the current study is the timing of blood collection. Previous reports indicate that cortisol peak concentrations occur at 0-15 min post-exercise (94, 113, 134). Within the current study, there was a trend for

increased cortisol response in R, but the results were not significant. This could perhaps be attributed to our first post-exercise blood draw being 30 min after the cessation of exercise or the high variability in cortisol concentration within the participants. Interestingly, when we analysed effect size (ES) there was a large effect for E against both R and C (-2.6 and -2.2, respectively). This indicates the study may have been underpowered to see the potential differences emerge. Future research using the current study E and R protocols should consider adding blood collection at closer intervals immediately post-exercise and up to 15 min and studying various times of day.

The postprandial response of insulin during the post-exercise recovery period was not different between groups. Previous reports indicate that in an untrained population the response of insulin to E was not significantly different from C, post-exercise and throughout a meal tolerance test (179). Given that during the post-exercise recovery we fed our subjects, we did expect a rise in insulin, in addition to the continual decline in serum insulin concentration throughout the remainder of the postprandial period. This is supported by previous research that found that 45% VO_{2peak} and 65% VO_{2peak} E produced no significant differences in serum insulin concentration throughout a 180 min post-exercise recovery period compared to one another (80). Research studying the impact of exercise on insulin response, both fasted and postprandial, has tested individuals both the same day and the following day, with conflicting results. There are reports of E reducing (12, 21, 65, 126, 166, 198), having no change (77, 125, 179), and elevating (144) serum insulin, while R reduces (86, 167) or has no change (125, 144, 177, 197) on serum insulin levels. Gill et al. demonstrated that moderate intensity E (64% VO_{2peak}) reduced fasting serum insulin the morning after, but did not result in a significant postprandial

incremental insulin concentration change (65). Short et al. had participants partake in a meal tolerance test either within 30 min or at 16 h following a prior E bout in comparison to a sedentary control and reported a similar total peak inulin concentration among all groups. However, only those administered the meal tolerance test on the same day that they exercised demonstrated significantly lower insulin concentration from 30-180 min postprandial (165). Throughout the 180 min postprandial time course, there was a significant and continuing rise in FAs in the same-day group only, which while not reported, may have increased fat oxidation throughout and beyond the 180 min assessment period (165). The current finding of no significant difference in insulin concentration changes throughout the postprandial period between trials, yet a significantly different fat oxidation (results reported elsewhere) suggests that insulin concentration does not contribute to the elevated fat oxidation seen within this study. We also observed large variability in the insulin concentration response within the current study and had moderate-to-large ES for both E (ES = 0.3) and R (ES = 1.5) vs. C, and this may have contributed to the lack of significance as well.

The current data suggest that a 60 min bout of E at a moderate intensity is enough of a stimulus to cause a significant rise in GH. Previous research has demonstrated significant increases in GH using E of maximal intensity during sprint exercises or at intensities above AT (150, 151). Our study results indicate E of moderate intensity (61% $VO_{2peak)}$ and below the AT (79.3% AT) significantly increased the GH response during the post-exercise recovery period. A time-matched high-intensity R bout was also able to significantly elevate the GH response during the post-exercise recovery period. This suggests the two different exercise modalities, which are of different intensity, may cause

a similar GH response, however the individual variability in GH response and large ES warrants further investigation. GH is important because its presence signals for an increase in lipolysis and amino acid uptake and storage, which supports and can enhance the retention or increase of lean body mass. While the acute effects of cortisol lead to the mobilization of stored fuel to provide metabolic tissues with energy substrates, one result of a sustained cortisol increase is the degradation of skeletal muscle for the mobilization of amino acids. The lack of a cortisol response over the course of the day in the current study is encouraging. Given that we found a significant rise in GH but not cortisol from exercise, an anabolic state was achieved and could contribute, chronically, to the potential retention or increase in lean body mass.

Current exercise recommendations include 60 min per day of moderate to vigorous intensity E, and 8 exercises with 3 sets, 8-12 reps, and ~90-second rests of R, which in the current study amounted to ~60 minutes. Given the current study results, we can confidently suggest both E and R as potent stimuli for GH release in a sedentary obese female. As circulating GH is reduced in obesity, with potential metabolic implications, the present observation could be considered beneficial, particularly alongside the absence of enhanced cortisol level after exercise. Future work may indicate if the endocrine response to E and R can be further enhanced through chronic training in this population.

Chapter 4

The Effects of a Combined Resistance Training and Endurance Exercise Program in Inactive College Females: Does Order Matter?

ABSTRACT

While both endurance exercise (E) and resistance training (R) have been shown to improve various health and fitness variables, there is still considerable debate regarding the optimal ordering of these modes of exercise within a combined exercise bout. It is often assumed that order should be dictated by the priority of the desired outcomes. PURPOSE: To determine the effects of performing E before R (E-R) or R before E (R-E) on strength, VO_{2peak}, and body composition over the course of an 8-week exercise program. METHODS: Inactive college females (N = 23, 19.8 $\pm$ 0.22 y; 163.5 $\pm$ 1.68 cm; 61.0 $\pm$ 2.5 kg) were randomly assigned to either an E-R group (n = 13) or an R-E group (n= 10). Subjects participated in 4 days of exercise per week over the 8-week study. The E component of the program consisted of 30 min of aerobic exercise at 70-80% HRR, and HR and RPE were monitored continuously. The R component utilized a 3-way split routine (chest and back; shoulders, biceps, and triceps; lower body) with subjects performing 3 sets of 8-12 repetitions for 5-6 different exercises using a load equal to 90-100% 10RM. Subjects completed 2 days of testing before and after 8 weeks of exercise training to determine strength, VO_{2peak}, and body composition. RESULTS: There were significant improvements in chest press (Pre = 34.4 $\pm$ 1.5 kg; Post = 46.1 $\pm$ 1.8 kg; P< 0.001), leg press (Pre = 76.0 $\pm$ 6.3 kg; Post = 105.7 $\pm$ 7.0 kg; P < 0.001), $VO2_{peak}$ (Pre = 38.8 $\pm$ 1.4 ml/kg/min; Post = 44.9 $\pm$ 1.3 $ml \cdot kg^{-1} \cdot min^{-1}$; P < 0.001), and FFM (Pre = 43.2 $\pm$ 1.3 kg; Post = 44.2 $\pm$ 1.2 kg; P = .005) across both groups over the 8 weeks. Weight also significantly increased (Pre = 61.0 $\pm$ 2.5 kg; Post = 61.9 $\pm$ 2.2 kg; P = 0.038), but %BF did not change (Pre = 28.4 $\pm$ 1.4 %; Post = 28.0 $\pm$ 1.2 %; P = 0.46). There were no differences in fitness or body composition as a function of group (P>.267).

CONCLUSIONS: There were significant improvements in strength, aerobic capacity, and FFM over an 8-week combined R and E training program in previously inactive college females. These improvements occurred regardless of the order in which R and E were performed. PRACTICAL APPLICATIONS: Contrary to popular belief, it appears that fitness markers improve similarly regardless of the order of R or E in a 4-day per week workout program. It is possible that differences may emerge with longer training programs or in a more active population. Given the similarities of fitness outcomes, it appears that the order of R and E exercises for beginning exercisers should be organized based on personal preference to facilitate adherence.

INTRODUCTION

The benefits of both endurance exercise (E) and resistance training (R) as interventions are well documented, and both are recommended to improve health and fitness. E has been seen as a benefit to one's health and fitness for many years, as it improves aerobic capacity, capillary and mitochondrial density, lipid profiles and weight loss (33, 34, 47, 51, 117, 121, 130, 138, 158). R has been recognized largely for its impact on strength and lean body mass (FFM), as well as for its impact on fat loss, and improvements on lipid profiles (34, 61, 121, 147, 158). Current recommendations for exercise prescription suggest a combination of E and R, since the benefits may provide an overall synergistic effect, and each intervention has overlapping as well as unique benefits (5, 119).

Studies comparing E or R alone to a combined training group have found that the combined groups did have positive improvements in strength and aerobic capacity as well as increases in basal metabolic rate and fat loss (47, 61, 117, 119, 130). However, several of these studies suggest that the benefits of combining exercises into one session may not always result in the same magnitude of selected outcomes compared to performing each exercise alone (30, 61, 117, 119). Kraemer et al. have shown an attenuation of strength gains when comparing R-only to a combined R and E group (115). Still, the argument for using combined training is that it may be more beneficial as a whole for overall health purposes (61, 117, 119).

While the benefits of combining E and R into one session have been demonstrated for strength and aerobic capacity, the sequence in which the modalities are performed may also be an important consideration in order to maximize benefits. Chtara et al. found

that performing E before R improved 4km time trial and VO_{2peak} significantly more than performing R before E, as well as either exercise modality (R or E) alone, in a fit male population (33). It was suggested that performing R before E fatigues the muscles that are used during the aerobic bout (33). However, contrary to the suggestions of Chtara et al., other researchers have found no significant impact of the order of these modalities on oxygen consumption during the exercise bout (4). On the other hand, attenuations in chronic strength gains when performing E prior to R have been explained by a diminished ability of the neuromuscular pathway leading to the reduction in strength gains (29, 118). As evidence for potentially greater strength gains when R is performed before E, Cadore et al. saw a significant increase in strength gained in comparison to a group performing E before R, which was related to an increase in the force generation of the muscle per unit of muscle mass (29). However, there were no differences in aerobic fitness gains between the exercise sequences (29). Other research has indicated no significant difference in either aerobic or strength gains when comparing the sequence in which both E and R were performed (38, 70). One potential reason for this may be the variability in training frequency and intensity given that many of the studies had subjects only training 2-3 days per week and performing exercises of low to moderate intensity (29, 33, 34, 70). Average increases in aerobic capacity and strength varied from ~5-14% and ~12-33%, respectively (29, 33, 34, 38, 70, 138). Duration, frequency, and intensity play an important role in determining the effectiveness of desired outcomes, and 2 days per week of lower to moderate intensity training may not be sufficient to elicit large enough changes to see differences in the ordering of the exercises.

