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The effect of anaerobic exercise on the thermic effect of food

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THE EFFECT OF ANAEROBIC EXERCISE ON THE THERMIC EFFECT OF FOOD.

by

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ABSTRACT

The Effect of Anaerobic Exercise on the Thermic Effect of Food

by

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The thermic effect of food (TEF) is the increment in energy expenditure above resting metabolic rate associated with the cost of absorption, metabolism, and storage of food. Previous studies have shown that TEF is enhanced by aerobic exercise. The purpose of this study was to determine if a similar effect occurs with anaerobic exercise (weight lifting). VO2 was measured after ingestion of a 660 kcal meal with and without prior completion of a weight-training regimen. TEF was 42% higher after the exercise trial ($t=2.539$, $p<.017$), compared with the control trial. These results indicate that prior anaerobic exercise also leads to an enhanced TEF.

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CHAPTER 1

INTRODUCTION

Dietary induced thermogenesis (DIT) or the thermic effect of food (TEF) is the increment in energy expenditure above resting metabolic rate (RMR) associated with the cost of absorption, metabolism, and storage of food within the body. It has previously been shown that the thermic effect of food (TEF) is increased after aerobic exercise of a sufficiently high intensity (>70%) and duration to deplete muscle glycogen (Treadway and Young, 1990). TEF is associated primarily with the energy cost of storing glucose as glycogen. Restoration of muscle glycogen after exercise has two phases. In phase one glycogen resynthesis is independent of the stimulating effects of insulin on glucose transport into skeletal muscle. In phase two, glycogen levels have returned to near base-line values and glycogen resynthesis is dependent on the increase in insulin sensitive transport (Garetto, Richter, Goodman, & Ruderman, 1984). TEF may also be affected by the sympathetic nervous system (SNS). Insulin stimulates the release of norepinephrine (Rowe, Young, Minaker, Stevens et al.,1981). Carbohydrate has also been shown to enhance the turnover rate of norepinephrine (Landsberg and Young, 1978). While strenuous aerobic exercise has been shown to increase TEF, The effect of anaerobic type exercise on TEF has not been published to my knowledge. During anaerobic exercise, every glucose unit in glycogen that is converted to lactic acid yields only three molecules

of ATP compared with the 39 that would have been produced if it had been oxidized to CO_2 and H_2O, which leads to less efficient utilization of glycogen and necessitates more glycogen breakdown. Thus, it may be possible that the TEF is also increased due to anaerobic exercise.

Statement of the Problem

It has previously been shown that the TEF is increased after aerobic exercise, however the effect of anaerobic exercise on the TEF has not been studied. This study investigated the effects of resistance-training (anaerobic exercise) on the TEF.

Purpose of the Study

The purpose of this study was to compare the TEF in participants after a weight-training regimen and in a resting state. The hypothesis was that weight training would significantly increase the TEF over baseline value, when compared with a control trial.

Need for the Study

The effects of anaerobic exercise on the TEF have not previously been examined. The results will further research in the field of metabolism and give a better outlook on exercise as a whole rather than solely aerobic exercise. If anaerobic exercise increases the TEF, then training regimens may focus on anaerobic metabolism as a larger portion of weight loss and controlling obesity.

Limitations and Assumptions

1. The age range of the participants was from 19-24 years old. The age range was limited to insure that age doesn't affect the results in any way.

2. Meals were administered at approximately the same time on the control and treatment day to assure the diurnal effect did not alter the results.

3. All participants were physically fit, because individual differences in the response to TEF may occur in unfit compared to fit individuals (Segal and Gutin, 1983).

4. Dietary journals were kept for three days prior to the exercise trial because dietary state can alter RMR, leading to an inaccurate baseline RMR (Apfelbaum, Bostsarron. & Lacatis, 1971; Ballor, 1991; Ballor, Tommerup, Tomas, Smith & Keesey, 1990).

5. After exercise, VO_2 returned to baseline before feeding the meal to accurately assess TEF. Results from past studies have varied due to administering the glucose load before returning to baseline VO_2. If the VO_2 doesn't return to baseline it is hard to distinguish between the thermic effect of food and the thermic effect of exercise.

6. A 12-hour fast was imposed before treatment to eliminate residual effects of previous diet and reduce glycogen, which facilitates glycogen depletion.

Statement of Hypotheses

Null Hypothesis:

Ho: Anaerobic metabolism (weight lifting) will not increase the TEF.

Research Hypotheses:

H1: Anaerobic metabolism (weight lifting) will increase the TEF.

CHAPTER 2

LITERATURE REVIEW

Energy

Energy is the ability to perform work, which only takes place when chemical energy in food is converted into heat and mechanical work by muscle contraction. Food energy in the US is expressed as a kilogram calorie or kilocalorie (kcal). This is the quantity of heat needed to raise the temperature of one gram of water one degree Celsius under standard temperature and pressure conditions.

Macronutrients are the combination of atoms, which provide energy to the body in the form of carbohydrates, fats, and protein. Energy content of each macronutrient is measured in caloric units. The gross energy for each macronutrient is 4.1 kcal/gram for carbohydrates, 4.5 kcal/gram for protein, and 9.3 kcal/gram for fat (McArdle, Katch, F.I., Katch, V.L., 1999).

Total Energy Expenditure

The four components of daily energy expenditure are; resting metabolic rate (RMR), thermogenic effect of food (TEF), energy expended during physical activity (TEA), and adaptive thermogenesis (AT). The four components vary with different circumstances.

The energy expended during metabolic processes for maintenance of normal body functions and regulation during rest is referred to as resting metabolic rate (RMR). An individual's RMR is the major factor in energy expenditure. RMR accounts for 60-75% of total daily energy expenditure. Factors that effect RMR (McArdke et al., 1999) are:

1. Body composition: RMR is directly related to the amount of muscle mass a person has (Mole, Stern, Schultz, Bernauer, & Holcomb, 1989). Factors that effect body composition may include gender and age.
2. Exercise: Exercise increases RMR for 15 minutes to five hours after exercise.
3. Environmental temperature: A decrease in environmental temperature causes an increased RMR.
4. Nutritional State: Energy deficit may decrease metabolic rate and energy excess may increase RMR. When studying nutritional state, Stock (1980) demonstrated that overeating compared to fasting, one day prior to exercising caused a 50% higher RMR.
5. Fever: Fever can increase RMR up to 7% for each degree rise in temperature.
6. Hormonal profile: Thyroid state can influence RMR (Danforth, 1983).
7. Caffeine and Nicotine: May increase RMR by 10-12% each.

Rubner (1902) observed that the increase in metabolism was greater after the ingestion of protein than after fat or sugar ingestion. Rubner found that this calorigenic effect of food impacts the metabolic rate for a number of hours. The term specific dynamic action (SDA) was the name given to this process by Rubner. Subsequently, SDA has been replaced with the term thermic effect of food (TEF), or dietary induced thermogenesis (DIT). TEF, SDA, or DIT is the next component of total daily energy

expenditure. TEF is defined as the increase in energy expenditure above resting metabolic rate due to the cost of absorption, digestion, transport, metabolism, and storage of food. TEF comprises approximately 10% of the total daily energy expenditure (Jequier and Schutz, 1983).

The two components of TEF are obligatory thermogenesis and facultative thermogenesis (Poehlman, 1989). Obligatory thermogenesis is the energy required for digestion, absorption, and assimilation of food nutrients (Horton, 1983). Obligatory thermogenesis comprises approximately 75% of the TEF. Facultative thermogenesis is the energy expended due to an increase on the SNS (Landsberg and Young, 1983) and metabolic cycling due to food ingestion (Newsholm, 1978). TEF lasts for one to four hours and is affected by several factors. The factors influencing TEF include meal size, meal frequency, and meal composition. Additional factors affecting TEF include nicotine, caffeine, spices, and cold temperature. TEF has also been shown to be blunted in obese individuals (Segal and Gutin, 1983; Segal, Gutin, Nyman, & Pi-Sunyer, 1985).

Physical activity or thermic effect of activity (TEA) also affects total daily energy expenditure. This component is the most variable with 15-30% of the total daily energy expenditure (Poehlman, 1989).

The final component of total daily expenditure, adaptive thermogenesis (AT), is often overlooked. AT is the change in RMR in response to changes in the environmental temperature and physiological stresses. This component contributes no more than 10-15% of total daily energy expenditure. Poehman and Horton (1989) identified various components of AT such as shivering, increases/decreases in metabolic rate due to overfeeding or underfeeding, and changes in metabolic rate due to chronic exercise.

The four components of total daily energy expenditure, RMR, TEF, TEA, and AT, vary from person to person depending on different circumstances. An increase in energy expenditure over food consumption leads to a decrease in weight. Learning how to increase the total daily energy expenditure may be beneficial in the treatment of obesity.

Energy Supplies for the Body

The body is supplied with energy from one of three systems: Phosphocreatine/Adenosinetriphosphate (PC/ATP), glycolysis, or the aerobic system (Astrand and Rodahl, 1986). ATP is the medium for storage and exchange of energy, but each system creates ATP in a different way.

The three systems overlap each other in time, but the primary usage of each system depends on the duration of the exercise. The PC/ATP system provides immediate energy for a short period of time (<10sec) (Serresse, Simoneau, Bouchard, & Boulay, 1991). PC and ATP are stored in small amounts in the muscle, which allows instant energy for immediate activity. This system is used for activities such as when an individual is in a rested state and then begins to run. The glycolytic pathway is primarily utilized from 10 seconds to three minutes. Glycolysis provides immediate energy for a short period of time by degrading glycogen into pyruvate and lactate. While glycogen in the muscles is able to provide energy anaerobically, the cycle is short in duration because lactic acid decreases the body's pH and leads to fatigue. After approximately three minutes of exercise, the aerobic system becomes the primary system utilized. The aerobic system utilizes muscle glycogen and fat, depending on intensity, for the primary

fuel. At high intensities muscle glycogen is the primary fuel and at lower intensities fat is the primary substrate utilized (McArdle et al., 1999).

Action of Substrates in Provoking TEF

The composition of a meal and the quantity of energy intake have both been shown to influence overall energy expenditure. The body may regulate energy intake as a protective mechanism to prevent excessive energy loss during times of starvation. It has been shown that severe dietary restriction results in a decreased RMR (Apfelbaum et al., 1971; Ballor, 1991, Ballor et al., 1990). A decrease in SNS (Landsberg and Young, 1983) and decreased thyroid function (Danforth, 1983) also result from dietary restriction. Others have suggested that exercise may play a role in maintaining RMR during caloric restriction by maintaining lean body mass (Mole et al., 1989).

Overnutrition of carbohydrates has been shown to increase RMR and the TEF. The alterations in RMR may be due to genetics, dietary composition, and current energy stores of the body (Acheson, Ravussin, Wahren, & Jequier, 1984; Schutz, Acheson, & Jequier, 1985; and Weststrate and Hautvast, 1990).

Studies have yielded conflicting results on the effect of meal composition on the TEF. Kinabo and Durnin (1990) have shown that meal composition does not have an effect on TEF. They studied 16 males consuming four different test meals. The four trials were high-carbohydrate-low-fat and low-carbohydrate-high-fat, with each of the compositions repeated with both 600 kcal and 1200 kcals. The results indicated that the energy content of the meal played a role in increasing the TEF, but there was no significant effect of the meal composition. Other studies have found no TEF at all. Bahr

and Sejersted (1991) examined the effect of feeding and fasting on EPOC. The study included six untrained subjects who were studied in the fasted state and after vigorous exercise (70 minutes at 80% VO_{2max}). After two hours of rest, they were fed a mixed meal and oxygen uptake was measured. The results indicated that EPOC was significantly increased due to exercise but there was no difference in EPOC between fed and non-fed exercised participants. Welle (1984) found that few studies demonstrated a TEF when the meal size was smaller than 900 kcal. Contrary to the preceding study, Samueloff, Beer, & Blondheim (1982) found an increased TEF with a mixed meal consisting of 400 kcal.

Young (1995) determined the effects of meal size and frequency on the potentiation of TEF by prior exercise. Two groups of women exercised at 70% VO_{2max} for 45 minutes on a cycle ergometer. Once the metabolic rate returned to the pre-exercise baseline, the participants were fed either a meal containing 600 kcal or 1200 kcal given in two separate meals. The results indicated that post-exercise thermic response to a carbohydrate meal was not a function of energy content or caloric density, rather it was a function of meal bulk or volume. It was found that a meal taken in one bolus produced a larger TEF than the meal separated into two separate meals. The results also indicate that a meal (1200 kcal fed in two separate portions) given frequently maintained the TEF.

Acheson, Flatt, & Jequier (1982) studied the effect of glycogen synthesis versus lipogenesis after a 500 kcal carbohydrate meal. Six males participated, and after their RMR was measured they began to consume a 500 kcal meal. The meal ingestion took approximately 50 minutes. Following the completion of the meal, RMR was measured for the following ten hours. The results indicate that a single 500 kcal-carbohydrate meal

resulted in maximum muscle glycogen storage and decreased the rate of fat metabolism while increasing carbohydrate oxidation.

The energy expenditure and thermogenic response to progressive carbohydrate overfeeding in man has been studied by Schutz et al., (1985). Three participants each consumed three different diets. The diets were high-fat-low-carbohydrate fed below energy requirement for three days; a seven day high-carbohydrate-low-fat diet providing approximately 136 kcal in excess of energy needs; and a hypocaloric, carbohydrate-free diet fed for the final two days to study the utilization of stored carbohydrate. The results indicated that short-term overfeeding with carbohydrate induced a marked stimulation of energy expenditure, equaling 33% excess energy intake. The authors of the study attributed the results to stimulation of lipogenesis and increased activity of the SNS.