Aside from the aerobic and strength gains, a chronic benefit of including R in a combined exercise regime is increased fat free mass (FFM) (47, 73, 117). Given the variability in strength gains between different exercise order sequences (29, 34, 70, 138), it stands to reason there may have been differences in FFM gains. Interestingly, all of the studies mentioned above have measured body composition, but none have reported on the significance or differences in FFM, specifically (29, 34, 70, 138). Therefore, the differences between performing E before or after R on changes in FFM warrants further investigation.

Selecting an exercise program that will maximize efficacy and allow an individual to achieve the optimal benefits is important. While both R and E have been shown to improve various health and fitness variables, there is still considerable debate regarding the optimal ordering of these modes of exercise within an exercise bout. Given the few studies that exist, there is need to determine the effects that E and R have on specific desired outcomes (i.e., strength, aerobic capacity, body composition). It is often assumed that order should be dictated by the priority of the desired fitness and health outcomes. Therefore the purpose of this study was to determine the effects that the order of exercise modality has on strength, VO_{2peak}, body weight, body fat (%BF), and lean body mass (FFM), over the course of an 8-week exercise program.

METHODS

Experimental Approach to the Problem

To determine if there is a significant difference between R-E and E-R on aerobic capacity, strength, weight, FFM, and %BF, we employed an 8-week combined exercise program using aerobic exercise (70-80% $HR_{reserve}$) and a comprehensive resistance training protocol (90-100% 10RM) using inactive college-aged females. This study was approved by Rutgers University Institutional Review Board. Subjects participated in two days of familiarization, two days of pre-testing, eight weeks of exercise intervention, and two days of post-testing. After completing baseline testing, subjects were matched on body weight and randomly assigned to either an R-E or E-R group.

Subjects.

Inactive college females (N = 23, 19.8 $\pm$ 0.22 y; 163.5 $\pm$ 1.68 cm; 61.0 $\pm$ 2.5 kg) volunteered to participate in the study. Subjects were informed of the study protocol and signed an informed consent prior to participation. Inclusion criteria required that subjects did not exceed 30 minutes of aerobic exercise 3 times per week, engage in moderate intensity R more than 2 times per week, take any medications or have any illnesses that would disrupt metabolic activity or body composition, or have any disabilities that would prohibit them from engaging in the required physical activities. For subject baseline data as a function of group, see Table 4-1.

Table 4-1

Variable	R-E (n=10)	E-R (n=13)	p-value
Age (y)	19.9 ± 0.4	19.8 ± 0.3	0.78
Height (cm)	164.3 ± 2.6	162.9 ± 2.7	0.67
Weight (kg)	60.4 ± 3.8	61.5 ± 3.4	0.84
BMI	22.2 ± 1.2	23.1 ± 0.6	0.52
Body fat (%)	26.8 ± 2.1	29.6 ± 1.8	0.32
FFM (kg)	43.8 ± 2.1	42.8 ± 1.8	0.74
Fat mass (kg)	16.6 ± 2.3	18.6 ± 2.0	0.52
VO_{2peak} (ml/kg/min)	37.4 ± 2.2	39.9 ± 1.9	0.4

Table 4-1. **Characteristics of study participants**. Values expressed as mean ± SEM. FFM, lean body mass; BMI, body mass index.

Procedures

Body Composition. Body Composition was determined by measuring body volume via air displacement plethysmography using the BOD POD (Life Measurements Instruments, Concord, CA) as described in previous literature (43, 186). Percent body fat (%BF) was calculated through a two-stage procedure. In addition to %BF, FFM was also calculated. Height and weight were recorded in conjunction with body composition assessment. All subjects were required to fast for at least 3 hours, arrive normally hydrated, and without having exercised prior to the test.

Aerobic capacity. Study participants underwent a progressive exercise test to determine aerobic capacity (VO_{2peak}) before and after the 8-week intervention. A continual progressive protocol (Bruce Protocol) was used to determine $\dot{V}O_{2peak}$ with an increase in power output at 3-minute intervals until volitional exhaustion (9). The test and experimental trials were performed on a high-speed treadmill (Trackmaster, Newton, KS) and direct gas exchange (VO_2 and VCO_2) measurements were made using a ParvoMedics TrueOne 2400 metabolic cart (ParvoMedics, Provo, UT). The maximal graded exercise test was considered valid if 3 or more of the following 4 criteria were met: (a) HR_{max} within ± 15 beats·min^{-1} of age-predicted maximum HR or a HR that fails to increase with increased workload, (b) respiratory exchange ratio > 1.10, (c) RPE greater than 17 (6-19 scale), and (d) plateau of VO_2 (< 2.0 ml/kg/min) despite an increase in workload (5). HR was measured throughout the graded exercise test and experimental trials using a Polar S610 HR monitor (Polar Electro Co., Woodbury, NY).

Strength. 48 hours after the VO_{2peak} test subjects came back to the lab to determine maximal strength for each participant, using a 10-repetition maximum

(10RM). This is considered a safer and more reliable form of testing than the 1RM, since the subject pool is unskilled in weight training (7). The 10RM was assessed for chest press and leg press. Subjects warmed up for 3-5 minutes on a stationary bicycle at 50% of their HR_{max} to increase blood flow and prepare for the maximal testing. Weight was increased between sets until precisely 10 repetitions, executed in good form, were attained for each of the exercises. The 10RM was achieved within 4 sets for all subjects (9).

Experimental protocol. Subjects were randomly assigned to perform either R before E (R-E) or E before R (E-R). The training program consisted of 4 sessions per week for 8 weeks, with each session lasting approximately 1 hour. The aerobic component of the program consisted of 30 minutes of moderate to moderate-high intensity E at 70-80% HRR, with HR and RPE being monitored continuously throughout each session. The cardiovascular exercise intensity was progressively increased each week based on RPE and HR response (5). The R component utilized a 3-way split routine (chest and back; shoulders and arms; lower body) with subjects performing 3 sets of 8-12 repetitions for 5-6 different exercises using a load equal to 90-100% 10RM. The rest period between sets and exercises was 60-90 seconds. The weight for each R exercise was recorded and, when 12 repetitions could easily be attained, adjustments were made to allow progressive overload in accordance with exercise prescription guidelines (5). To ensure safety and proper technique of the exercises, a trained research staff member supervised each exercise session. The time between E and R was no more than 5 minutes.

Statistical Analysis.

The results are expressed as mean ± SD. Repeated measures ANOVA with univariate follow-ups were used. The design consisted of a 2-way (group × time) analysis with repeated measures for the last factor. VO_{2peak}, 10RM Chest Press, 10RM Leg Press, body weight, %BF, and FFM were the dependent variables and were compared before and after 8 weeks of training for the R-E and E-R groups. Statistical significance was set at $P< 0.05$. Effect sizes (ES) were computed using Hedges' g formula. Statistical analyses were performed using SPSS v.19 software (SPSS Inc., Chicago).

RESULTS

Aerobic Capacity Changes

VO_{2peak} increased significantly ($p<0.05$) in both the E-R and R-E groups (E-R, pre 39.9 ± 1.9, post 46.2 ± 1.8 ml/kg/min, ES = 1.1; R-E, pre 37.4 ± 2.2, post 43.2 ± 2.0 ml/kg/min, ES = 0.7, $P < 0.05$). (See Figure 4-1). There was no significant difference between the groups ($P>0.05$, ES = 0.2).

Strength Changes

There was a significant increase in muscular strength for chest press (E-R, 13.1 ± 1.2 kg, ES = 1.7; R-E, 9.9 ± 1.8 kg, ES = 1.4, $P<0.001$) and leg press (E-R, 30.2 ± 4.8 kg, ES = 1.8; R-E, 28.6 ± 4.4 kg, ES = 0.7, $P<0.001$) (Figure 4-2). Increases in strength were not significantly different as a function of group for chest press ($P > 0.05$, ES = 0.7), or leg press ($P > 0.05$, ES = 0.1).

Body Composition Changes

Both groups significantly increased FFM ($P<0.05$, ES = 0.4), but there were no significant differences between the groups (E-R, 1.2 ± 0.3 kg, ES = 0.3; R-E, 0.6 ±, 0.6 kg, ES = 0.1, $P>0.05$) (See Figure 4-3). There was a significant increase in body weight as a function of time (E-R, 0.8 ± 0.6 kg, 0.1; R-E, 1.0 ± 0.5 kg, ES = 0.1, $P=0.038$) but not as a function of group ($P>0.05$, ES = -0.1) (See Figure 4-4). There were no significant changes in %BF for either group ($P > 0.05$, ES = -0.5) over the course of 8 weeks (E-R, -0.9 ± 0.6%, ES = -0.1; R-E, 0.2 ± 0.7%, ES = 0.0) (See Figure 4-5).

Figure 4-1

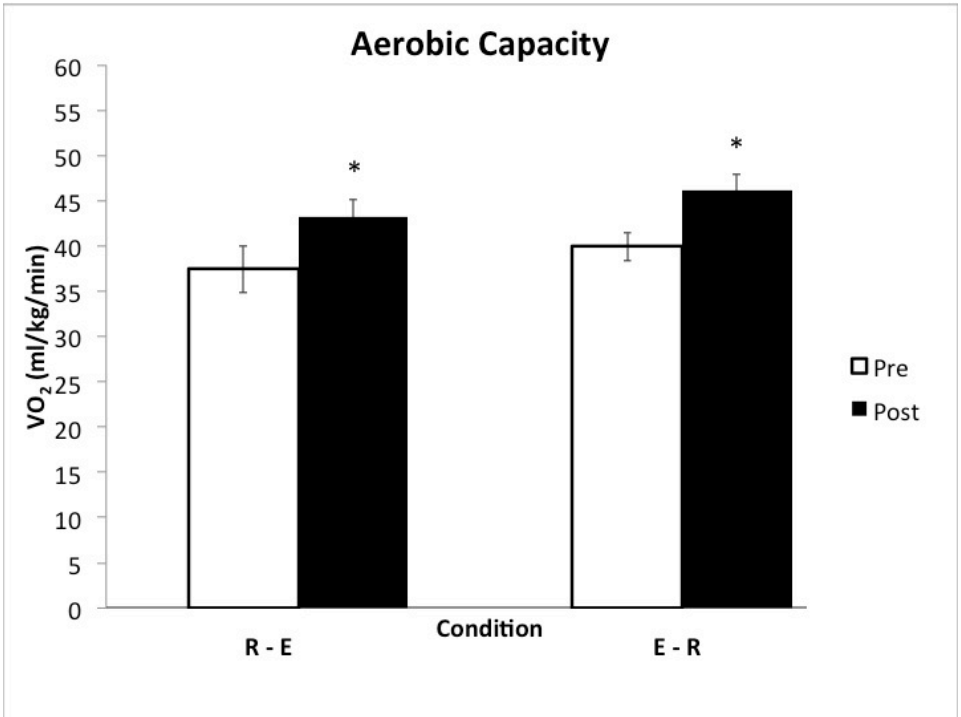
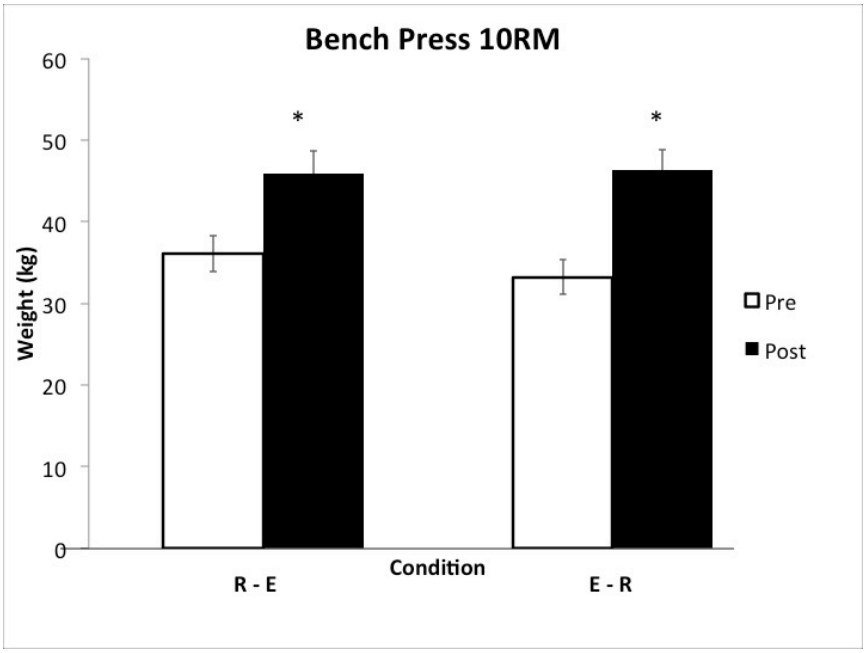


Figure 4-1. Aerobic capacity before and after the 8-week training program. There was a significant difference as a function of time ($P < 0.001$), but not as a function of group ($P > 0.05$). * Significantly different from corresponding Pre-value.

Figure 4-2

A



B

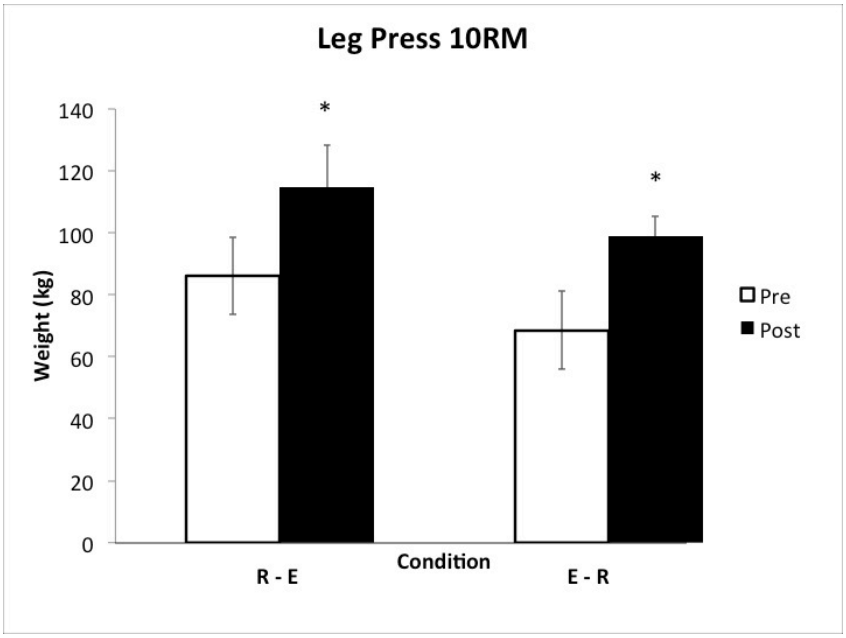


Figure 4-2. 10RM strength changes before and after 8 weeks of training. (A) Upper body strength changes. (B) Lower body strength changes. There was a change in strength as a function of time ($P < 0.001$), but not as a function of group ($P > 0.05$). * Significantly different from corresponding Pre-value.

Figure 4-3

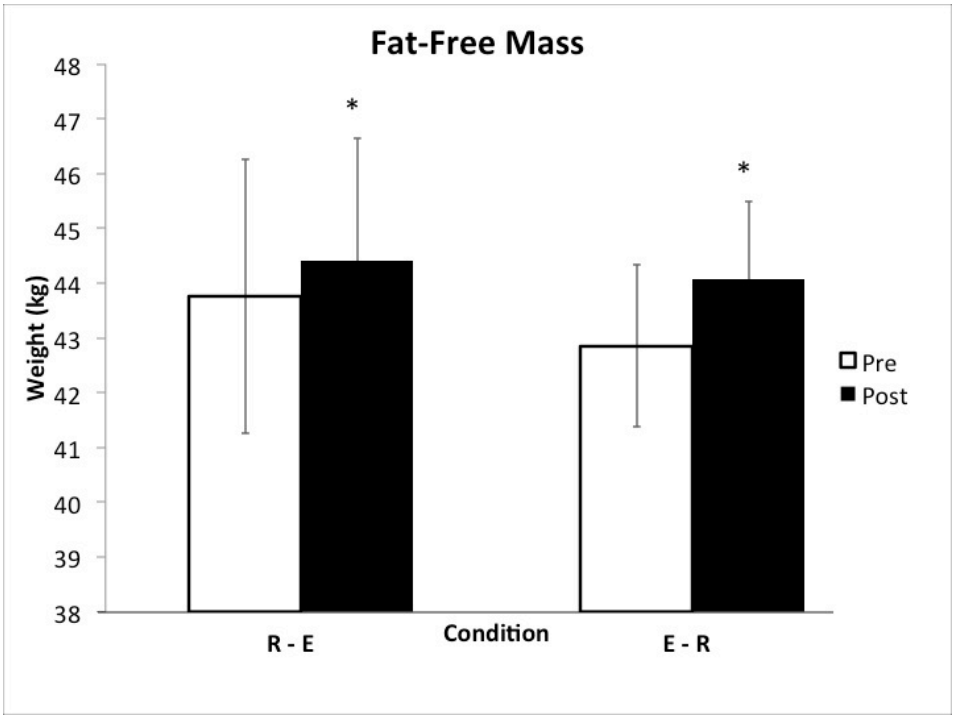


Figure 4-3. Changes in FFM before and after 8 weeks of training. Changes in FFM were significantly different as a function of time ($P = 0.005$), but not as a function of group ($P > 0.05$). * Significantly different from corresponding Pre-value.

Figure 4-4

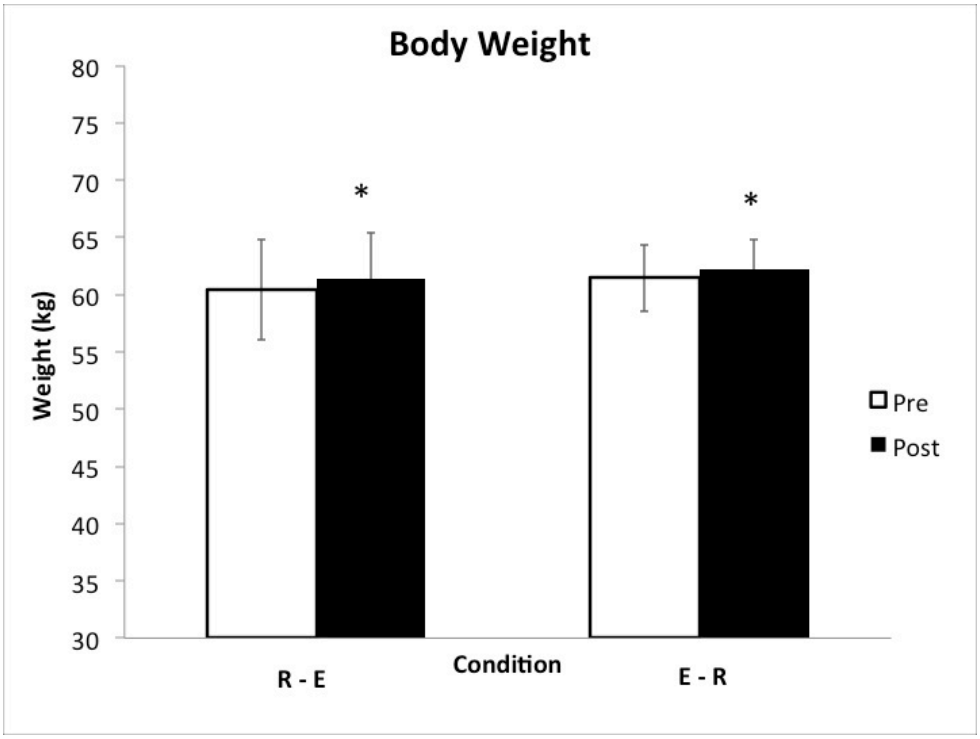


Figure 4-4. Changes in weight before and after 8 weeks of training. There were significant differences as a function of time (P = 0.038), but not as a function of group (P > 0.05). * Significantly different from corresponding Pre-value.