Ivy, Lee, Brozinick, & Reed (1988) investigated the storage of muscle glycogen after different amounts of carbohydrate ingestion. Eight males, who cycled regularly, were involved in the study. The participants cycled on three separate occasions. The cycling durations were two hours at 75% VO_{2max} in order to deplete muscle glycogen. Immediately after cycling the subjects consumed either a placebo, 1.5g/kg glucose, or 3g/kg glucose solution. The researchers found that a load of glucose equal to 1.5g/kg/body weight is appropriate for an increased TEF. The study demonstrated that a glucose load greater than this did not have an increased TEF.

Protein is thought to be the most thermogenic substrate (Glickman, Mitchell, Lambert, & Keeton, 1948). Samueloff et al., (1982) studied the influence of physical activity on the TEF in young men and found no difference in a mixed meal compared to a protein meal. Eleven high-school students participated in two different trials. In the first

trial, the students consumed a 400 kcal meal and then exercised for ten minutes at 50% VO2max. The second trial followed the same exercise regimen but participants were fed a 1,200 kcal meal. The TEF was demonstrated in all subjects, but the magnitude of the TEF depended on the caloric content of the meal, with the 1,200 kcal meal producing a higher TEF than the 400 kcal meal. These results indicate that a meal as small as 400 kcal can potentate the TEF.

Time of meal ingestion has been shown to play a role in the TEF. Agete and Chiplonkar (1992) found that TEF was higher from breakfast than from lunch. They also found that a response to 20% overfeeding produced an adaptive thermogenesis by increasing the RMR by 4.9%. The participants gained weight and adipose tissue from overfeeding but not as much as expected from the increased caloric load.

Lean and James (1988) studied the effect of carbohydrate and protein ingestion on the TEF using obese, and previously obese individuals. Ten obese and six post-obese participants were examined after three fasting and three fed days, one fed day with low fat and the other two with high-fat diets. The results indicate that obese individuals have a lower energy expenditure per kilogram of fat free mass than formerly obese individuals (Lean and James, 1988). Fat has also been shown by Acheson et al., (1984) to have blunted the thermogenic effect of a meal. Carbohydrates and protein promote the highest TEF. These two macronutrient are stored in minimal amounts, which leads to a correlation between protein or carbohydrate intake and rate of oxidation (Abbott, Howard, Rutolo, & Ravussin, 1990; Acheson et al., 1982; Jequier and Shutz, 1983; Weststrate and Haulvast, 1990). Conversely, fat intake does not seem to affect the rate of fat oxidation. Rather, fat induces the lowest TEF of the three substrates. Kinabo and

Durnin (1990) found that there was no difference in the effect of low fat compared with high fat meals on the TEF. The decreased TEF from fats may be due to the efficient path to resynthesize adipose triglyceride stores stores from dietary triglyceride. Palmer-Lynch (1995) tested the difference between the thermic effect of a meal containing 100% carbohydrate compared to the thermic effect of a meal containing 90% fat and 10% carbohydrates. Fifteen subjects exercised for 45 minutes at 70% VO_2max on a cycle ergometer. After exercise, when VO_2 returned to pre-exercise baseline, the subjects ingested a test meal. On a control day they ingested the meal without prior exercise. The findings were that a carbohydrate meal had a significantly higher TEF than the fat meal in both the rested and exercised state. These results indicate that high fat diets do not potentate TEF induced by prior exercise.

Fuels for Energy

Carbohydrate, fat, and protein are macronutrients that provide fuel for the working muscles. Carbon, hydrogen, and oxygen are atoms that make up carbohydrates and fats. The addition of a nitrogen group (amino group) to carbon, hydrogen, and oxygen forms amino acids, which comprise proteins (McArdle et al., 1999). The use of each fuel depends on the intensity and duration of the exercise as well as dietary considerations.

Carbohydrates are the immediate energy source for metabolism. Carbohydrates are stored as glycogen in the muscles and liver and a small amount is present as blood glucose. Muscle glycogen can provide energy for two hours of moderate to high intensity exercise.

As exercise intensity increases, energy demands require an increase in carbohydrate oxidation. The reasons for the switch from fat to carbohydrate utilization during high intensity exercise are (McArdle et al., 1999):

1. The oxidation of fat is slower and doesn't provide ATP fast enough to match demands.
2. Glucose oxidation provides more energy per liter of oxygen than fat.
3. The increased recruitment of fast twitch fibers, which have fewer intramuscular triglycerides and lipolytic enzymes, and increased glycolytic enzymes.
4. An increase in epinephrine and norepinephrine, which increases glycolysis and glycogen breakdown. Epinephrine and norepinephrine also increase lactate production leading to an inhibited fat oxidation.

Protein metabolism consists of removing the amino group (deamination), making the carbon skeleton available for energy synthesis or metabolic processes. Protein is the fuel that is used the least for energy production because it is more important for structural and regulatory functions (McArdle et al., 1999).

Protein breakdown is approximately 5% per day. Exercise leads to protein catabolism during and immediately after exercise, but an increase in protein synthesis after exercise. Protein as a fuel for energy is spared and the immediate fuels are primarily carbohydrates and fats. Hedman (1957) found that nitrogen excretion is not increased during exercise, determining that protein was not a major contributor to energy during exercise. The brain and other vital organs normally only use glucose for fuel McArdle et al., (1999), so when exercise causes the muscles and liver to become

glycogen depleted the body relies on protein breakdown for blood glucose. This occurs after exercise of high intensity (>55%) and long duration (>2 hours).

Measuring Energy used During Exercise

Different amounts of oxygen are used and carbon dioxide are produced for the oxidation of each substrate (carbohydrate, fat and protein). The ratio of carbon dioxide produced to the amount of oxygen consumed provides a value referred to as the respiratory quotient (RQ) (Astrand and Rodahl, 1986). The RQ provides important information on the amount of each nutrient that is being catabolized for energy. Weir (1949) found that there is a caloric value that correlates with each R-value. The formula that Weir developed is: $Kcal = \{(1.1 \times RQ) + 3.9\} \times VO_2$. This allows accurate estimation of the energy expenditure during exercise.

Direct and indirect calorimetry are two of the most common methods of measuring the bodies rate of energy expenditure. Direct calorimetry measures the actual heat produced by the body (McArdle et al., 1999). The participant lives in an airtight chamber with an oxygen supply. A water supply at a certain temperature runs through coils at the top of the room. The water absorbs any change in heat produced by the participant. The expired air is filtered for moisture and absorbs carbon dioxide. The environment is not free-living and the procedure is expensive to administer, so it is rarely used (McArdle et al., 1999).

Indirect calorimetry is a relatively simple and less expensive method used to measure energy expenditure. Indirect calorimetry measures carbon dioxide produced and

oxygen consumed by an individual. The values are then used to determine the RQ (Table 4).

Gas exchange is determined by one of two methods: open-circuit or close-circuit spirometry. The two systems are similar in that they require the total volume of gas expired.

Closed-circuit spirometry requires the participant to breathe from a spirometer of either oxygen or room air. The carbon dioxide is filtered out and the remaining gas is directed back into the spirometer. The difference in the volume of gas in the spirometer determines the portion of oxygen that is used over the allotted time period.

Open-circuit spirometry is the most widely used method of determining the amount of oxygen consumed and carbon dioxide produced over a time period. The participant breaths ambient air and exhaled air is measured. Energy metabolism is then determined by comparing the difference in the pre-gas composition and post-gas composition of oxygen and carbon dioxide (Astrand and Rodahl, 1986).

Excess Postexercise Oxygen Consumption

After a single bout of exercise there is an increase in energy expenditure during recovery, which has been termed the excess postexercise oxygen consumption (EPOC). EPOC was first described by Benedict and Carpenter in 1910. EPOC was first referred to as oxygen debt (Hill, 1913). The increase in oxygen uptake after exercise has been shown to be increased for as much as 36-48 hours after exercise (Benedict and Carpenter, 1910), and is now known to be effected by intensity and duration. Results of studies (Benedict and Carpenter, 1910; Bray, Whipp, & Koyal, 1974; Segal and Gutin, 1983)

have varied in the effect of EPOC due to different measuring times, durations, intensities, and fitness levels of the individuals.

EPOC is effected by the synthesis of protein, ATP, PC, and glycogen. Hormones, calcium ion concentrations, sodium pump activity, and body temperature are also factors found to effect EPOC (Brooks and Gasser, 1984). Another factor found to influence EPOC is substrate cycling from increased catecholamines causing enhanced fat mobilization from adipose tissue reserves and an increased rate of cycling between triglycerol and fatty acids (Newsholme, 1978). The increased substrate cycling may be why trained subjects have been shown to have a smaller EPOC than untrained subjects (Hagberg, Mullin, & Nagle, 1980).

The synthesis of muscle glycogen after exercise also effects EPOC. Various studies (Bahr, Ingnes, Vaage, Sejersted, & Newsholme, 1987; Bielinski, Schutz, & Jequier, 1985; Gore and Withers, 1990) found a decreased RQ after exercise suggesting a higher fat utilization. Vigorous exercise leads to glycogen depletion. Glycogen depletion results in increased fat utilization, following exercise, to provide the energy needed to restore muscle glycogen. This process leads to an increase in energy expenditure.

EPOC and the Effects of Intensity and Duration

The effect of exercise intensity on EPOC was observed using rat skeletal muscle by Balon et al., 1985. It was determined that the increase in oxygen consumption, varied with different exercise intensities. It was also determined that insulin increases oxygen consumption following exercise, which suggested a thermogenic effect of exercise.

In 1987, Bahr et al. researched the effect of duration of exercise on EPOC. Six male subjects exercised for 80, 60, and 40 minutes on three separate occasions. Rectal temperature and oxygen uptake were measured throughout the procedure. The results indicated that EPOC was a constant percent of exercise duration resulting in approximately 15% of exercise energy expenditure for 12 hours. The length of EPOC varied with different durations of exercise.

In 1988, Sedlock, Fissinger, & Melby researched the effect of exercise intensity and duration on postexercise energy expenditure. Ten male triathletes were chosen so that a high intensity could be used. Participants performed three exercise conditions on a cycle ergometer. The first condition was a high intensity (75% VO_{2max}) short duration, the second was low intensity (50% VO_{2max}) short duration, and the third was low intensity-long duration. The results indicated that while energy expenditure was held constant, exercise intensity effected both the magnitude and duration of EPOC. This was demonstrated by the high intensity, short duration group. This group had a significantly higher caloric expenditure, but both groups had significantly higher EPOC's for a similar duration.

Gore and Withers (1990) measured the EPOC of nine male individuals after exercising on a treadmill in one of nine conditions. The treatments consisted of one of three intensities of 30, 50, or 70% VO_{2max}. Each intensity was performed for durations of 20, 50, and 80 minutes on separate days. The results found that after exercise there was no evidence for a sustained elevation in metabolism after exercise intensities under 55% VO_{2max}. It was also shown that there does not appear to be any evidence for a sustained elevation in metabolism after exercise of durations under 50 minutes and EPOC did not

last over three hours. The results indicate that the intensity must be high (>70% VO_{2max}) enough to begin glycogen depletion. Duration (>50 min.) was found to lead to a linear increase in EPOC. In conclusion, in order to stimulate EPOC the intensity of exercise must be over 55% VO_{2max} and the duration sufficiently long enough to begin glycogen depletion.

Aerobic Exercise and TEF

Many studies on the effect of aerobic exercise on TEF have been conducted. There are conflicting results on the impact of aerobic exercise and the TEF due to errors in methodology. Insufficient duration and intensities of exercise may comprise studies that did not observe a significant exercise-induced thermogenesis. Various studies have shown an increase in TEF due to aerobic exercise (Segal, Gutin, Albu, & Pi-Sunyer, 1987; Maehlum, Grandmontagne, Newsholme, & Sejersted, 1986; Miller, Mumford, & Stock, 1967; Segal and Gutin, 1983; Weststrate and Hautvast, 1990; Segal et al., 1985). Bielinski et al. (1985) exercised ten men for three hours at 50% VO_{2max}, and found a significant increase in TEF when compared to a non-exercised state. The morning after the exercise bout, the exercised group continued to display a significant increase in TEF.

Researchers have shown that aerobic exercise training may influence TEF. LeBlanc, Mercier, & Samson (1983) demonstrated that there was a lower TEF in aerobically trained individuals compared with sedentary individuals. They also found a decreased RQ in aerobically trained subjects indicating reduced carbohydrate oxidation.

Young and others (1986) studied the effect of prior exercise on the thermic effect of a carbohydrate load. Six participants were involved in the study. RMR was measured,

then the subjects exercised at 70% VO_{2max} for 45 minutes. After RMR returned to pre-exercise levels, a 100g-glucose load was ingested, and oxygen uptake was measured for the following three hours. Results indicated that carbohydrate-induced thermogenesis was increased following exercise.

Other studies have shown no exercise-induced TEF (Belko, Teresa, & Wong, 1986; Dallosso and James, 1984; Welle and Campbell, 1983). The duration of TEF depends on the previous exercise intensity and duration. The intensity needs to be greater than 55% VO_{2max} while the duration needs to be over approximately 20 minutes to begin glycogen depletion.

Anaerobic Exercise and TEF

Research has not been conducted on TEF and anaerobic metabolism. There has been a study comparing the TEF between untrained, aerobically trained, and resistance trained individuals using aerobic exercise. Researchers studied the response to a 763 kcal mixed meal at rest and during 20 minutes of exercise at 50% VO_{2max} (Gilbert, Misner, Boileau, Lili, & Slaughter, 1991). The intensity and duration were sufficient to elevate the TEF. The results concluded that the thermic effect of metabolism did not differ significantly between the groups, and none of the groups had a significant increase in the TEM.

Exercise and the TEF

The thermic effect of food has been shown to be enhanced by exercise in some studies, (Segal et al., 1987; Maehlum et al., 1986; Miller et al., 1967; Segal and Gutin,

1983; Weststrate and Hautvast, 1990; Segal et al., 1985) while other studies found no exercise-induced TEF (Belko et al., 1986; Dallosso and James, 1984; Welle and Campbell, 1983). The results may have been insignificant in these studies due to insufficient measuring time, inadequate duration (<20 minutes) or intensity (<55% VO2max) of exercise, or an inadequate meal size (< 400 kcal).