Figure 4-5

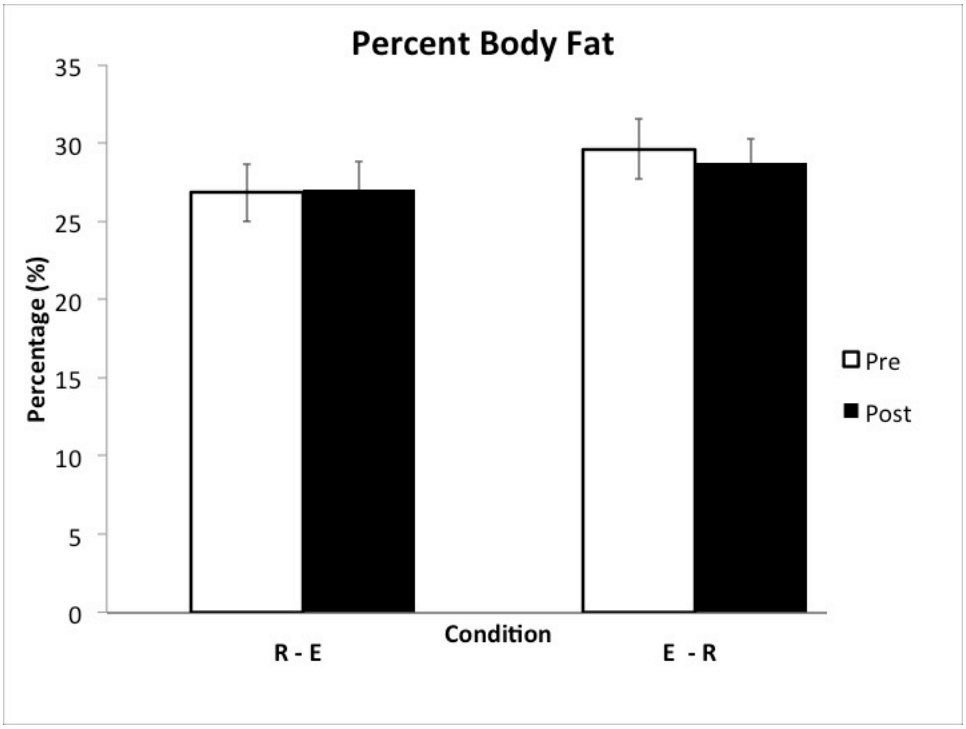


Figure 4-5. Changes in % body fat before and after 8 weeks of training. The changes in body fat were not significantly different (P = 0.461).

DISCUSSION

The findings of this study indicate that the combination of E and R into one session results in an improvement in aerobic capacity, strength, and FFM in inactive college-aged females. These effects were seen independent of the order in which the modes of exercise were performed. The increase in aerobic capacity seen with both groups in our study (R-E, 15.3%, E-R, 15.6%, respectively) was similar to improvements seen in other studies comparing exercise sequence. Chtara et al. demonstrated 13.6% and 10.7% increases in VO_{2peak} for both E-R and R-E (33). The increase in their E-R group was significantly different than the group that performed R first. They argued that performing R before E resulted in a inferior improvement in aerobic capacity due to the resultant fatigue from the prior R workload (33). They did, however, indicate the R-E group increased aerobic capacity similar to an E-only group, which means the addition of R before E improved aerobic capacity to a similar extent as E-only (33). While we did not see significant differences in VO_{2peak} between groups, one difference between our study and that of Chtara et al. was that we used inactive female subjects and they used active aerobically fit males. Perhaps the changes as a function of exercise modality order are not as pronounced in the population we studied, and there may be greater impact for trained individuals. In comparing a combined E and R protocol versus each exercise modality alone, Dolezal et al. reported that using a combined R-E protocol is inferior to E-only for producing improvements in VO_{2peak} in aerobically fit men ($VO_{2peak} \geq 50$ ml/kg/min) (47). While they did not compare different exercise order groups, they did indicate there combined group always performed R first, and this disrupted the gains in aerobic capacity, which supports the findings of Chtara et al. They postulate that the

impedance of aerobic capacity gains with R inclusion is a result of a reduction in capillary and mitochondrial volume density (47). All other studies comparing exercise order used non-endurance trained participants and revealed no difference in VO_{2peak} between groups, (29, 38, 70). It has been reported that the addition of R to E improves the efficiency of the muscles through a muscle fiber type shift, with a transformation of type IIb fibers into type IIa (173), which can aid in overall oxidative metabolic capabilities (170). Another study that also compared the sequential ordering of exercises used active females and found that after 12 weeks of training, both exercise orders increased VO_{2peak} but only the group that performed R first increased VO_{2peak} significantly (70). This is contrary to previous research, and the authors indicate that a reduction in one subject's VO_{2peak} may have contributed to the lack of significance in the E-R group (70). Though many of these studies seem to have conflicting results, they nonetheless do show improvements in aerobic capacity when combining E and R exercise modalities into one session. Collins and Snow used both males and females in a 7-week study and saw significant VO_{2peak} increases for both exercise orders but no significant difference between the groups (R-E 6.7%, E-R 6.2%) (38). The lack of significant difference between the sequential ordering in Collins and Snow's study closely resembled the results of our study. Regardless of the differences (or lack thereof) between groups, the aerobic capacity improvements in the current study were higher than any of the previously mentioned studies (29, 33, 38). While conflicting conclusions may persist in this area, inclusion of a combined program resulted in significant improvements in VO_{2peak}, regardless of the order in which the exercise is performed. Perhaps this and the different findings among previous and current research can be attributed to the intensity,

duration, and frequency of the different training protocols. For example, the average sessions attended per week for both groups in the current study was 3.4, which was higher than all previously reported studies comparing exercise sequence (29, 33, 38, 70, 138). Other important factors, as discussed above, are training status and fitness level.

With regards to strength changes in a combined program, we saw significant improvements for both chest press (27.4%, 39.5%) and leg press (33.2%, 44.1%) for R-E and E-R, respectively. Further analysis indicates an effect size (ES) for chest press of 0.7, in favor of E-R. The ES for leg press was small (0.1) but interestingly, the ES for group gains were both large yet different (R-E, ES = 0.7; E-R, ES = 1.8). The between-subject variability may be contributing to the lack of statistical difference despite the ES values. The overall changes in strength were similar in both groups and were in accordance with several other studies examining combined exercise modalities (38, 47, 70, 117, 130). One study showed a combined group having similar significant increases in both chest press and squat (18%, 22%) when compared with an R-only group (18%, 23%) (130). The training schedule had subjects exercising 3 days per week for 10 weeks using a high intensity R protocol (130). Comparing the sequential ordering of E and R in active females, Gravelle et al. found no significant differences between exercise orders even though both groups saw significant increases in leg press (R-E = 26.6%, E-R = 27.4%) (70). It is also worth noting that E did not appear to inhibit strength improvements considering that an R-only group had a similar increase in leg press when compared to both exercise order groups (25.9%) (70), which is consistent with other findings in both male and female participants (38). This is in conflict with some previous findings of exercise modality order reporting R before E did result in significantly greater strength

gains than E-R in elderly men (29). Other studies comparing a combined R and E versus R-alone have indicated the addition of E to R results in inferior strength gains in men (47, 115). Previous findings of attenuations in strength gain from the addition of E to an R program may suggest the mechanism of action to be less neuromuscular motor unit time or recruitment and therefore less muscle tissue being used to carry out the exercise (73, 115). In cyclists, diminished muscular power after a previous bout of E appears to be the result of a reduction in muscular recruitment (118). This can be explained by the different bioenergetics demands of E and R. R typically results in hypertrophy of fast twitch, type II muscles, with an increased recruitment of faster and more force generating muscle fibers and is highly reliant on ATP-PCr and glycolysis (115, 135, 170, 173). E, which relies on oxidative phosphorylation, induces changes in the metabolic machinery to increase oxidative metabolism capabilities, often times reducing hypertrophy and power generating muscle fibers, which would impede overall gains in muscular strength and anaerobic power (54, 115). However, not all research using a concurrent E and R program saw decrements in strength gain compared to R-alone (117, 130). Lemura et al. used a similar population to the current study and reported significant increases in strength for a R-only group and a combined R and E group, with no significant differences between the groups (117). Again, even though there were discrepancies between studies, they all seem to agree that there are benefits and gains to be made, whether E is added to R and regardless of the order in which the modalities are performed.

It is important to note that there are several major differences between the studies in this area. These include, but are not limited to: the subjects' activity status, the

frequency of exercise during the study, and the duration of the study. Some studies have had their subjects training as little as 2 days per week (33, 138) while others, including the current study, have used as many as 4 days per week of training. The subjects being sedentary vs. active, or even male vs. female will potentially play a large role in determining the somewhat short-term effects of both E and R. For the sedentary individual or novice exerciser, the initial changes and improvements may be from the subjects learning and mastering proper form and from neuromuscular adaptations which will simply allow them to become more efficient (31). When using a previously sedentary population for examining exercise modality order effects, perhaps differences would emerge with longer periods of training. This is partly supported by an interference and actual reduction in strength gains in a combined E and R group only showing up after 8 weeks of training (85). Given the rather large initial fitness improvements that would be seen for a sedentary population compared to an active one, it is possible that any exercise modality order effects are superseded by the robust physiological effects simply produced by a combined protocol.

The combining of E and R into one exercise session is very common, especially for those individuals who have limited time to exercise. It has also been the intention of individuals to try and achieve the specific adaptations that each exercise provides. Body composition change (fat loss and muscle gain) is perhaps one of the most sought after benefits that people seek when beginning an exercise program. These changes have been attributed to both E and R programs alike. Many times when combining a program of R and E the individual will see dramatic changes in body composition, which is typically from a loss of body fat and an increase or maintenance in FFM (47, 117). The body

composition results of the current study were similar to many other studies that used a combined exercise group and saw increases in total body weight (34, 38, 47, 138). FFM increased significantly for both groups (E-R, 1.2 kg and R-E, 0.6 kg), and there was a significant increase in body weight (E-R, 0.8 kg, and R-E, 1.0 kg). However, there were no significant differences between groups. Chtara et al. showed a significant difference between pre and post body fat percentages in R-E and E-R groups (-2.2%, -2.2%) with no difference between groups. Okamoto et al. used sedentary males and females to study sequential ordering of exercise and found a significant decrease in body fat percentage in both groups, with no significant difference between groups (E-R, -2.9%; R-E, -2.7%) (138). Though FFM changes were not reported, it can be assumed that there was an increase in FFM considering that subjects lost body fat and increased total weight by about 1 kg (38). There were also significant increases in strength, which support the findings that all of the studies mentioned, regardless of exercise order, saw strength increases concomitant with increases in FFM (29, 33, 34, 38, 47, 70, 138). Differences in strength and FFM gains are likely attributable to the various intensities, durations, frequencies, training status, age, and gender.

Within the current study there was no significant difference between the groups with regard to a change in body fat percentage from pre to post (E-R, 0.64% and R-E, -2.99%). This is consistent with some previous findings (70, 154), but inconsistent with others (33, 38, 138). Given the significant increases in strength, VO_{2peak}, and FFM we would have generally expected to see a decrease in fat mass, given a frequency of 4 days per week of exercise. However, this was not the case. Though we cannot entirely account for the lack of body fat change, we do recognize that subjects were instructed to continue

their regular diet throughout the training program. Given the subject population, the body fat results in the current study are not completely unexpected, as it is consistent with weight gain typically seen in college underclassmen (35, 67). Upon calculation of ES for body fat percentage (-0.5) we notice a moderate-to-large difference between groups. Again, subject variability likely influenced the lack of statistical differences.

There are a limited number of studies performed examining the sequential order of exercise modalities in a single session, though several others have compared combined training against each exercise alone. While one study did demonstrate inferior aerobic capacity gains when E was preceded by R (33), the overall consensus appears to be that concurrent use of R and E in a single session does not appear to, consistently and significantly, influence the adaptations to training, regardless of the order or sequence in which one performs them. The exception to this observation appears to be whether an individual is primarily aiming to maximize improvements in muscular strength, as concurrent E and R has been shown to cause inferior gains in strength compared to R-alone (73). Though an increase in strength will ensue, it is typically not to the extent of an R-only program. Perhaps for the untrained or sedentary person, the exercise modality order (R-E or E-R) may not necessarily matter, as either will produce neuromuscular adaptations and improvements in aerobic fitness. If both orders provide similar benefits, the only rationale for prescription may be personal preference with implications towards adherence. Further research is needed to determine if the lack of significant differences seen in sequential ordering, within an untrained population, persist when continued for more than 8 weeks. Based on the results of this study, it can therefore be advised to recommend a concurrent and combined exercise program consisting of E and R,

regardless or sequential ordering, towards the improvement of one's health and fitness in an inactive female population.

CHAPTER 5:

Discussion and Conclusions

With the need to rectify the negative disruption in fat balance obese individuals seek treatments that will positively alter the hormonal and metabolic state in favor of promoting lipid oxidation and reducing plasma TG concentrations. Given the role that eating has in the daily balance of fat, studying individuals in the fed state is quite pertinent. As the benefits of exercise have been associated with positive improvements in lipid oxidation and plasma TG concentration in addition to benefits in physical fitness (e.g., strength and aerobic capacity), the further understanding of the significance that various exercise modalities (E and R) can have on these obesity related parameters may help improve the life of such individuals in need.

As both E and R were of sufficient magnitude to cause a significant elevation in GH concentration, this rise in GH was concomitant with an elevation in lipid oxidation. This is consistent with previous literature reporting that significant elevations in GH have been linked with a lower RER, thus contributing to an elevation in lipid oxidation. While both E and R resulted in significantly greater GH release, future research using the current design warrants studying of GH plasma concentration changes immediately post and at more frequent intervals as compared to the 30 min initial post-exercise blood draw used in the current study. The current design may have resulted in a masking of potentially significant differences between E and R, based on previous reports indicating peak GH response near the end of exercise or within 30 min post (97, 113, 134, 140, 195). Additionally, the large ES for GH response between E and R (ES = 1.6) suggests a potential difference between E and R that may not have emerged statistically due to large individual variability.

Since obesity is associated with health risks and reduced lipid oxidation, the elevated lipid oxidation for both E and R has importance for inducing a negative energy balance, or more specifically a negative fat balance (76). Due to the transient nature of the postprandial TG excursion, the exaggerated response in obese individuals, and the association of such an elevated plasma TG with CVD, the current finding that a prior bout of E and R can attenuate this TG concentration excursion (Figure 2-3,A) suggests E and R may provide the stimulus necessary to reduce the risk for CVD in obese women.

The current data are the first to show significant attenuations in postprandial plasma TG excursion from a prior bout of E and R in obese women. This reduction was likely the result of either reduced hepatic derived VLDL-TG or increased plasma VLDL-TG clearance. Given the complex inter-relationship of both chylomicron and VLDL-TG particles throughout the postprandial period, the ability to accurately use their plasma concentration to identify exogenous (dietary) vs. endogenous contributions to plasma TG is insufficient. We therefore created a novel approach for the separation and identification of exogenous and endogenous contribution to plasma TG. Using a calculation to compare the enrichment of tracer within the isotopic labeled meal and enrichment of plasma TG and FFA, we were able to directly identify the exogenous or endogenous contribution to plasma TG. This relative contribution of exogenous- and endogenous-derived plasma TG and FFA allowed us to differentiate the source of plasma TG concentration reduction. Interestingly, the reduction in postprandial plasma TG concentration was from endogenous TG only. Again, this is a novel and surprising finding regarding postprandial lipemia after exercise.

The duration of the postprandial period can vary, but typically the resultant peak in plasma TG concentration occurs ~3-4 h (14, 28, 163) after meal consumption. During these early hours after food intake, there is a continual elevation in exogenous-derived plasma FAs that arises from a process known as spillover (131, 132). The significant increases in exogenous-derived plasma FFA for both E and R are the result of spillover within the current study and this is a result of incomplete uptake of FAs released from vascular lipolysis of plasma TG. The resultant increase in FFA from exogenous origin was seen in combination with exogenous FA lipid oxidation. It is likely that the elevation in these exogenous FFAs directly contributed to the significant oxidation of these same FAs. This study is the first to substantiate the efficacy of R for the oxidation of exogenous (dietary) fat. This provides obese women with an additional means to improve the oxidation of fat and postprandial TG concentration.

When E and R are combined and performed chronically, the adaptations that ensue are the result of the accumulation of responses that each exercise bout produces. Given an adequate intensity, duration, and frequency of such exercise, the adaptations that result should be significant. The question is whether the acute impact of either E or R, when performed immediately prior to the other, causes significant alterations to the chronic adaptive responses of both exercises. We report that chronic participation in E and R leads to significant increases in both upper and lower body strength, in conjunction with increases in FFM. In addition, there is also a resultant increase in aerobic capacity, but no change in fat mass. This was achieved regardless of the order in which the exercise was performed. The suggestion that the order of the performance of the exercise modalities would result in differences in chronic adaptations in fitness and body

composition is not supported by our current findings. Given the substantial strength and aerobic capacity gains found within this study, perhaps a larger subject size or longer study duration would produce differential order effects. However, within our inactive female population no such significances exist. These results give us confidence in recommending the combination of both E and R within the same session in order to achieve the desired benefits that each exercise modality uniquely contributes. We cannot, however, make conclusions regarding potential inferiority of concurrent training in comparison to performing either of the exercises alone given the current study design. It should be noted that this was not the intent of this particular study, though.

In conclusion, we provided evidence to support the recommendation of moderate intensity E and high intensity R for the attenuation of the postprandial plasma TG excursion and elevation in total lipid oxidation, in conjunction with significantly elevated GH and partitioning of dietary fat away from storage and into oxidation in obese women. Our current data also support the chronic adaptations resulting from performing E and R in the same exercise session, evidenced by significant improvements in physical fitness and FFM. Future studies comparing the potential applications for E and R on acute postprandial lipid metabolism and partitioning of FA into oxidation should consider the use of various populations in addition to chronic interventions that combine each modality and address body composition changes (i.e., fat mass and FFM) and various fitness parameters (e.g., strength and aerobic capacity).