Effects of Intensity and Duration on TEF

Studies on the effect of aerobic exercise on TEF have been inconclusive. Studies that have shown no significant increase in TEF with exercise have had inadequate durations or intensities of exercise. It has been determined that intensity exceeding 55% VO2max is necessary to enhance TEF. Exercise duration over 20 minutes has been shown to be linearly related to the TEF.

The two components of TEF are the energetic cost of processing and storage of glucose as glycogen in muscle and liver, and additional effect due to insulin mediated stimulation of the SNS (Young et al., 1986). The intensity and duration of exercise are important factors in the depletion of muscle glycogen. The intensity sufficient enough to stimulate catecholamine release may also be important. Insulin has been shown to increase norepinephrine release (Rowe et al., 1981), while carbohydrate has been shown to enhance the turnover rate of norepinephrine (Landsberg and Young 1978).

Goben, Sforzo, & Frye (1992) examined the effect of exercise intensity on TEF. In this study, 16 males participants were assigned to either a low (<50%) or high intensity (>70%) group for a 30-minute exercise bout on a treadmill. There were three trials, which included a 750 kcal meal, a 750 kcal-meal followed by low intensity exercise, and

a 750 kcal-meal followed by high intensity exercise. The authors concluded that low and high intensity exercises potentate equivalent thermic responses, but TEF with high intensity exercise was blunted effect until 180 minutes. The authors proposed that exercise following a meal has a synergistic effect on metabolism, which is that "exercise increases the metabolic cycles for synthesizing muscular fuel while eating increases those cycles needed for assimilation and uptake of nutrients for storage in tissue." This suggests that the two opposing signals from eating and exercise lead to futile metabolic cycling, and increasing the response for stimuli. This study demonstrated that the TEF following intense exercise rose more slowly but remained higher than in low intensity exercise.

In 1990, Treadway and Young, studied the effect of exercise intensity on the TEF. Five participants were used to determine the TEF after ingestion of a glucose load (400 kcal) followed by either a non-exercise condition, or one of three separate exercise conditions. The three exercise conditions were low (34%), moderate (54%), and high (75%) intensities of exercise. The results indicated that there was no significant difference in energy expenditure, but that the high intensity exercise lead to a significantly higher thermic effect compared with the low and moderate intensities. This finding could explain the non-significant increase in TEF determined in various studies where intensities were fewer than 54% (Welle, 1984; and Pacy, Barton, Webster, & Garrow, 1985).

The duration of the exercise, given appropriate intensity, also has an impact on the TEF. Glycogen depletion increases as the duration of the exercise increases, leading to a greater TEF. While increased TEF has been observed with a minimum of ten

minutes of exercise at 50% VO_{2max} (Samueloff et al., 1982), Bahr et al. (1987) found the duration of exercise to be linear to the length of increased EPOC. In conclusion the appropriate intensity and duration must be over 55% and long enough to begin glycogen depletion respectively in order to stimulate TEF.

Pre-meal versus Post-meal Consumption and the TEF

Various studies (Willcutts et al., 1988; Segal and Gutin, 1983; Bahr and Sejersted, 1991) have shown a greater TEF due to feeding before rather than after exercise and vice versa. Various methodologies have been used which may have confounded the results. A meal fed prior to or immediately after exercise causes an inability to distinguish between the effect of exercise and the effect of the meal (TEF).

Willcutts et al., (1988) studied energy expenditure during exercise that begun at different time intervals following a meal or in a fasted state. Eight participants exercised in a fasted state or 30, 60, or 90 minutes after a 940 kcal meal. The exercise was a 30 minute run on a treadmill at 67% VO_{2max}. Oxygen consumption was measured during the final 23 minutes of the 30 minute run. The researchers found that although there was no significant difference in total energy expenditure, the participants oxidized more fat on an empty stomach than when they exercised 60 or 90 minutes after a meal. It was concluded that consuming a meal prior to exercise disrupts the pattern of substrate utilization, leading to a decrease in the use of fat as an energy source. Also, the consumption of a meal prior to exercise does not increase the energy cost of the activity.

Trained versus Untrained

Studies have been conducted on aerobically trained, resistance trained, and untrained individuals (Astrup, Bulow, Christensen, Madsen, & Quaade, 1986; Poehlman, Melby, Badylak, & Calles, 1989; Gilbert et al., 1991). The majority of the studies were conducted on aerobically trained rather then on untrained individuals. Trained individuals utilize fuels differently than untrained individuals. Aerobic exercise improves the ability to oxidize long-chained fatty acids during low to moderate exercise. This leads to a carbohydrate sparing mechanism, which allows the athlete to perform at a higher absolute power output without becoming glycogen depleted which, in turn, delays fatigue. The increased fat utilization can occur from an increased release of fatty acids from adipose tissue or from an increased utilization of fat stores in muscle (Hurley, 1986). Resistance-trained individuals have increased skeletal muscle which has been found to be a significant contributor to thermogenesis (Astrup et al., 1986). Poehlman et al. (1989) studied the effect of training state on RMR and TEF. In this study, RMR was measured after an overnight fast. There were three separate groups of individuals (untrained, moderately trained, and highly trained). Each individual consumed a liquid meal, and metabolism was measured by indirect calorimetry for 180 minutes. A correlation was found between RMR and VO_{2max}, with the highest RMR observed in the highly trained individuals. A curvilinear relationship was found between VO_{2max} and TEM, with the highest TEM noted in moderately trained individuals. RMR was the largest in the highly trained group. Tremblay, Fontaine, & Nadeau (1985) studied eight trained and five non-trained men to determine the contribution of glucose storage to the reduced glucose-induced thermogenesis exhibited by endurance-trained athletes. The

participants ingested an oral glucose load before and immediately after a 90-minute exercise bout at 64.1% VO_{2max} on a cycle ergometer. The results indicated that the trained individuals had a higher RMR than untrained individuals, which was thought to be a consequence of modifications of other energy-requiring energy processes rather than from glucose storage.

However, although the sample size was small, other investigators have shown no increase in RMR in trained individuals compared with untrained individuals (Bringham et al., 1989). Researchers (Schulz et al., 1985) have also found no difference in RMR between trained and untrained individuals. Schulz (1983) suggested that an increased RMR in trained athletes might only be present in individuals who train vigorously and consume high calorie diets.

The effect of aerobic training on lean and obese individuals has been studied by Tremblay, Fontaine, Poehlman, Mitchell et al. (1986). It was found in comparing untrained and trained individuals with similar fat free mass, that trained individuals had an 11% higher RMR. When a group of moderately obese women were put through a training program of five hours a week at 50% VO_{2max} for 11 weeks, it was found that the training induced a significant rise in RMR corresponding to eight percent of the pre-training value in calories burned per minute per kilogram of fat-free mass. This indicates that aerobic exercise training is associated with elevated RMR in lean and obese individuals.

Conversely, studies have shown trained individuals to have a lower TEF than untrained individuals. Gilbert et al., (1991) studied the TEF in aerobically trained,

resistance trained, and non-trained individuals. The participants were tested with and without a 763 kcal meal on two separate days. RMR was measured after which the participants either ate the meal prior to or after a 30 minute exercise session at 50% VO_2max. TEF was found to be higher in the untrained compared with the aerobically and resistance trained individuals. The results also indicated that the consumption of a meal prior to exercise potentates TEF post-exercise to a lesser extent in aerobically trained and resistance-trained subjects than in untrained subjects. The authors claimed that the aerobically trained group, as compared to the resistance trained and the untrained group, might utilize a higher percentage of fat as substrate during and after exercise. The increased TEF may be due to increased catecholamines and fatty acids may stimulate the rate of the triglyceride-fatty acid substrate cycle in adipose tissue which leads to increased availability of fatty acids for energy production. The activity of this cycle may be decreased in aerobically trained individuals due to lower epinephrine and norepinephrine levels.

Witt, Snook, O'Dorisio, Zivony, & Malarkey (1993) studied the TEF on aerobically trained individuals. Eight trained and seven untrained individuals consumed diets containing 15%, 45%, or 75% carbohydrates for five days. After the five-day diet, the subjects consumed an 868 kcal liquid breakfast, and blood samples were collected throughout the fifth day. The results showed an increased TEF in the aerobically trained group, however there was no difference between trained and untrained individuals in carbohydrate, fat, and protein utilization. The authors also found that there was a curvilinear relationship between VO_{2max} and TEF. The results indicated that highly trained and untrained individuals had a lower TEF than moderately trained individuals.

This may be due to a decreased SNS stimulation in highly trained and reduced insulin sensitivity in untrained individuals. The authors attributed the response to an altered insulin metabolism in trained individuals. They claimed that the TEF in endurance-trained individuals is greater than that of their sedentary counterparts.

Aerobic Exercise and EPOC

Aerobic exercise has been shown to increase EPOC. Hermansen, Grandmontagne, Maehlum, & Ingnes (1984) had participants exercise at 75% VO_{2max} for 80 minutes to deplete muscle glycogen, then measured VO_2 to assess metabolism over the next 24 hours, 12 hours of which participants were awake. They found that metabolic rate was increased for several hours after exercise.

Possible mechanisms for the increased EPOC from aerobic exercise of sufficient intensity and duration may include the elevation of several hormones, substrate cycling, and the resynthesis of glycogen in the muscle and liver. The elevation in hormones such as cortisol, growth hormone, catecholamines, thyroid hormone, noradrenaline, and adrenaline may play a role in increasing EPOC (LeBlanc, Diamond, Cote, & Labrie, 1984). Glycogen breakdown occurs with exercise of sufficient intensity (>50%) and duration (>20 minutes). Resynthesis of muscle glycogen is thought to be a much slower process than glycogen breakdown. Alanine and other amino acids have been shown to be oxidized during prolonged exercise (Felig and Wahren, 1971). The resynthesis of muscle glycogen and amino acids requires ATP and therefore oxygen. Substrate cycling may be increased immediately before, during, and after exercise. The initial increase in substrate cycling is necessary to provide adequate ATP for muscle contraction. After exercise

there is an increase in substrates for different cycling enzymes. This increase in cycling requires oxygen and in turn increases EPOC.

Maehlum and others (1986) conducted a similar study using healthy participants who exercised for 80 minutes at 70% VO_{2max}. The results demonstrated an increased EPOC for at least 12 hours following exercise and an increased TEF when the meal was administered after exercise. From the previous studies it is apparent that aerobic exercise of sufficient intensity and duration leads to an enhanced EPOC and may potentiate TEF.

Anaerobic Exercise and EPOC

Melby, Schmidt, & Corrigan (1990) found that postexercise metabolic rate remains elevated for at least one hour following a moderate level of resistive exercise. The protocol in this study consisted of 42 minutes of weight training. Possible reasons for this elevation in metabolism are, rephosphorlation of ADP, elevated body temperature, and elevated levels of catecholamines. Increased mitochondrial calcium uptake, which appears to stimulate mitochondrial respiration, and futile cycling of various intermediates of energy metabolism also influence EPOC.

Subsequently, Melby, Scholl, Edwards, & Bullough (1993) studied the effect of resistance exercise on the magnitude of EPOC. The study included seven males who participated in two separate trials. In the first trial, RMR was determined followed by 90-minute bout of weight lifting. In the second trial, RMR was measured without the

addition of exercise. EPOC was found to be increased for at least two hours after exercise compared with baseline VO_2, and that VO_2 remained significantly higher than baseline when measured 15 hours after exercise. The elevation in oxygen consumption was 11-12% above baseline for the final six minutes of the two-hour measurement.

Difference between Lean and Obese Individuals in Metabolism

Obese individuals have been shown to have impaired thermogenesis, and a blunted capacity to dissipate heat by means of variations in metabolic rate (Segal and Gutin, 1983; Segal, Presta, & Gutin, 1984; Segal et al., 1985). Segal and Gutin (1983) researched the effect of TEF on lean compared to obese individuals. Ten lean and ten obese participants were involved in six different experiments. The six different protocols included first a postabsorptive RMR, and second a postprandial RMR. The third day was exercising for five minutes every half-hour, for four hours, at a set workload and the fourth day was conducted at the participant's anaerobic threshold. The fifth and sixth days had a similar exercise protocol as the third and fourth day respectively. The difference is that the third and fourth day were postabsorptive and the fifth and sixth day were postprandial beginning exercise 30 minutes after ingestion of the meal. The results indicated that the TEF was higher for lean than for obese individuals in a resting state and in an exercise state. Participants were matched for lean body mass (LMB), there was a maximal response when the meal preceded the exercise for lean men and when it was fed after exercise in obese men. The meal was fed directly after exercise in the postabsorptive feeding day. This could have flawed the accuracy of the TEF because it is hard to differentiate between the effect of exercise and the TEF. When the subjects were

to be allowed to come back to a baseline metabolic rate before they were fed, the TEF could be distinguished from the effect of exercise.

Segal et al., (1985) studied the TEF in lean compared to obese participants. The participants were matched for age, height, weight, and BMI. The participants were involved in three conditions including a resting condition, after a meal (750 kcal), and after 30 minutes of exercise on a cycle ergometer at each individual's metabolic threshold then participants consumed a mixed meal (750 kcal). The results indicated that TEF was negatively related to body fat content under rest, post exercise, and exercise conditions, suggesting that body composition is a significant determinant of postprandial thermogenesis.

Summary

The four components of total energy expenditure are RMR, TEF, AT, and TEA. It is has been shown that anaerobic and aerobic exercise of sufficient intensity (>55%) and duration (>20 minutes) increase an individuals metabolism. It has also been shown that food of sufficient quantity (>400 kcal) increases metabolism. Researchers found that aerobic exercise of sufficient duration (>20 minutes) and intensity (>55%) led to an increased TEF. Therefore the next component to examine is the effect of anaerobic exercise on TEF.