Appendices

Appendix A-1: Health History Questionnaire

MEDICAL AND EXERCISE HISTORY

NAME_____ DATE_____

BIRTHDATE_____ AGE_____ HEIGHT_____ WEIGHT_____

1. Has your body weight changed substantially in the recent past? _____

   1 = yes If yes, describe completely_____
   2 = no _____
   _____

2. Has your diet recently changed? _____

   1 = yes If yes, describe completely_____
   2 = no _____
   _____

3. How often do you exercise? _____ times/week

4. If you exercise, on average, what is the duration of a typical exercise session for you? _____ min/session

5. Describe the intensity of your exercise (circle one)
   1 = none
   2 = light (e.g. casual walking, golf)
   3 = moderate (e.g. brisk walking, jogging, cycling, swimming)
   4 = heavy (e.g. running, high intensity sport activity)

6. What types of exercise do you engage in and how much do you do each session? (circle all that apply)
   1 = none
   2 = walking _____ miles or minutes
   3 = jogging/running _____ miles or minutes
   4 = swimming _____ yards or minutes
   5 = cycling _____ miles or minutes
   6 = team sports (basketball, softball, soccer, etc.) _____minutes _____ intensity
   7 = racquet sports _____minutes
   8 = weight training _____minutes _____# reps _____# sets
   9 = other _____

7. In total, how much time per week do you spend exercising? _____ hours/week

8. Have you recently changed your exercise habits? _____

   1 = yes If yes, describe completely_____
   2 = no _____

9. Have you ever been diagnosed with diabetes? _____
   If yes: When?_____ How is it controlled (diet, insulin, medications, uncontrolled)?_____

_____

10. Do you or have you ever smoked? _____
If yes: How long ago?_____ For how many years?_____ How many packs/day?_____

11. How much and what type of alcohol do you consume in an average week?
_____
_____
_____

12. Has a close blood relative had or died from heart disease or related disorders (Heart Attack, Stroke, High Blood Pressure, Diabetes etc.)?
1=Mother
2=Father
3=Brother - Sister
4=Aunt - Uncle
5=Grandmother - Grandfather
6=None
If yes- Give ages at which they died or had the event and the problem they had.
_____
_____
_____

13. Have you ever had your cholesterol measured?
1=yes
2=no

If yes- write the date and value (or if it was normal or abnormal)
_____

14. Indicate which of the following apply to you (circle all that apply).
1 = high blood pressure
2 = high blood fats or cholesterol
3 = cigarette smoking
4 = known heart disease or abnormalities
5 = family history of heart disease (parents or siblings before age 50)
6 = sedentary lifestyle
7 = stressful lifestyle at home or at work
8 = diabetes mellitus
9 = gout (high uric acid)

15. Any medical complaints now (illness, injury, limitations)?
1 = yes If yes, describe completely_____
2 = no _____
_____

16. Any major illness in the past?
1 = yes If yes, describe completely_____
2 = no _____
_____
_____

17. Any surgery or hospitalization in the past?
1 = yes If yes, describe completely_____
2 = no _____
_____

18. Are you currently taking any medications (prescription or over-the-counter: including birth control)?
1 = yes If yes, list drugs and dosages _____
2 = no _____
_____
_____

19. Are you allergic to any medications?
1 = yes If yes, list medications_____
2 = no _____
_____
_____

20. Have you ever had any neurological problems?
1 = yes If yes, describe completely_____
2 = no _____
_____

21. Do you now have, or have you ever had, any of the following? (circle all that apply)
1 = heart murmurs
2 = any chest pain at rest
3 = any chest pain upon exertion
4 = pain in left arm, jaw, neck
5 = any palpitations
6 = fainting or dizziness
7 = daily coughing
8 = difficulty breathing at rest or during exercise
9 = any known respiratory diseases

Please describe fully any items you circled_____
_____
_____
_____

22. Do you now have, or have you ever had, any of the following? (circle all that apply)
1 = any bone or joint injuries
2 = any muscular injuries
3 = muscle or joint pain following exercise
4 = limited flexibility
5 = any musculoskeletal problems which might limit your ability to exercise

Please describe fully any items you circled_____
_____
_____
_____

Appendix A-2: Recruitment flyer (Lipid metabolism/hormone response)

OVERWEIGHT WOMEN NEEDED FOR EXERCISE/ FAT METABOLISM RESEARCH STUDY

IF YOU CONSIDER YOURSELF TO BE AT LEAST 20 POUNDS OVERWEIGHT, ARE A WOMAN BETWEEN THE AGES OF 18-40, AND DO NOT SMOKE, YOU MAY BE ELIGIBLE TO PARTICIPATE IN A RESEARCH STUDY FOCUSING ON THE CHANGES IN METABOLISM IN WOMEN FOLLOWING MODERATE EXERCISE SESSIONS. THIS IS A RESEARCH PROGRAM WITH THE GOAL OF IDENTIFYING WHAT EXERCISE PROGRAMS MAY OPTIMIZE BODY FAT LOSS FOR WOMEN, BUT NO PREVIOUS EXPERIENCE WITH EXERCISE PARTICIPATION IS NEEDED.

VALUE OF BEING A SUBJECT:

1) **Body composition measurements**
2) **Resting and exercise electrocardiograms**
3) **Information on your body's metabolism**
4) **Up to $500 in compensation for your time**

Interested subjects must not be involved in a regular exercise program and should not be pregnant or diabetic. Participation would include spending an entire weekday (e.g., approximately 8:30AM-7:00PM) in the laboratory on three separate occasions.

FOR MORE INFORMATION EMAIL PATRICK DAVITT: davitt@eden.rutgers.edu

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Appendix A-3: Informed Consent (Lipid metabolism/hormone response)

Resistance vs endurance exercise: Metabolic and hormonal responses in overweight women

Informed Consent Form

It is the policy of Rutgers University that all subjects participating in research read and sign an informed consent form prior to participation. Read the following carefully, initial the first page, and sign the form if you understand it.

I have been informed that:

1) Dr. Greg Henderson and Dr. Shawn Arent, professors in the Department of Exercise Science and Sport Studies at Rutgers University, have identified me as a potential participant in a research study at this institution.
2) The purpose of this study is to examine the impact of two types of exercise (endurance exercise and resistance exercise) upon hormone levels and metabolism of macronutrients (i.e., fats and proteins).
3) My participation in the study is completely voluntary and will involve 2 pre-study visits and participating in 3 full days (study days) in the Human Performance Laboratory.
4) On the first pre-study visit, I will report to the Rutgers University Human Performance Laboratory in the morning in the over-night fasted state (no food since the night before) and a small amount of blood will be taken by finger-stick to test my blood sugar level. I will be asked to fill out a health questionnaire. Also during this visit, my body composition will be assessed and I will undergo a progressive exercise test on a treadmill to determine my peak cardiovascular capacity. The visit will be approximately 2 hours in duration.
5) On the second pre-study visit, I will be taught to perform the weight lifting exercises that will be carried out during the exercise sessions of study days. The visit will be approximately 1 hour long. At that time, I will have my strength tested for each of those exercises.
6) For the days preceding each of 3 study days, the study team will provide a standardized diet to meet estimated energy requirements. I will be asked to eat all of the food at prescribed times and consume nothing else other than water. The study team will also provide an additional breakfast that will be eaten on the mornings of study days prior to arrival at the laboratory.
7) For each study day, I will report to the Rutgers University Human Performance Laboratory at 8:30AM. I will have consumed a small breakfast one hour earlier (at 7:30AM) that will have been provided by the study team in advance. I will be asked to arrive for testing normally hydrated, having eaten the prescribed breakfast 1 hour prior, and to refrain from ingesting substances that could affect normal physiological functioning (i.e., tea, coffee, alcohol, nicotine). Upon arriving at the laboratory, I will have blood drawn from an arm vein through a needle. Tests to study metabolism will be conducted during exercise and for 8.5 hours of rest after exercise. In randomized order, each of my 3 study days will include either 1 hour of walking on a treadmill at 65% of my maximal cardiovascular ability (a moderate intensity), resistance exercise (weight lifting) for approximately 1 hour, or no exercise at all (control day). After exercise (or resting control period) I will have a small cannula (like an IV) inserted into a hand vein in order to collect blood samples throughout the day, and a heating pad will be kept on this hand for the remainder of the day in order to increase blood flow to the hand. In total, approximately 90 ml of blood will be drawn during each study day. 1 hour after completing exercise (or same time-of-day in the control occasion), I will be asked to consume a shake. The shake will contain something called “labeled fats”. These are fats that can be traced for absorption through the body because they are slightly chemically modified, but are safe. The body processes them the same as it does “unlabeled” fats. There is approximately a 25% chance that my shake will not contain the labeled fats. As well, I will be asked to wear headgear at various times during the day so that the study team can collect and measure my breath. My urine will also be collected throughout the day so that the researchers can measure my rates of protein metabolism. Each exercise or control day visit will be approximately 10.5 hours long. Each of these 3 study days will be separated by at least 1 week.