CHAPTER 3

METHODOLOGY

Participants

Participants were selected according to their age and fitness level. The sample included three males (21–24 years old) with an average of 13.6% body fat, and six females (19-24 years old) with an average of 19.1% body fat (Table 1). The participants were required to train aerobically at least two hours per week and weight train at least two times per week for two months prior to the start of the study. Each participant had no previous history of cardiovascular disease or diabetes. The UNLV Institutional Review Board approved the use of human subjects and each participant signed an informed consent and was aware of the design of the study.

Participants were asked to keep a daily journal for three days prior to testing to make certain they were not in energy deficit or exceeding a normal range, which would alter the RMR (Poehlman and Horton, 1989). The participants were asked not to drink alcohol or use tobacco products for 24 hours prior to testing and they were asked not to participate in any physical activity for 36 hours prior to testing.

Table 1

Participant Characteristics

Participants	Sex	Age (Years)	Mass (kg)	Height (cm)	% Fat	Predicted VO_{2max} (L/min)	Average HR	Max HR
1	*M*	24	80	172.72	14.5%	3.85	128	65%
2	*F*	23	62	160.02	19.8%	3.75	106	65%
3	*M*	23	82	180.34	12.0%	2.71	99	50%
4	*F*	22	57	160.02	21.1%	1.47	119	60%
5	*M*	21	70	170.18	14.5%	1.7	134	67%
6	*F*	21	57	160.02	16.0%	1.31	139	70%
7	*F*	19	70	172.72	23.6%	2.05	137	68%
8	*F*	23	57	172.72	19.8%	3.45	123	62%
9	*F*	24	70	172.72	14.3%	1.95	117	60%
Average		22	67	169.05	17%	2.47	122	63%
SD		1.64	10	7.30	4%	1.00	13.75	6%
SE		.546	3.33	2.44	.013	.333	4.58	.02

Procedures

Participants reported to the laboratory on three separate days over a three-week time span. On the first day (approximately one week before testing began) the participants performed a submaximal VO_2 test on a cycle ergometer. Each participant cycled at a rate of 100 beats per minute. The first workload was set at 150kgm for every subject. Heart rate was then analyzed at the second and again at the third minute. If the two heart rates were within five beats the participant was considered to be in steady state zone and the next workload was administered. If the participant's second and third heart rates were not within five beats, the participant resumed cycling at that workload for a fourth minute. The next workload was determined by the participant's heart rate (Table 11). A third workload was administered if the first heart rate was lower than 110 beats per minute. The final two workloads, in which heart rate was over 110 beats per minute, were used to estimate VO_{2max}.

In addition to the prediction of VO_{2max}, skinfold measurements were taken on the first day of testing. Body composition was estimated from skinfold measurements using the Jackson and Pollack four-site formula Jackson & Pollock, 1985). The four sites used include the abdomen, iliac, tricep, and thigh.

The final measurement determined on the first day was the appropriate amount of weight to be lifted by each participant. Initial weights were determined by gender and body weight. The participant performed each exercise to exhaustion with the initial weight and then the weight was adjusted to the appropriate amount for each individual. The equation used is featured in Table 2.

Participants reported to the laboratory for the exercise trial after a 12-hour overnight fast. VO_2 was measured for a minimum of 15 minutes (until a steady state was attained) to establish a baseline rate of oxygen consumption. Participants then completed the prescribed weight-training regimen. The weight-training program was approximately 20 minutes in duration with one minute allowed for each set. A metronome was set at 60 beats per minute so that the concentric contraction was performed on the first beat and the eccentric contraction was performed on the second beat. Two sets of ten repetitions were completed leaving a rest period of 40 seconds for each set. Once the program was over, the participant rested and VO_2 was monitored until pre-exercise baseline was regained. Participants then ingested a meal of chocolate pudding, made with 1% milk

Table 2.

Weight lifting Load calculation and workout equation for males and females with an example of a 128lb female and a 154lb male.

Weight adjustments: Females

Exercise	Wgt.	Coeff.	Reps. Compl.	Adj	Training Load
Bench Press(F)	128 X	.35 = 45	9	-10	35
Bent Over Row(F)	128 X	.35 = 45	14	0	45
Seated Press (F)	128 X	.15 = 20	20	+15	35
Bicep Curl (F)	128 X	.23 = 30	9	-10	20
Lunges (F)	128 X	5lbs/hand	15	0	5lbs/hand
Low Pulley(C)	128 X	.15 = 20	20	+15	35
Tricep Ext.(C)	128 X	.13 = 20	20	+15	35
Pullover (M)	128 X	.40 = 50	20	+15	65
Leg Press (M)	128 X	1.0 = 130	10	-5	125
Twisting Trunk curl	128 X	no load ---------------no load			

Weight adjustments: Male

Exercise	Wgt	Coeff.	Reps Compl.	Adj	Training Load
Bench Press(F)	154 X	.60 =95	20	+15	110
Bent Over Row(F)	154 X	.45 =70	20	+15	85
Seated Press (F)	154 X	.35 = 55	20	+15	70
Bicep Curl (F)	154 X	.30 = 50	20	+15	65
Lunges (F)	154 X	10lbs/hand	20	+15	25lbs/hand
Low pulley(C)	154 X	.25 = 40	20	+15	55
Tricep Ext.(C)	154 X	.35 = 55	20	+15	70
Pullover (M)	154 X	.55 = 85	20	+15	100
Leg Press (M)	154 X	1.3 = 200	20	+15	215
Twisting Trunk curl	154 X	no load --------------no weight			

Adjustment Chart:

Reps Completed	Adjustment (In pounds)
<7	-15
8-9	-10
10-11	-5
12-15	0
16-17	+5
18-19	+10
>20	+15

(660 kcal; 80% CHO, 13.3% protein, 6.8% fat). The meal was completed within 15 minutes after which VO_2 was measured at 10, 30, 60, 90, and 120 minutes post-ingestion to determine the TEF.

Participants reported to the laboratory for the control trial in the morning after a 12-hour overnight fast (approximately the same time as the feeding on the exercise trial). VO_2 was again measured for a minimum of 15 minutes to establish a baseline. Participants then ingested the same test meal as on the exercise day. Oxygen consumption was measured at 10, 30, 60, 90, and 120 minutes post-ingestion to assess the TEF.

Statistical Analysis

Resting RQ and VO2 were each analyzed using a one-way repeated measures analysis of variance with the three levels being pre-exercise, post-exercise, and the control condition. A dependent t-test was performed to evaluate the changes in the total TEF above baseline in the exercise trial compared with the control trial ($\alpha = .05$). The TEF was determined by the increase in caloric expenditure (kcal/2hr) above baseline (calculated from VO2 and RQ) using the trapezoid method.

Similarly, a dependent t-test was used to evaluate the changes in the total VO_2 above baseline in the exercise trial compared with the control trial ($\alpha =.05$). The total VO_2 was also determined by the trapezoid method.

CHAPTER 4

RESULTS

There was no significant change in baseline resting VO_2 between the pre-exercise trial, post-exercise trial, and the control trial (Table 3, Figure 1; $F_{(2, 16)}$ =.013, p=.987). Resting RQ was not significantly different between the pre-exercise trial, post-exercise trial, and the control trial (Table 3, Figure 2. $F_{(2,16)}$ = 3.163, p=..070).

Table 3.

Resting VO_2 and RQ before exercise, after exercise, and during the control trial.

	VO2 (ml/min)	RQ
Pre-exercise	178.394 ± 18.28	0.875 ± 0.03
Post-exercise	181.45 ± 18.58	0.829 ± 0.03
Control	179.41 ± 18.61	0.840 ± 0.02

The meal caused an immediate and persistent thermic effect in both the exercise trial and the control trial. Figure 3 illustrates the VO2 response to the meal, expressed as increase over baseline, and Figure 4 presents TEF as Kcal over baseline following meal ingestion. Total oxygen consumption (area under the response curve above baseline) was 38.7% greater in the exercise trial compared with the control trial (t=2.180, p=.030) (Table 4, Figure 5). The exercise trial also led to a significantly greater increase in TEF,

expressed as caloric expenditure, than the control trial (t=2.539. p=.017). There was an average 42% increase in TEF from the control trial to the exercise trial. (Table 4, Figure 6).

TABLE 4

Total area under the curve for VO2 & Caloric Expenditure

VO_2 ml/hr		
Participants	Exercise	Control
1	5277.75	5147.52
2	6755.625	5648.28
3	2833.72	5603.415
4	6902.27	3084.395
5	7306.5	7806.13
6	7694.69	3721.605
7	5919.455	3456
8	10272.34	1532.59
9	10943.53	3124.32
	Exercise	Control
Average	7100.652	4347.139
SD	2457.281	1873.277
SE	819.09	624.425

Kcal/2hr		
Participants	Exercise	Control
1	29.874	24.346
2	33.414	31.3375
3	19.6955	27.8175
4	34.263	14.494
5	41.4825	40.3595
6	38.1765	18.478
7	29.9815	16.2805
8	55.7845	8.1315
9	59.25715	15.911
	Exercise	Control
Average	37.992	21.906
SD	12.652	9.964
SE	4.217	3.321

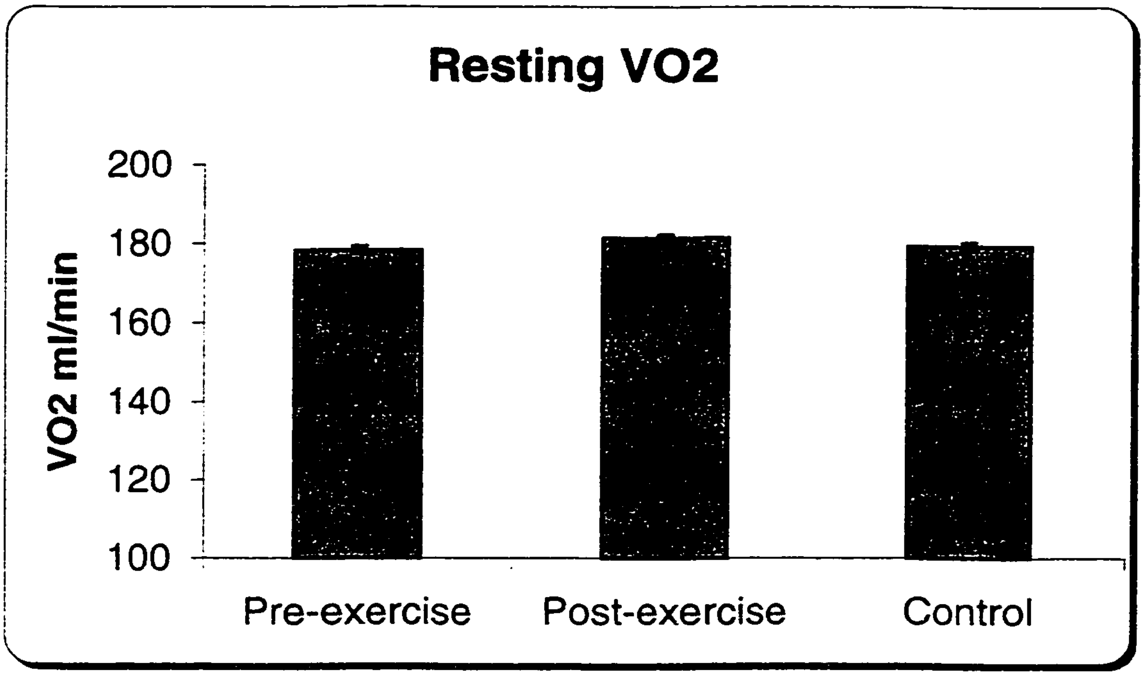


Figure 1. The mean resting VO_2 (ml/min) before exercise, after exercise and during the control trial.

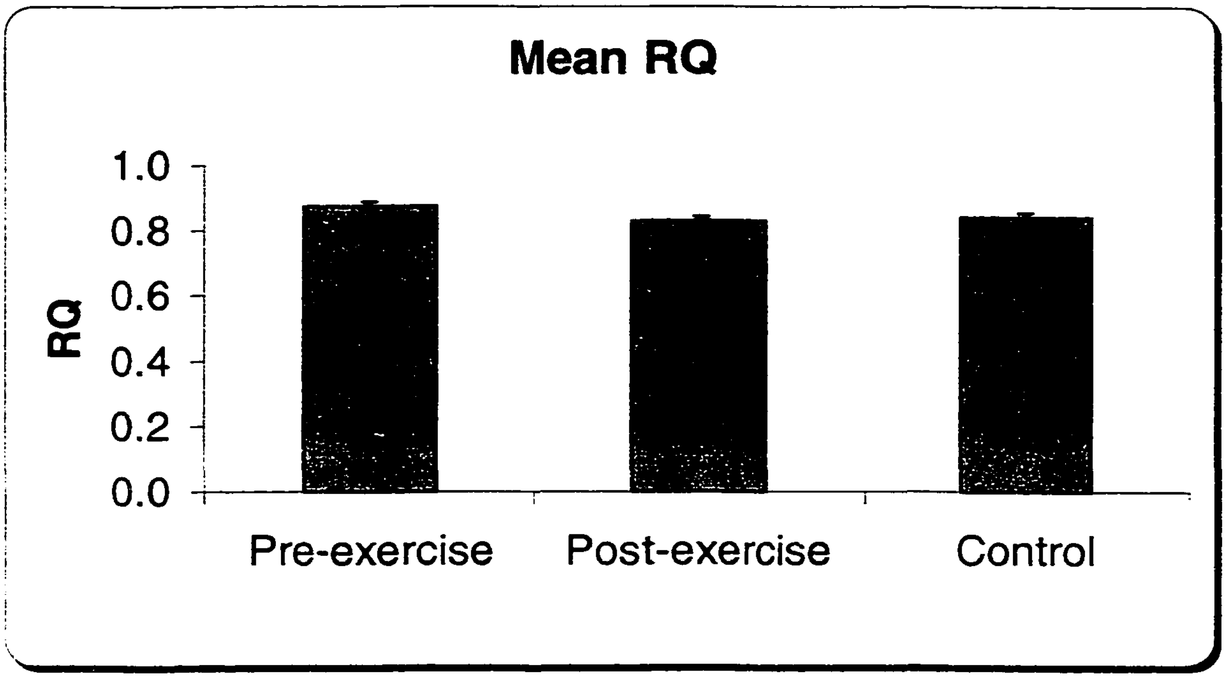


Figure 2. The mean RQ (VCO_2/VO_2) values from the exercise trial (before and after exercise) and the control trial.