8) I understand that I will be paid $500 if I complete all testing. If I withdraw early, my payment as a participant in this study will be prorated accordingly.
9) During participation in the study, there may be certain risks due to the exertion of the exercise and drawing of blood. These include such things as shortness of breath, abnormal blood pressure responses, fainting, nausea/vomiting, irregularities in heartbeat, or injury. There may also be some mild discomfort associated with insertion of the needle and cannula for blood draws. However, I understand that steps will be taken to minimize all of these risks, that only the minimal required amount of blood will be drawn, and that emergency protocols and trained personnel are available to deal with the situations if they arise.
10) The possible benefits of my participation in this study include the contribution to scientific knowledge regarding lipid metabolism in women, while also gaining a greater understanding of my own physiology and metabolism, as well as being educated on how to perform well-designed exercise bouts if in the future I do decide to take on formal exercise training. My individual results will be provided to me after completion of the testing upon my request.
11) The results of this research may be published, but my name or identity will not be revealed. In order to maintain confidentiality of my records, my data will be reported in group form only. No subject will be identified individually. Dr. Henderson and Dr. Arent and their research teams will be the only people with direct access to the subject number decoding list.
12) In case of injury, I can expect to receive the following treatment or care which will be provided at my own expense: first aid will be administered and transportation to a hospital will be arranged if necessary. I am aware that facilities and professional care, which are available, will not be provided free of charge and that monetary compensation will not be made.
13) Any questions regarding my participation in the study, before or after my consent, will be answered by Dr. Greg Henderson or Dr. Shawn Arent of the Department of Exercise Science and Sport Studies, Rutgers University, 70 Lipman Dr., New Brunswick, NJ, 08901-8525. Dr. Henderson can be contacted at (732)932-7564 or at ghender@rci.rutgers.edu. Dr. Arent can be contacted at (732)932-8669 x.28 or at shawn.arent@rutgers.edu.
14) In case of injury, if I have questions about my rights as a participant in this research, or if I feel I have been placed at risk, I can contact the Sponsored Programs Administrator at Rutgers University at (732)932-0150 x.2104 in ASB III, 3 Rutgers Plaza, New Brunswick, NJ 08901 or at humansubjects@orsp.rutgers.edu.
15) The nature, demands, benefits, and any risk of the project have been explained to me. I knowingly assume any risks involved. I UNDERSTAND THAT MY PARTICIPATION IS VOLUNTARY AND THAT I MAY WITHDRAW MY CONSENT AND DISCONTINUE PARTICIPATION AT ANY TIME WITHOUT PENALTY OR LOSS OF BENEFIT TO MYSELF. In signing this consent form, I am not waiving any legal claims, rights, or remedies. A copy of this consent form will be offered to me.

I have read the above informed consent form.

Participant's Signature _____ Date _____

"I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature."

Signature of Investigator _____ Date _____

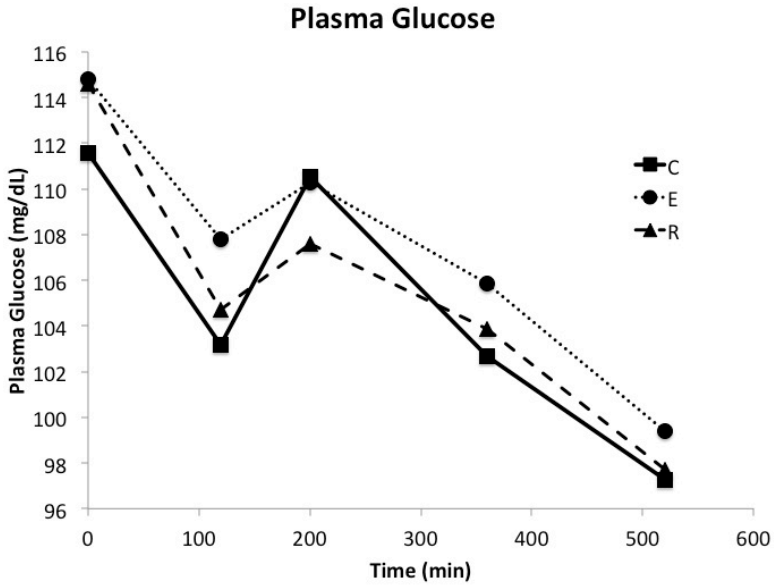
Appendix A-4: 10RM testing/trial day log sheet (Exercise order)

Lipid Metabolism Exercise List (Whole Body)

EXERCISE	10 RM Max	WT/Reps	WT/Reps	WT/Reps	
Bench Press (BB or DB)					WT
					Reps
Pulldowns (close-grip)					WT
					Reps
Shoulder Press (DB or BB)					WT
					Reps
Squats					WT
					Reps
Pushdowns (rope)					WT
					Reps
Bicep Curls					WT
					Reps
Leg Curls					WT
					Reps
Lunges					WT
					Reps

Appendix A-5: Plasma Glucose

A



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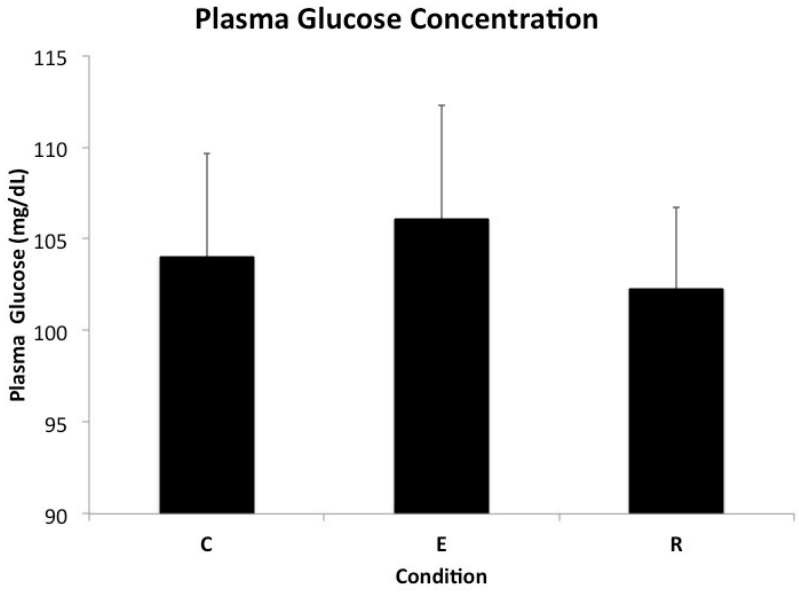


Figure A-1. Plasma glucose concentration. Values are means ± SE. n = 12. (A) Plasma glucose concentration throughout the entire study day. $P > 0.05$. Time (min), duration elapsed since the commencement of the first blood draw. (B) Time-weighted average plasma glucose concentration. $P > 0.05$. C, control. E, endurance exercise. R, resistance exercise.

Appendix A-6: Informed consent (Exercise order)

Resistance Training and Cardiovascular Exercise: Does Order Matter?

Informed Consent Form

Dear Potential Participant,

It is Rutgers' policy that all people participating in research at the university must read and sign an informed consent form prior to participating in the study. Please read the following information carefully, initial each page, and then sign the form if you understand what you have read.

YOU HAVE BEEN INFORMED THAT:

1. Dr. Shawn Arent, an Assistant Professor in the Department of Exercise Science and Sport Studies at Rutgers University, has requested your participation in a study at the university.
2. The purpose of this study is to determine whether exercise mode order (i.e., resistance exercise before or after cardiovascular exercise as part of an exercise bout) impacts gains in strength, lean body mass, body composition, and cardiovascular fitness over the course of an 8-week training program.
3. Your participation will involve a two-day testing session at the beginning of the study to determine your body fat percentage and muscle mass, your aerobic fitness using a treadmill test, and your muscular strength for 4 different strength exercises. You will be given sufficient time to rest between testing days to recover from any soreness. Body fat and aerobic fitness will be tested on the first day. Your body fat will be measured using a high-tech, non-invasive type of test called the BODPOD. Your aerobic fitness will be measured using a maximal effort treadmill test where heart rate and oxygen consumption will be measured. The strength testing will be comprised of bench press and leg press. Each of these testing days will take approximately 1 hour. Following completion of these two days of testing, you will be expected to return to the gym 4 times per week for 8 weeks to participate in the remainder of the study. The weight lifting sessions will be divided into upper body one day and lower body the next and these two days will be rotated to fill the three days per week lifting requirement. You will be expected to perform each of the prescribed exercises for 3 sets per exercise, using 8-12 repetitions per set. You will be expected to lift 80-100% of your maximal weight for each set. The cardiovascular exercise will consist primarily of fast walking and running at 70-75% of your maximal ability for 25-30 minutes per session and you will be monitoring your heart rate and rating perceived exertion during each exercise session. It is expected that each exercise session will take approximately 75 minutes, including warm-up and cool-down. You will be randomly assigned to either a group that does the weight training first in each session, followed by the aerobic exercise, or to a group that does the aerobic

exercise first, followed by the weight training. In order to participate in this study, you must agree to follow the exercise order and intensity that you are assigned for the entire 8 week program. You will be asked to keep an exercise log (which will be provided) throughout the exercise program. At the end of the 8-week program, you will return to repeat the tests that were done at the beginning of the study to determine changes in strength, body fat, lean muscle, and aerobic capacity. As with the pre-testing, these assessments will be completed over 2 separate days, with each testing day lasting approximately 1 hour. In addition, if you complete testing, you will be placed in a lottery and could win one of four $100 gift cards.

4. There are possible risks involved by participating in this study. The risks are normal for intense exercise and include temporary increases in breathing rate, muscle fatigue or soreness, and an increased heart rate. Some unusual but still possible risks are dizziness, nausea, fainting, and muscle cramping or strains. Improper technique could also result in joint injury. Every effort will be made to minimize risk by showing proper technique and by exercising under the supervision of qualified personnel conducting the research who are experienced in exercise training and who are CPR certified.
5. The possible benefits of your participation in this study include an improved understanding of a well-designed exercise program and instruction in proper exercise technique, a likely increase in strength and lean muscle, and a likely improvement in cardiovascular fitness. You will also learn about your physiological responses to resistance training and aerobic exercise and obtain the results of fitness tests that are not normally readily available to the general public. This research will also be a benefit to others when the results of this study are finalized. The benefits obtained from different exercise orders (i.e., weight training or aerobic exercise first) might allow individuals and trainers to use the most effective and time efficient approach for exercise to gain the best results.
6. The results of this study may be published but you will in no way be individually identified. In order to maintain the confidentiality of my name and records, a coding system will be used that is only known by Dr. Arent and his research team. They will be the only ones with direct access to the subject list and their code numbers. Results will only be published as group data.
7. In case of injury during the exercise sessions you will be entitled to the following treatments which will be provided at your own expense: first aid will be administered and transportation to a hospital will be arranged if necessary. You agree that facilities and professional care will not be compensated, or provided free of charge.
8. Any questions you have before or after you sign this informed consent form concerning this research and your participation will be answered by Dr. Shawn Arent at (732) 932-8669 x.28 in the Department of Exercise Science and Sport Studies, Rutgers University, 70 Lipman Drive, New Brunswick, NJ 08901-8525 or at shawn.arent@rutgers.edu.
9. If you have any questions about your rights as a participant in this research or feel that you have been placed at risk, you may contact the Sponsored Program Administrator at (732) 932-0150 x. 2104 in the Office of Research and Sponsored

Programs, ASB III, 3 Rutgers plaza, New Brunswick, NJ 08901 or at humansubjects@orsp.rutgers.edu.