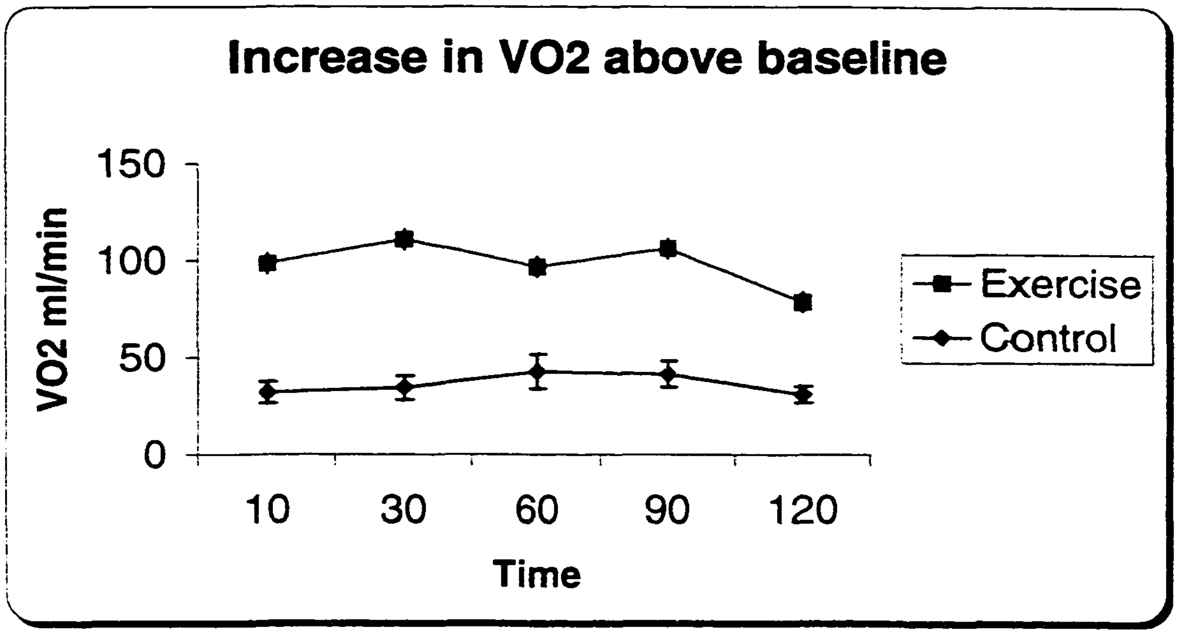


Figure 3. Mean increase in VO_2 (ml/min) above baseline at 10, 30, 60, 90, and 120 minutes in the exercise and control trial.

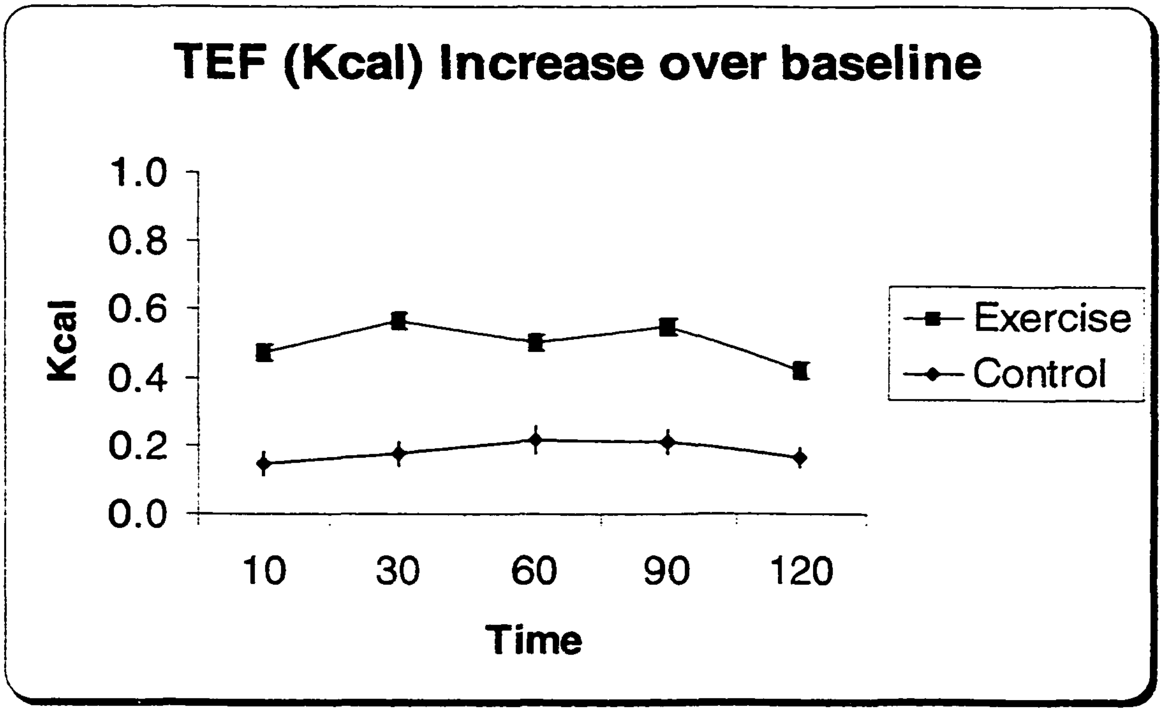


Figure 4. Mean increase in Kcal over baseline at 10, 30, 60, 90, and 120 minutes during the exercise and control trial.

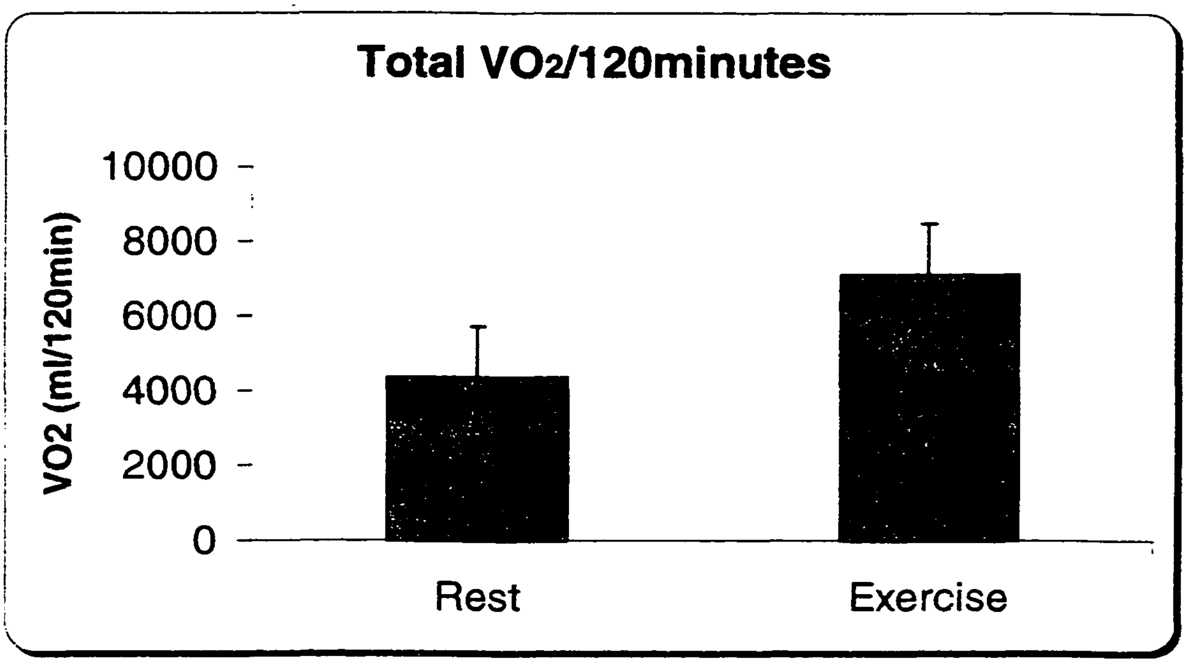


Figure 5. Total VO_2/120 minutes determined by area under the curve above baseline.

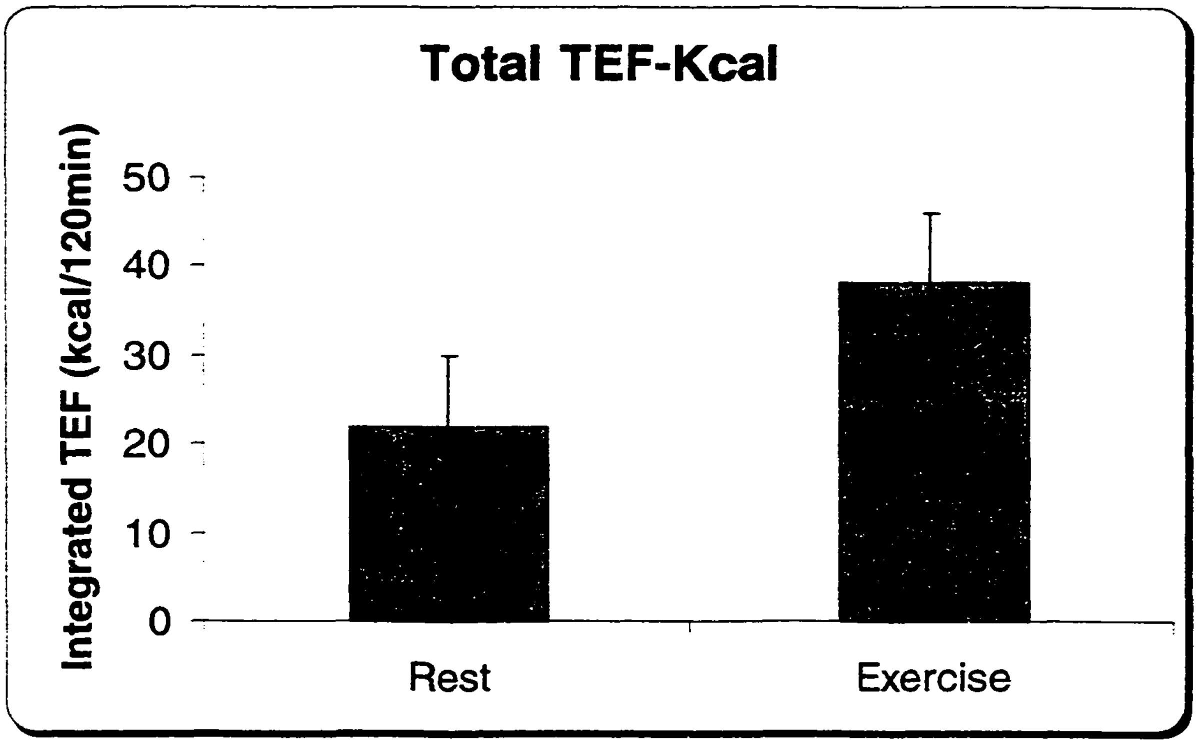


Figure 6. Total TEF (Kcal/120min) determined by area under the curve above baseline.

CHAPTER 5

DISCUSSION

Total energy expenditure consists of the thermic effect of food (TEF), adaptive thermogenesis (AT), physical activity (TEA), and resting metabolic rate (RMR). TEF comprises approximately 10% of total daily energy expenditure. It has previously been shown that aerobic endurance type exercise of sufficient intensity (>55% maximal aerobic capacity) and duration (>20minutes) leads to an increased TEF (Segal et al., 1987; Maehlum et al., 1986; Segal et al., 1985; Treadway and Young, 1990). However, there have not been any studies on the effect of anaerobic exercise on TEF. Therefore, the purpose of this study was to determine if a single bout of anaerobic exercise (weight lifting) would have a similar effect on TEF.

The participants in this study were non-obese with a normal percentage of body fat (17%). All participants were currently weight training two times a week and performing aerobic exercise two hours per week for two months prior to the study. This criterion was set because various fitness levels (unfit, aerobically fit, and anaerobically fit) have been shown to result in different thermic responses to a test meal (Segal and Gutin, 1983; Hurley, 1986; Poehlman et al., 1989). The age range was also limited with the participants varying from 19 to 24 years of age. Again this was done to minimize any age related variability in the thermic response to the exercise. Although age and fitness

levels were controlled for, the participant's TEF varied greatly (Table 4). This could be due to individual differences in the amount of muscle mass; the participants' actual fitness level; or the amount of weight lifted during testing. While the calculated weight to lift was appropriate for most of the participants, one male participant (participant 3) was stronger than his prescribed target weight. This could account for the lower thermic response displayed by this participant. One participant claimed to have performed a weight-training workout one night before testing causing the RMR between the exercise and control trial to be significantly different. The participant refused to repeat the test, so this participant was dropped from the study.

There are two components of TEF, obligatory thermogenesis and facultative thermogenesis. Obligatory thermogenesis is the energy required for digestion, absorption, and assimilation of food nutrients (Horton, 1983). In this study, in both the control trial and the exercise trial, the participants consumed an identical meal. The second component of TEF is facultative thermogenesis, which is the energy expended due to an increase in the activity of the SNS (Landsberg and Young, 1983) and metabolic cycling due to food ingestion (Newsholme, 1982). The energy expended in facultative thermogenesis would be expected to be greater in the exercise trial in this study, since the exercise would have led to an increased SNS activity leading to an increase in the activity of the Na/K-ATPase pumps, and the ingestion of the meal would be expected to lead to an increased metabolic cycling. Rowe et al., (1971) showed that insulin increases SNS activity by stimulating norepinephrine release. Therefore it would appear that facultative thermogenesis is the major factor in the excess energy expenditure observed in the exercise trial compared with the control trial.