10. The nature, demands, benefits and risks of the study have been explained to you. You have read the risks and benefits of the study and knowingly assume the risks involved in my participation. YOU FURTHER UNDERSTAND THAT YOU MAY WITHDRAW AT ANY TIME AND DISCONTINUE YOUR PARTICIPATION WITHOUT PENALTY OR LOSS OF BENEFIT TO YOURSELF. In signing this informed consent form you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be offered to you.

By signing below, you acknowledge that you have read and understood the information provided in this informed consent form.

Subject's Name (PRINT) _____

Subject's Signature_____Date_____

11. "I have offered the subject/participant a copy of this signed consent document."
12. "These elements of the Informed Consent conform to the Assurance given by Rutgers University to the Department of Health and Human Services to protect the rights of human subjects."

Signature of Investigator_____Date_____

Appendix A-7: Endurance session log sheet (Exercise order)

Name: ____________________________ Week of: _________________

Exercise mode: ________________

	5min	10min	15min	20min	25min	30min
HR:	_____	_____	_____	_____	_____	_____
RPE:	_____	_____	_____	_____	_____	_____
Speed:	_____	_____	_____	_____	_____	_____
Ramp:	_____	_____	_____	_____	_____	_____

Total Duration: _____ NOTES: ____

____

____

Exercise mode: ________________

	5min	10min	15min	20min	25min	30min
HR:	_____	_____	_____	_____	_____	_____
RPE:	_____	_____	_____	_____	_____	_____
Speed:	_____	_____	_____	_____	_____	_____
Ramp:	_____	_____	_____	_____	_____	_____

Total Duration: _____ NOTES: ____

____

____

Exercise mode: ________________

	5min	10min	15min	20min	25min	30min
HR:	_____	_____	_____	_____	_____	_____
RPE:	_____	_____	_____	_____	_____	_____
Speed:	_____	_____	_____	_____	_____	_____
Ramp:	_____	_____	_____	_____	_____	_____

Total Duration: _____ NOTES: ____

____

____

Exercise mode: ________________

	5min	10min	15min	20min	25min	30min
HR:	_____	_____	_____	_____	_____	_____
RPE:	_____	_____	_____	_____	_____	_____
Speed:	_____	_____	_____	_____	_____	_____
Ramp:	_____	_____	_____	_____	_____	_____

Total Duration: _____ NOTES: ____

____

____

Appendix A-8: Resistance Training session log sheet (Exercise order)

Name:_____ Date:_____

Chest and Back Workout

EXERCISE (please circle)	WT/Reps	WT/Reps	WT/Reps	Ideal WT
Bench Press (BB, DB, or Machine)	/	/	/	/
Rows (DB or Machine)	/	/	/	/
Incline Press (DB or Hammer Strength)	/	/	/	/
Pulldowns (Wide grip or reverse grip)	/	/	/	/
Flies (DB, Cables, or Machine)	/	/	/	/
Upright Rows or Close-grip pulldowns	/	/	/	/
ABS:				
Planks (2 Sets x 25-60 sec hold)	/	/	/	/
Ball crunches (2 sets x 15-20)	/	/	/	/

Name:_____ Date:_____

Shoulders and Arms Workout

EXERCISE (please circle)	WT/Reps	WT/Reps	WT/Reps	Ideal WT
Shoulder Press	/	/	/	/
Lateral Raises or Upright Row	/	/	/	/
Bent over lateral raises or High row	/	/	/	/
Pushdowns (bar or rope)	/	/	/	/
Bicep Curls (DB, BB, or machine)	/	/	/	/
Tricep Extensions or bench dips	/	/	/	/
Hammer Curls (DB or rope)	/	/	/	/
ABS:				
Planks (2 Sets x 25-60 sec hold)	/	/	/	/
Leg Lifts (2 sets x 15-20)	/	/	/	/

Name:_____ Date:_____

Lower Body Workout

EXERCISE (please circle)	WT/Reps	WT/Reps	WT/Reps	Ideal WT
Squats *or* Leg press	/	/	/	/
Lunges *or* Bench dips	/	/	/	/
Leg extensions	/	/	/	/
Leg Curls	/	/	/	/
Hyperextensions *or* good mornings	/	/	/	/
Seated *or* standing calf raises	/	/	/	/
ABS:				
HipThrusts (2 Sets x 15-20)	/	/	/	/
Ball crunches (2 sets x 15-20)	/	/	/	/

Appendix A-9: Regression analysis (Lipid Metabolism/hormone response)

Figure A-2

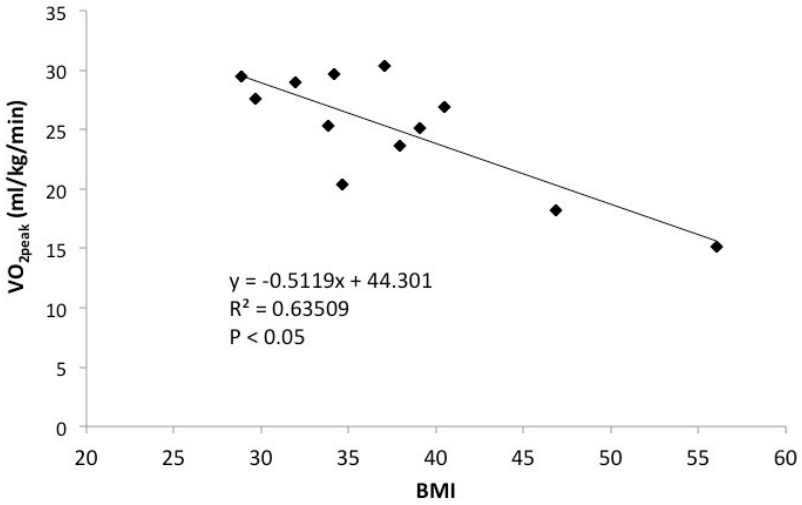
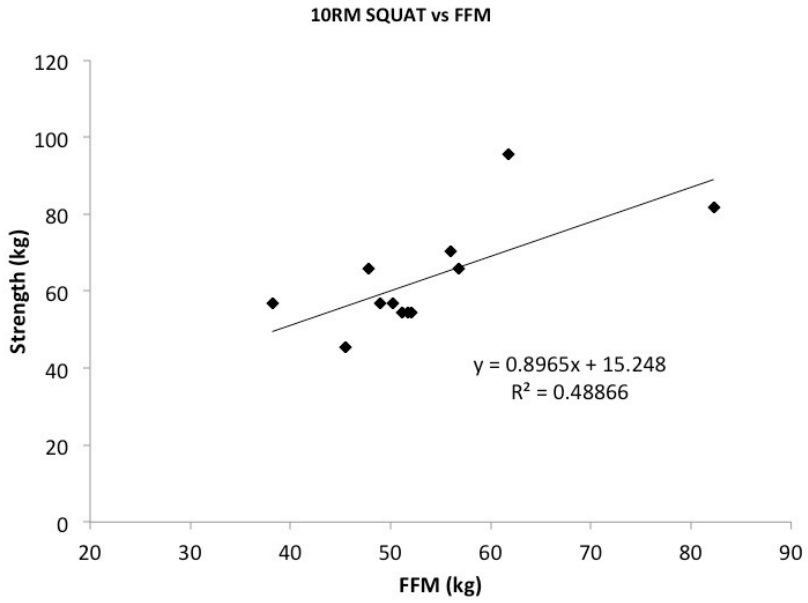


Figure A-2. Relationship between aerobic capacity and BMI. BMI, body mass index.

Figure A-3

A



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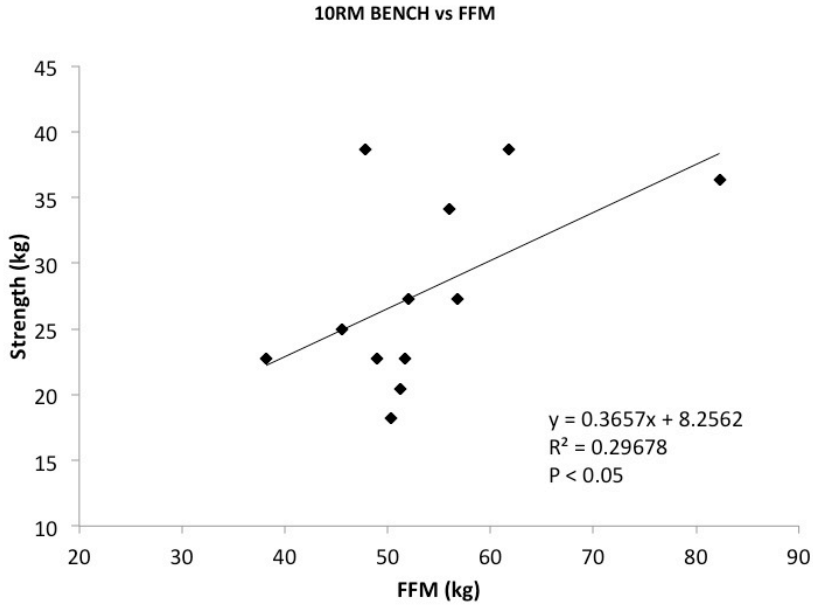

Figure A-3. (A) Relationship between 10RM lower body strength and FFM. (B) Relationship between 10RM upper body strength and FFM. FFM, fat free mass.

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