There are several possibilities for the increased TEF due to the weight lifting regimen used in the present study. The first possibility is the energy cost of storing glucose as glycogen. There are two phases of restoring muscle glycogen after exercise. In Phase I, glycogen resynthesis is independent of the stimulating effects of insulin on glucose transport into skeletal muscle (Garetto et al., 1984). In Phase II, glycogen levels have returned to near baseline and the synthesis of glycogen is dependent on increased insulin sensitive glucose transport (Garetto et al., 1984). In the present study, glycogen depletion was not measured. However, glycogen depletion can be inferred from the findings of Tesch, Colliander & Kaiser (1986) who demonstrated that a similar weight-training regimen consisting of 20 sets of ten repetitions resulted in a significant depletion in muscle glycogen. Also, Melby et al., (1990) showed that a similar weight-training regimen resulted in an increased excess post-exercise oxygen consumption. Melby et al., (1990) determined that possible mechanisms for the increased EPOC could have been from rephosphorlation of creatine and ADP, elevated body temperature, elevated catecholamines, and futile cycling. Although the participants' EPOC had returned to baseline there was still an increase in TEF. The relationship between the two variables is that exercise causes an increase in glucose uptake into the muscle which is not insulin mediated. Also, contraction leads to an increased insulin sensitivity causing an enhanced glucose uptake. The two methods are additive and the cells remain sensitized after exercise is concluded. Therefore the cells are more able to resynthesize glycogen beyond baseline levels leading to an additional use of energy.

There is also a possibility of increased energy expenditure due to the resynthesis of protein that was catabolized during exercise. Viru (1987) demonstrated that there is an

inhibition of protein metabolism during exercise, while there is an increase in protein metabolism after exercise.

The role of hormones in mediating the increased TEF with anaerobic exercise should be considered. Young et al., 1986 found that feeding a carbohydrate meal after aerobic exercise lead to an increase in norepinephrine, indicating an increase in activity of the sympathetic nervous system. Catecholamines may lead to an increase in the activity of the Na/K-ATPase pumps leading to an increase in cellular respiration (Gasser and Brooks, 1984). Catecholamines may also lead to an increase in futile cycling (Newholme, 1978), and an increase in recycling of glucose through 3-carbon compounds (Defronzo et al., 1984).

Rowe (1981) demonstrated that insulin stimulated the release of norepinephrine leading to an increased TEF. In the present study, insulin would be expected to increase as a result of feeding the high carbohydrate test meal. The 660 kcal meal contained 132g CHO (80%), 5g fat (6.8%), and 22g protein (13.3%). TEF has been shown to be significantly higher in response to a carbohydrate meal compared with a fat meal. (Palmer-Lynch, 1995). It has also been shown that a meal needs to contain at least 400 kcal to increase the TEF (Samueloff et al., 1982). The 660 kcal meal containing 132g CHO ingested in this study meets these criteria.

In previous studies which found no increase in TEF from aerobic exercise, the meal was fed prior to exercise or the duration and/or intensity of exercise was not sufficient (Belko et al., 1986; Dallosso and James, 1984; Welle and Campbell, 1983). Therefore, in the present study, the meal was fed after the participants' VO2 had returned to pre-exercise baseline after exercise. As previously stated, with aerobic exercise the

duration and intensity need to exceed 20 minutes and 55% respectively. Maximum HR is estimated as 220 minus the age of the participant. This equation was used when determining the percent that the individual was working at. Although the exercise in the present study was anaerobic (weight training), the duration (>20 minutes) and the intensity, as determined by the heart rate during exercise (>63% Max HR), were sufficient to lead to an increased TEF.

There is the possibility that if measured over 36 hours, the TEF may be greater than was determined in this study. Witt et al., (1993) demonstrated that trained individuals had a decreased TEF for at least 12 to 16 hours after exercise, but an increased TEF by 36 hours post-exercise. The participants in the present study, while not elite athletes, were trained individuals. The participants displayed a greater TEF due to exercise, the possibility of an even greater TEF 36 hours post-exercise should be considered.

In summary, the results of this study indicate that TEF in response to a CHO meal is significantly increased following a single bout of anaerobic exercise. The factors leading to the increased TEF most likely include an increase in SNS activity, and increased energy expenditure for the restoration of glycogen in muscle. In addition, elevation of several hormones, increased substrate cycling, increased protein resynthesis, lactate removal, and resynthesis of creatine phosphate, may also have contributed to the enhanced TEF after exercise. From these results, it may be estimated that over a one year period, a person who weight trains three times a week, would have an increased energy expenditure of approximately 2,500 kcal beyond that which is expended by the activity

alone. This additional caloric expenditure may contribute to long-term weight maintenance.

CHAPTER 6

CONCLUSION and FUTURE RESEARCH

The purpose of this study was to examine the effect of a single bout of anaerobic exercise on TEF. The hypothesis tested was that anaerobic exercise would not increase TEF over that observed in a control trial. The results suggest that anaerobic exercise led to a significant increase in the TEF above a control trial (t=2.180, p=.030). Thus, the null hypothesis was rejected and the alternate hypothesis was accepted.

The present study examined the effect of anaerobic exercise on the TEF. It has been shown that aerobic exercise of sufficient intensity (>55%) and duration (>20 minutes) has led to a significantly higher TEF when compared to a control trial. This study demonstrated that anaerobic exercise also leads to a significant increase in TEF when compared with a control trial. Important questions that remain unanswered are the duration sufficient to significantly increase TEF, and whether different age groups, gender, or fitness level (unfit, aerobically fit, and anaerobically fit) react similarly to anaerobic exercise. This study is the bases for future research on anaerobic metabolism and TEF.

APPENDIX I

INSTITUTIONAL REVIEW BOARD APPROVAL

INFORMED CONSENT

HUMAN SUBJECT FORM

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

DATE: October 25, 2000

TO: Charlene Denzer
Kinesiology
MS 3034

FROM: Dr. William E. Schulze, Director
Office of Sponsored Programs (x1357)
UNLV Institutional Review Board

RE: Status of Human Subject Protocol Entitled:
"The Effects of a Weight Lifting Regimen (anaerobic exercise) on the Thermic Effect of Food (TEF)"

OSP #504s0900-087

This memorandum is official notification that the Biomedical Sciences Committee of the Institutional Review Board has approved the above protocol. This protocol is approved for a period of one year from the date of this notification and work on the project may proceed.

Should the use of human subjects described in this protocol continue beyond a year from the date of this notification, it will be necessary to request an extension.

If you have any questions or require any assistance, please contact the Office of Sponsored Programs at 895-1357.

Human Subjects Protocol

The effect of a weight training regimen (anaerobic metabolism) on the Thermic Effect of Food.

1. **PARTICIPANTS:**

8-10 adult students of UNLV (including both males and females) will be selected according to their age and fitness level. The participants will be required to train aerobically at least two hours per week and weight train at least two times per week for two months prior to the start of the study. Each participant had no previous history of cardiovascular disease and is not diabetic.

2. **PURPOSE, METHODS, PROCEDURES:**

The purpose of the study is to determine if a weight training regimen (anaerobic metabolism) increases the Thermic Effect of Food (TEF).

The equipment used will be a heart rate monitor (polar), gas analyzer (Vista), bicycle ergometer and weight machines.

Procedure: Pretest and posttest: Approximately one week before testing begins the participants will perform a submaximal VO_2 test on the cycle ergometer. The test entails the participant to cycle at a rate of 100 beats/minute. Once the participant is in a steady state zone, the workload is increased and the procedure is repeated. The submaximal VO_2 test is performed to determine the participant's fitness level.

During the control trial the participants will report to the laboratory in the morning after an overnight fast. The participants have their VO_2 taken for 15min when they come to the lab to determine their baseline VO_2. They will then be given a meal in the form of pudding, which is made with skim milk. The VO_2 will be monitored at 10, 30, 60, 90 and 120min. to assess the TEF.

During the exercise trial (approximately one week later at the same time of day) the participants will report to the laboratory and have their VO_2 measured to determine baseline VO_2. Then they will participate in a weight-training regimen designed to keep their heart rate in the anaerobic zone. The program will be approximately 20 minutes in duration. Once the program is over the participants will rest and VO_2 will be monitored until it reaches baseline again. The participants will then eat the meal (pudding), which is the same amount as on the control day. The participants VO_2 will be monitored at 10, 30, 60, 90 and 120min to determine the TEF.

3. **RISKS:**

The participants presently weight train, so the only potential risk is minimal and may include muscle soreness due to new exercises used in the study. To prevent over-lifting, the participants were walked through a trial run of the program, and the weights were adjusted to their current strength.

4. **BENEFITS:**

The results from this research will be beneficial to all individuals and athletes whom use weight lifting as part of their regimen. Alternate forms of anaerobic exercise were considered, but for practical purposes weight lifting was the preferred method.

5. RISK-BENEFIT RATIO:

The slight risk of muscle soreness or overuse injury will be controlled for. The benefit is that research will greatly benefit and individuals/athletes whom presently weight lift will benefit in knowing the metabolic capabilities of anaerobic metabolism. Overall the benefits outweigh the risks.

6. COSTS TO SUBJECTS:

There will be no cost to the participants except for their time in this study. All participants will be tested at a convenient time to them excluding any missed time from work.

7. INFORMED CONSENT:

Informed consents will be given to each participant prior to the study. Following the exclusion of the study, the informed consent will be stored with the thesis at the UNLV Kinesiology department.

Informed Consent

Title of Study:
The effects of a weight lifting (anaerobic exercise) regimen on the thermic effect of food (TEF).
Investigator: Charlene Denzer
Department: Kinesiology

PURPOSE:
You have been invited to participate in a study that investigates the effect of weight lifting (anaerobic metabolism) on the thermic effect of food (TEF). The thermic effect of food is the increase of VO_2 above that of baseline after the ingestion of a meal. The purpose of this study is to determine if there is a significant increase or no change at all in the TEF due to a weight-training program. You are invited to participate because you meet the criteria necessary for participation in the study.

PROCEDURE:
If you decide to participate in the study, you will be asked to report to the S.I.R.C. (Sports Injury Research Center) on three separate days at a mutually agreed upon time for testing. The testing will take place on three separate days over a three-week time course. The experimental session will last approximately 150 minutes on the control day and 310 minutes on the test day. The first day will be the submaximal VO2 test (submaximal oxygen consumption) test, skinfolds (measurement of % body fat), and getting the weight training program adjusted to the individual. The first day will take approximately 45min.

The second day (treatment) will include measuring resting VO_2 for 15min followed by a 20min-weightlifting program. After the exercise you will have your VO_2 measured until it reaches baseline again. At this time you will be given pudding (meal) to eat. Following the completion of the meal, VO_2 will be measured at 10, 30, 60, 90 and 120min.

The third day (control) will begin with a resting VO_2 measured for 15min. Pudding (meal) will then be eaten. Resting VO_2 will then be measured at 10, 30, 60, 90 and 120min.

You will be asked not to drink alcohol or use tobacco products for 24hrs prior to testing. Also you will be asked not to participate in any physical activity for 36hrs prior to testing. 12hrs prior to testing you should not eat anything.

RISKS:
A possible risk involved in connection with this study is sore or strained muscles from weight lifting. This will be controlled for by individualizing the weight program to the current strength of the participant.

BENEFITS:
Benefits will include broadening the research field. Any benefits from this study are not guaranteed or promised.

CONFIDENTIALITY:
Informed Consents will be provided at least 24hrs. prior to testing. Any information obtained in connection with this study that can be identified with you will remain confidential and will be disclosed only with your permission. Signed Informed Consents will be stored in a locked file cabinet located in room 528 in the BHS.

In the unlikely event that physical injury results from your participation in this study, you should also understand that emergency medical treatment may be available at the University of Nevada, Las Vegas Student Health Center. You should also understand that the cost of such treatment will be your responsibility.

RIGHT TO REFUSE OR WITHDRAW:
Your decision whether or not to participate is voluntary and will not prejudice your future relations with the University of Nevada, Las Vegas or the investigator. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without prejudice. The investigators may terminate your participation at any time.

QUESTIONS:

For any questions you have regarding this research or your rights as a subject contact the investigator at (702)-737-6913 or the Office of Sponsored Programs at (702)-895-1357.

You will receive a copy of this form to keep in your files.

AUTHORIZATION
YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE, HAVING READ THE INFORMATION PROVIDED ABOVE AND ALL QUESTIONS HAVE BEEN ANSWERED TO YOUR SATISFACTION.

______________________ ______________________

Name of the Participant (Print) Signature Date

APPENDIX II

STATISTICAL ANALYSIS

TABLE 5

Analysis of Variance - Resting VO_2's

Participants	Pre-exercise	Resting VO_2's Post-exercise	Control
1	201.912	205.999	282.658
2	130.556	124.028	232.816
3	267.019	262.2485	170.875
4	172.396	195.723	136.936
5	237.919	244.621	213.417
6	99.784	98.926	109.457
7	120.588	124.044	188.355
8	194.221	191.426	153.106
9	181.153	185.99	127.096

	Pre-exercise	Post-exercise	Control
Average	178.394	181.445	179.413
SD	54.834	55.732	55.843
SE	18.278	18.577	18.614

One-way repeated measures ANOVA

Source	SS	df	MS	F	p-value
Trials	43.425	2	21.712	0.013	0.987
Error	25878.54	16	1617.409		
Total	25921.97	18			

TABLE 6

Analysis of Variance - Resting RQ

Participants	Pre-exercise	Post-exercise	Control
	Resting RQ		
1	1.0991	0.9764	0.9885
2	0.8038	0.8497	0.8275
3	0.895	0.8241	0.9045
4	0.9286	0.8886	0.7989
5	0.818	0.8003	0.8297
6	0.8427	0.7891	0.77439
7	0.7752	0.6769	0.7965
8	0.8843	0.8732	0.8358
9	0.8269	0.7818	0.807
	Pre-exercise	**Post-exercise**	**Control**
Average	0.875	0.829	0.840
SD	0.097	0.083	0.067
SE	0.032	0.027	0.022

One-way repeated measures ANOVA

Source	SS	df	MS	F	p-value
Trials	0.01	2	0.01	3.163	0.07
Error	0.02	16	0.02		
Total	0.03	18			

TABLE 7

Dependent t-test for mean RQ during the exercise and control trials

Mean RQ Values

	Exercise	Control
1	1.088	0.961
2	0.876	0.912
3	0.960	0.913
4	0.904	0.787
5	0.962	0.911
6	0.841	0.817
7	0.777	0.788
8	0.859	0.861
9	0.860	0.851
Mean	0.903	0.867
SD	0.090	0.062
SE	0.030	0.021

t-Test: Paired Two Sample for Means

	Exercise	*Control*
Mean	0.903	0.867
Variance	0.008	0.004
Observations	9	9
Pearson Correlation	0.791	
Hypothesized Mean Difference	0	
Df	8	
t Stat	1.927	
P(T<=t) one-tail	0.045	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.090	
t Critical two-tail	2.306	

TABLE 8

Dependent t-test for total area under

the curve above baseline (VO_2)

	VO2 Exercise	Control
1	5277.750	5147.520
2	6755.625	5648.280
3	2833.720	5603.415
4	6902.270	3084.395
5	7306.500	7806.130
6	7694.690	3721.605
7	5919.455	3456.000
8	10272.335	1532.590
9	10943.527	3124.320

t-Test: Paired Two Sample for Means

	Exercise	*Control*
Mean	7100.652	4347.139
Variance	6038227.707	3509167.758
Observations	9.000	9.000
Pearson Correlation	-0.523	
Hypothesized Mean Difference	0.000	
df	8.000	
t Stat	2.180	
P(T<=t) one-tail	0.030	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.061	
t Critical two-tail	2.306	

TABLE 9

Dependent t-test for total area under

the curve above baseline (TEF)

	Kcal Exercise	Control
1	29.874	24.346
2	33.414	31.338
3	19.696	27.818
4	34.263	14.494
5	41.483	40.360
6	38.177	18.478
7	29.982	16.281
8	55.785	8.132
9	59.257	15.911

t-Test: Paired Two Sample for Means

	Exercise	*Control*
Mean	37.992	21.906
Variance	160.087	99.300
Observations	9.000	9.000
Pearson Correlation	-0.404	
Hypothesized Mean Difference	0.000	
Df	8.000	
t Stat	2.539	
P(T<=t) one-tail	0.017	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.035	
t Critical two-tail	2.306	

TABLE 10

Respiratory quotients (VO_2/VCO_2), Kcal used per liter of oxygen

		Percentage kcal Derived from		*Grams per LO₂*	
Nonprotein RQ	*kcal per LO₂*	*Carbohydrate*	*Lipid*	*Carbohydrate*	*Lipid*
0.707	4.686	0.0	100.0	0.000	.496
.71	4.690	1.1	98.9	.012	.491
.72	4.702	4.8	95.2	.051	.476
.73	4.714	8.4	91.6	.090	.460
.74	4.727	12.0	88.0	.130	.444
.75	4.739	15.6	84.4	.170	.428
.76	4.750	19.2	80.8	.211	.412
.77	4.764	22.8	77.2	.250	.396
.78	4.776	26.3	73.7	.290	.380
.79	4.788	29.9	70.1	.330	.363
.80	4.801	33.4	66.6	.371	.347
.81	4.813	36.9	63.1	.413	.330
.82	4.825	40.3	59.7	.454	.313
.83	4.838	43.8	56.2	.496	.297
.84	4.850	47.2	52.8	.537	.280
.85	4.862	50.7	49.3	.579	.263
.86	4.875	54.1	45.9	.621	.247
.87	4.887	57.5	42.5	.663	.230
.88	4.889	60.8	39.2	.705	.213
.89	4.911	64.2	35.8	.749	.195
.90	4.924	67.5	32.5	.791	.178
.91	4.936	70.8	29.2	.834	.160
.92	4.948	74.1	25.9	.877	.143
.93	4.961	77.4	22.6	.921	.125
.94	4.973	80.7	19.3	.964	.108
.95	4.985	84.0	16.0	1.008	.090
.96	4.998	87.2	12.8	1.052	.072
.97	5.010	90.4	9.6	1.097	.054
.98	5.022	93.6	6.4	1.142	.036
.99	5.035	96.8	3.2	1.186	.018
1.00	5.047	100.0	0	1.231	.000

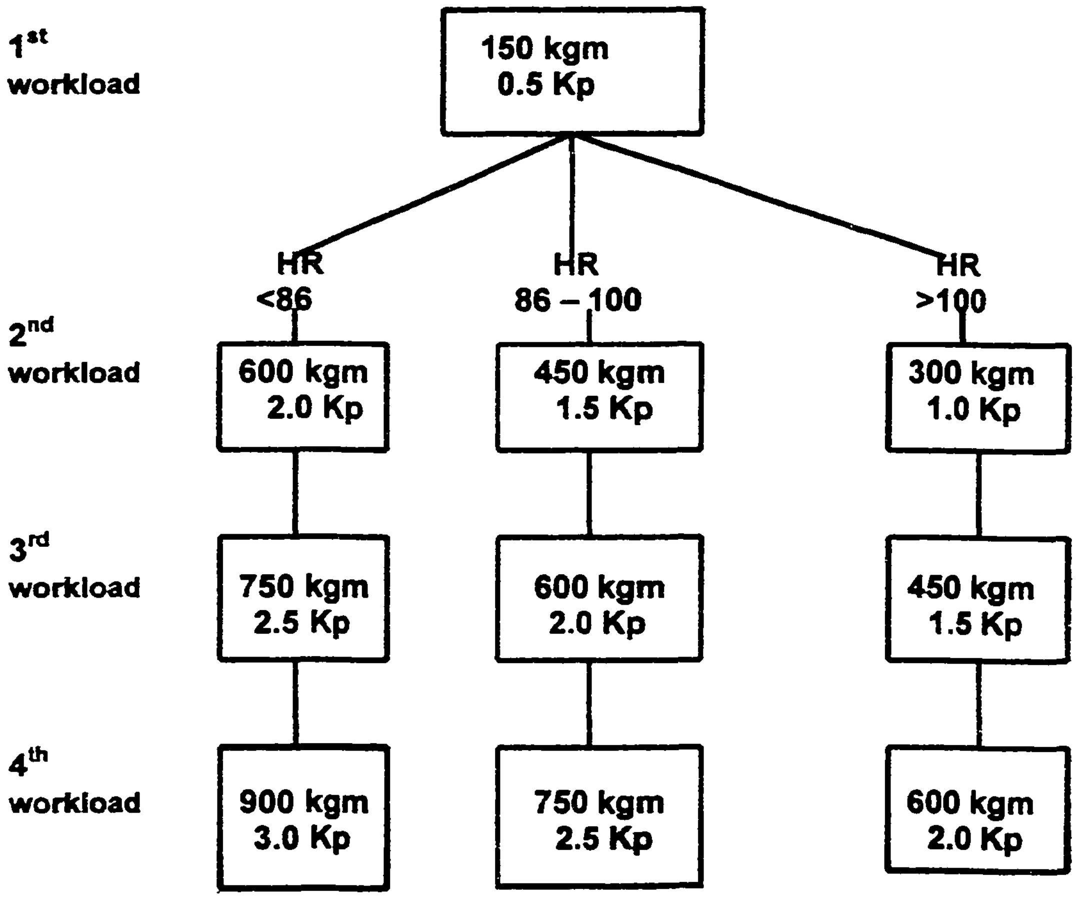
Note. From Sports and Exercise Nutrition (p. 178), by W.D. McArdle, F.I. Katch, and V.L. Katch, 1999, Philadelphia, PA:Lippincott, Williams, and Wilkins. Copyright 1999 by Lippincott, Williams, and Wilkins.

TABLE 11

Heart rate chart for cycle ergometer test

UNIVERSITY OF NEVADA, LAS VEGAS
EXERCISE PHYSIOLOGY LABORATORY

PWC MAX WORKLOAD GUIDE



Directions;

1. Set the first workload at 150 kgm/min (0.5Kp)
2. If the HR in the third min is:

- **less than (<) 86, set the second workload at600 kgm (2.0Kp);**
- **86 to 100, set the second workload at450 kgm (1.5Kp);**
- **greater than (>) 100, set the second workload at 300 kgm (1.0Kp).**

3. Set the third (and fourth if required) load according to the loads in the column below the second load

Note. From Y's Way to Physical Fitness, by L.A. Golding, C.R. Myers, & W.E. Sinning, 1989, Champaign, IL: Human Kinetics.

APPENDIX III

INDIVIDUAL PARTICIPANTS DATA

Raw Data

		VO_2	Kcal	RQ	VO_2	Kcal	RQ
	Participant	1	1	1	2	2	2
Exercise	**RMR**	205.999	1.0246	0.976364	124.028	0.5996	0.849758
	10	262.627	1.3205	1.024748	186.116	0.8853	0.779027
	30	242.353	1.243	1.117313	189.04	0.9242	0.89911
	60	251.054	1.2797	1.088735	169.116	0.8252	0.890221
	90	256.236	1.3065	1.089988	184.233	0.8998	0.894587
	120	250.002	1.2821	1.116863	193.379	0.9489	0.91553
Rest	**RMR**	282.658	1.4097	0.988547	232.816	1.1199	0.827525
	10	328.15	1.6260	0.959264	249.084	1.1896	0.796383
	30	323.62	1.615	0.991499	271.87	1.3558	0.988432
	60	352.25	1.7528	0.978192	294.202	1.4476	0.92771
	90	308.903	1.5139	0.910027	292.875	1.4615	0.99109
	120	320.39	1.5797	0.936996	285.12	1.4076	0.942547
	Participant	3	3	3	4	4	4
Exercise	**RMR**	262.458	1.2616	0.824051	195.732	0.9546	0.8886
	10	304.65	1.4949	0.915495	273.591	1.3458	0.926482
	30	294.826	1.4745	1.001206	265.429	1.3052	0.92514
	60	305.021	1.5332	1.023984	238.699	1.1701	0.911001
	90	262.123	1.3066	0.986209	261.229	1.2732	0.885518
	120	270.261	1.3539	1.008628	244.92	1.1948	0.889616
Rest	**RMR**	170.875	0.8364	0.904475	136.936	0.6544	0.798946
	10	218.386	1.0528	0.837237	177.962	0.8463	0.777854
	30	206.497	1.0239	0.962292	160.101	0.7655	0.8
	60	214.446	1.0596	0.946414	159.111	0.7603	0.79897
	90	240.836	1.1774	0.898966	155.448	0.7375	0.76806
	120	210.491	1.0336	0.918555	181.554	0.8656	0.789202

	Participant	5	5	5	6	6	6
Exercise	RMR	244.621	1.1693	0.800279	98.926	0.4685	0.789128
	10	327.918	1.5996	0.889147	189.526	0.8983	0.763337
	30	329.389	1.632	0.961177	207.528	0.9999	0.834557
	60	277.983	1.4054	1.050969	141.133	0.679	0.828452
	90	312.961	1.5464	0.946727	156.099	0.7629	0.89761
	120	303.74	1.5064	0.961391	141.542	0.6888	0.878835
Rest	RMR	213.417	1.0271	0.82974	109.457	0.5201	0.77439
	10	258.101	1.2428	0.832129	138.61	0.6516	0.727987
	30	286.237	1.4044	0.914884	147.581	0.7083	0.817872
	60	306.777	1.5032	0.909124	140.587	0.6767	0.830432
	90	285.944	1.3979	0.898835	145.497	0.7031	0.847425
	120	236.001	1.1794	0.997744	130.529	0.6326	0.860667

	Participant	7	7	7	8	8	8
Exercise	RMR	124.044	0.5767	0.676932	191.426	0.9304	0.873243
	10	148.718	0.6925	0.687888	271.9	1.3057	0.817969
	30	179.615	0.8513	0.763223	299.689	1.449	0.850076
	60	171.671	0.8242	0.819093	268.808	1.2856	0.802345
	90	203.284	0.9752	0.815608	287.456	1.3975	0.874343
	120	147.648	0.7054	0.797629	268.512	1.3272	0.948019
Rest	RMR	188.355	0.8996	0.796534	153.106	0.7379	0.835845
	10	231.999	1.0799	0.686332	155.022	0.7403	0.795839
	30	219.801	1.0392	0.752641	155.171	0.7595	0.904345
	60	208.604	0.9917	0.776214	164.288	0.7982	0.871545
	90	221.541	1.0689	0.840884	181.193	0.8804	0.871493
	120	215.826	1.0492	0.874008	171.383	0.836	0.889279

	Participant	9	9	9
Exercise	RMR	185.99	0.8852	0.781755
	10	266.146	1.2722	0.800135
	30	312.53	1.512	0.852625
	60	293.939	1.4374	0.900078
	90	291.587	1.4474	0.967238
	120	242.875	1.1759	0.856127
Rest	RMR	127.096	0.6085	0.806988
	10	145.603	0.6949	0.793141
	30	154.945	0.7477	0.841372
	60	161.16	0.7794	0.850925
	90	156.654	0.7642	0.88959
	120	143.218	0.6975	0.882121

APPENDIX IV

RAW DATA

Raw Data

		VO2	Kcal	RQ	VO2	Kcal	RQ
	Participant	1	1	1	2	2	2
Exercise	**RMR**	205.999	1.0246	0.976364	124.028	0.6246	0.849758
	10	262.627	1.3205	1.024748	186.116	0.8853	0.779027
	30	242.353	1.243	1.117313	189.04	0.9242	0.89911
	60	251.054	1.2797	1.088735	169.116	0.8252	0.890221
	90	256.236	1.3065	1.089988	184.233	0.8998	0.894587
	120	250.002	1.2821	1.116863	193.379	0.9489	0.91553
Mean		252.4544	1.28636	1.087529	184.3768	0.89668	0.875695
SD		7.546455	0.029638	0.037738	9.202208	0.046725	0.054881
SE		3.374877	0.013255	0.016877	4.115353	0.020896	0.024544
Rest	**RMR**	282.658	1.4097	0.988547	232.816	1.1199	0.827525
	10	328.15	1.726	0.959264	249.084	1.1896	0.796383
	30	323.62	1.615	0.991499	271.87	1.3558	0.988432
	60	352.25	1.7528	0.978192	294.202	1.4476	0.92771
	90	308.903	1.5139	0.910027	292.875	1.4615	0.99109
	120	320.39	1.5797	0.936996	285.12	1.4076	0.942547
Mean		326.6626	1.58285	0.960754	270.9945	1.330333	0.912281
SD		15.97603	0.087388	0.032537	18.74961	0.110141	0.079309
SE		7.144696	0.039081	0.014551	8.385079	0.049257	0.035468

	Participant	3	3	3	4	4	4
Exercise	RMR	262.458	1.2616	0.824051	195.732	0.9546	0.8886
	10	304.65	1.4949	0.915495	273.591	1.3458	0.926482
	30	294.826	1.4745	1.001206	265.429	1.3052	0.92514
	60	305.021	1.5332	1.023984	238.699	1.1701	0.911001
	90	262.123	1.3066	0.986209	261.229	1.2732	0.885518
	120	270.261	1.3539	1.008628	244.92	1.1948	0.889616
Mean		283.9833	1.411183	0.959929	242.7107	1.189583	0.904393
SD		19.97421	0.097246	0.042282	14.53264	0.073973	0.019279
SE		8.93274	0.04349	0.018909	6.499194	0.033082	0.008622
Rest	RMR	170.875	0.8364	0.904475	136.936	0.6544	0.798946
	10	218.386	1.0528	0.837237	177.962	0.8463	0.777854
	30	206.497	1.0239	0.962292	160.101	0.7655	0.8
	60	214.446	1.0596	0.946414	159.111	0.7603	0.79897
	90	240.836	1.1774	0.898966	155.448	0.7375	0.76806
	120	210.491	1.0336	0.918555	181.554	0.8656	0.789202
Mean		218.1312	1.06946	0.912693	166.8352	0.79504	0.786817
SD		13.44322	0.062023	0.048769	11.99093	0.057001	0.013778
SE		6.011991	0.027738	0.02181	5.362508	0.025492	0.006162
		VO2	Kcal	RQ	VO2	Kcal	RQ

Participant		5	5	5	6	6	6
Exercise	RMR	244.621	1.16936	0.800279	98.926	0.4685	0.789128
	10	327.918	1.5996	0.889147	189.526	0.8983	0.763337
	30	329.389	1.632	0.961177	207.528	0.9999	0.834557
	60	277.983	1.4054	1.050969	141.133	0.679	0.828452
	90	312.961	1.5464	0.946727	156.099	0.7629	0.89761
	120	303.74	1.5064	0.961391	141.542	0.6888	0.878835
	Mean	310.3982	1.53796	0.961882	167.1656	0.80578	0.840558
	SD	21.03116	0.088434	0.058003	29.94097	0.139498	0.052119
	SE	9.40542	0.039549	0.02594	13.39001	0.062385	0.023308
Rest	RMR	213.417	1.0271	0.82974	109.457	0.5201	0.77439
	10	258.101	1.2428	0.832129	138.61	0.6516	0.727987
	30	286.237	1.4044	0.914884	147.581	0.7083	0.817872
	60	306.777	1.5032	0.909124	140.587	0.6767	0.830432
	90	285.944	1.3979	0.898835	145.497	0.7031	0.847425
	120	236.001	1.1794	0.997744	130.529	0.6326	0.860667
	Mean	274.612	1.34554	0.910543	140.5608	0.67446	0.816877
	SD	27.6657	0.131549	0.058972	6.672567	0.032578	0.05229
	SE	12.37248	0.058831	0.026373	2.984063	0.014569	0.023385

Participant	VO2 7	Kcal 7	RQ 7	VO2 8	Kcal 8	RQ 8
RMR	124.044	0.5761	0.676932	191.426	0.9304	0.873243
10	148.718	0.6925	0.687888	271.9	1.3057	0.817969
30	179.615	0.8513	0.763223	299.689	1.449	0.850076
60	171.671	0.8242	0.819093	268.808	1.2856	0.802345
90	203.284	0.9752	0.815608	287.456	1.3975	0.874343
120	147.648	0.7054	0.797629	268.512	1.3272	0.948019
Mean	170.1872	0.80972	0.776688	279.273	1.353	0.85855
SD	23.21328	0.116131	0.054356	13.81531	0.068268	0.057297
SE	10.38129	0.051935	0.024309	6.178394	0.03053	0.025624
RMR	188.355	0.8996	0.796534	153.106	0.7379	0.835845
10	231.999	1.0799	0.686332	155.022	0.7403	0.795839
30	219.801	1.0392	0.752641	155.171	0.7595	0.904345
60	208.604	0.9917	0.776214	164.288	0.7982	0.871545
90	221.541	1.0689	0.840884	181.193	0.8804	0.871493
120	215.826	1.0492	0.874008	171.383	0.836	0.889279
Mean	214.3543	1.021417	0.787769	163.3605	0.79205	0.861391
SD	8.554059	0.034199	0.073993	11.16676	0.056847	0.041817
SE	3.825491	0.015294	0.033091	4.993928	0.025423	0.018701

Participant	VO2 9	Kcal 9	RQ 9
RMR	185.99	0.8852	0.781755
10	266.146	1.2722	0.800135
30	312.53	1.512	0.852625
60	293.939	1.4374	0.900078
90	291.587	1.4474	0.967238
120	242.875	1.1759	0.856127
Mean	264.705	1.286033	0.85966
SD	27.14285	0.139581	0.062446
SE	12.13865	0.062423	0.027927
RMR	127.096	0.6085	0.806988
10	145.603	0.6949	0.793141
30	154.945	0.7477	0.841372
60	161.16	0.7794	0.850925
90	156.654	0.7642	0.88959
120	143.218	0.6975	0.882121
Mean	152.316	0.73674	0.85143
SD	7.61223	0.038679	0.038396
SE	3.404293	0.017298	0.017171

Exercise VO_2

	RMR	RMR -AE	10	30	60	90	120
1	201.912	205.999	262.627	242.353	251.054	256.236	250.002
2	130.556	124.028	186.116	189.04	169.116	184.233	193.379
3	267.019	262.485	304.65	294.826	305.021	262.123	270.261
4	172.396	195.723	273.591	265.429	238.699	261.229	244.92
5	237.919	244.621	327.918	329.389	277.983	312.961	303.74
6	99.784	98.962	189.526	207.528	141.446	156.099	141.542
7	120.588	124.044	148.718	179.615	171.671	203.284	147.648
8	194.221	191.426	271.9	299.689	268.808	287.456	268.512
9	181.153	185.99	266.146	312.53	293.929	291.587	242.875
Mean	178.3942	181.4753	247.9102	257.8221	235.303	246.1342	229.2088
SD	54.83422	55.76821	59.65644	55.80198	59.93777	53.14961	56.20531
SE	18.27807	18.5894	19.88548	18.60066	19.97926	17.71654	18.7351

Control VO_2

	RMR	10	30	60	90	120
1	282.658	328.15	323.62	352.25	308.903	320.39
2	232.816	249.084	271.87	294.202	292.875	285.12
3	170.875	218.386	206.497	214.446	240.836	210.491
4	136.936	177.962	160.101	159.111	155.448	181.554
5	213.417	258.417	286.237	306.777	285.944	236.001
6	109.4578	138.61	147.581	140.587	145.497	130.529
7	188.355	231.999	219.801	208.604	221.541	215.826
8	153.106	155.022	155.171	164.288	181.193	171.383
9	127.096	145.603	154.945	161.160	156.654	143.218
Mean	179.413	211.4703	213.9803	222.3806	220.9879	210.5013
SD	55.84319	62.9072	66.08568	76.82433	64.44688	62.86182
SE	18.6144	20.96907	22.02856	25.60811	21.48229	20.95394

Exercise Kcal

	RMR	RMR -AE	10	30	60	90	120
1	1.0316	1.0246	1.3205	1.243	1.2797	1.3065	1.2821
2	0.6246	0.5996	0.8853	0.9242	0.8252	0.8998	0.9489
3	1.304	1.2616	1.4949	1.4745	1.5332	1.3066	1.3539
4	0.8484	0.9546	1.3458	1.3052	1.1701	1.2732	1.1984
5	1.1419	1.1694	1.5996	1.632	1.4054	1.5464	1.5064
6	0.48165	0.4685	0.8983	0.9999	0.679	0.7629	0.6888
7	0.5731	0.5761	0.6925	0.8513	0.8242	0.9752	0.7054
8	0.9464	0.9304	1.3057	1.449	1.2856	1.3975	1.3272
9	0.8713	0.8853	1.2722	1.512	1.4374	1.4474	1.1759
Mean	0.869217	0.874456	1.201644	1.265678	1.159978	1.212833	1.131889
SD	0.2725	0.2735	0.3055	0.2813	0.3088	0.2689	0.2890
SE	0.0908	0.0912	0.1018	0.0938	0.1029	0.0896	0.0963

Control Kcal

	RMR	10	30	60	90	120
1	1.4097	1.6260	1.615	1.7528	1.5139	1.5797
2	1.1199	1.1896	1.3558	1.4476	1.4615	1.4076
3	0.8364	1.0528	1.0239	1.0596	1.1774	1.0336
4	0.6544	0.8463	0.7655	0.7603	0.7375	0.8656
5	1.0271	1.2428	1.4044	1.5032	1.3979	1.1794
6	0.5201	0.6516	0.7083	0.6767	0.7031	0.6326
7	0.8996	1.0799	1.0392	0.9917	1.0689	1.0492
8	0.7379	0.7403	0.7595	0.7982	0.8804	0.836
9	0.6085	0.6949	0.7477	0.7794	0.7642	0.6975
Mean	0.868178	1.0138	1.046589	1.0855	1.078311	1.031244
SD	0.281764	0.281764	0.341156	0.341156	0.337732	0.388822
SE	0.093921	0.093921	0.105394	0.105394	0.112577	0.129607

Increase in VO2 above baseline with exercise

	10	30	60	90	120
1	56.628	36.354	45.055	50.237	44.003
2	62.088	65.012	45.088	60.205	69.351
3	42.165	32.341	42.536	0	7.776
4	77.868	69.706	42.976	65.506	49.197
5	83.297	84.768	33.362	68.340	59.119
6	90.564	108.566	42.484	57.137	42.58
7	24.674	55.571	47.627	79.240	23.604
8	80.474	108.263	77.382	96.030	77.086
9	80.156	126.540	107.939	105.597	56.885
Mean	66.435	76.347	53.828	64.699	47.733
SD	21.882	33.142	23.631	30.315	21.690
SE	7.294	11.047	7.877	10.105	7.230

Increase in VO2 above baseline on control day

	10	30	60	90	120
1	45.492	40.962	69.592	26.245	37.732
2	16.268	39.054	61.386	60.059	52.304
3	47.511	35.622	43.571	69.961	39.616
4	41.026	23.165	22.175	18.512	44.618
5	45.000	72.820	93.360	72.527	22.584
6	29.152	38.123	31.129	36.039	21.071
7	43.644	31.446	20.249	33.186	27.471
8	1.916	2.065	11.182	28.087	18.277
9	18.507	27.849	34.064	29.558	16.122
Mean	32.057	34.567	42.968	41.575	31.088
SD	16.399	18.639	26.847	20.309	12.864
SE	5.466	6.213	8.949	6.770	4.288

TEF with exercise (Kcal) increase over baseline

	10	30	60	90	120
1	0.2959	0.2184	0.2551	0.2819	0.2575
2	0.2857	0.3246	0.2256	0.3002	0.3493
3	0.2333	0.2129	0.2716	0.045	0.0923
4	0.3912	0.3506	0.2155	0.3186	0.2438
5	0.4302	0.4626	0.236	0.377	0.337
6	0.4298	0.5314	0.2105	0.2944	0.2203
7	0.1164	0.2752	0.2481	0.3991	0.1293
8	.3753	.5186	.3552	.4671	.3968
9	0.3869	0.6267	0.5521	0.5621	0.2906
Mean	0.3271889	0.391222	0.285522	0.338378	0.257433
SD	0.1043224	0.149012	0.10898	0.143546	0.10034
SE	0.0347741	0.049671	0.036327	0.047849	0.033447

TEF (Kcal) increase over baseline on control day

	10	30	60	90	120
1	0.2163	0.205	0.343	0.104	0.170
2	0.070	0.236	0.328	0.342	0.288
3	0.216	0.188	0.223	0.341	0.197
4	0.192	0.111	0.106	0.083	0.211
5	0.216	0.377	0.476	0.371	0.152
6	0.132	0.188	0.157	0.183	0.113
7	0.180	0.140	0.092	0.169	0.150
8	0.002	0.022	0.060	0.143	0.098
9	0.086	0.139	0.171	0.156	0.089
Mean	0.146	0.178	0.217	0.210	0.163
SD	0.078	0.097	0.139	0.110	0.063
SE	0.026	0.032	0.046	0.037	0.021

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