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I am submitting herewith a thesis written by Karen Michelle Townsend entitled "Substrate Use During and Following High and Low Intensity Exercise: Implication for Weight Control". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport Studies.

Dixie L. Thompson, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

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Dean of the Graduate School

Substrate Use During and Following High and Low Intensity Exercise: Implications for Weight Control

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Karen M. Townsend

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DEDICATION

This thesis is dedicated to my family. Without their support, encouragement, and unconditional love, I would not be where I am today.

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ABSTRACT

Fat metabolism and total caloric expenditure during exercise have been the major foci for researchers investigating the impact of physical activity on weight loss; however, there is little research exploring the utilization of fat in the post-exercise period. The purpose of this study was to examine substrate utilization during and after two exercise bouts of different intensities, but with similar caloric expenditures, in an attempt to determine which exercise intensity was associated with a greater reliance on fat.

Ten male subjects participated in this study. All subjects had been physically active 6 months prior to the study and engaged in activity at least 3 days a week for a minimal of 30 minutes a session. Subject's average age, height , and weight were as follows: 26.9 (± 4.8) years, 181.1 (± 4.8) cm, and 75.7 (± 8.8) kg. An incremental cycle ergometer test was performed by each subject to determine their maximal oxygen consumption (VO_2 max). On subsequent days, subjects performed cycle ergometer exercise at 33% VO_2 max for 90 minutes and 66% VO_2 max for 45 minutes. Throughout the 6 hour recovery period, oxygen consumption was continuously monitored by the SensorMedics 2900 Metabolic Cart. Subjects were fed a standard meal 2 hours post-exercise.

During exercise, carbohydrate utilization was signifcantly ($p < 0.05$) greater during the high-intensity trial compared to the low-intensity trial (106.0 ± 27.8 g vs. 68.7 ± 20.0 g, respectively). Fat and protein utilization were greater during the low-intensity bout compared to the high-intensity bout (30.0 ± 11.0 g and 4.9 ± 2.9 g vs.

13.6 ± 6.6 g and 1.6 ± 0.6 g, respectively). Caloric expenditure between exercise bouts were similar.

Oxygen consumption throughout the 6 hour post-exercise period was not different between exercise bouts; however, average pre-meal VO_2 was significantly higher following the high-intensity exercise compared to the low-intensity exercise (288 ± 91.3 ml/min vs. 264 ± 48.6 ml/min, respectively). The R value was not different between exercise trials throughout the entire recovery period or during pre- and post-meal recovery periods. EPOC duration was similar between exercise bouts (60 minutes). After meal consumption, VO_2 never returned to baseline values in either exercise trial.

Total caloric expenditure (exercise and recovery combined) was not significantly different between exercise trials; however, total carbohydrate utilization was significantly greater during and after the high-intensity bout (188.8 ± 45.2g) compared to the low-intensity bout (142.5 ± 28.5 g). Total fat utilization was significantly greater in the low-intensity bout compared to the high-intensity bout (42.4 ± 13.6 g vs. 24.0 ± 12.2 g, respectively). Total protein utilization was similar for the low- and high-intensity trials.

Substrate utilization was similar between exercise bouts throughout recovery, therefore, the significant difference in total substrate utilization is due to the exercise bout itself. These results imply that low-intensity exercise is more beneficial for fat utilization than high-intensity exercise at the same caloric expenditure.

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CHAPTER 1

INTRODUCTION

With trends indicating an increase in obesity, treatments which help prevent this condition are of considerable interest to both the general public and health care professionals. A recent government survey reports that 33.4% of US adults are overweight, an increase of 8% since 1980 (Kuczmarski et al., 1994). Excess body fat is related to several negative health consequences such as coronary artery disease, hypertension, and diabetes (AMA, 1988). The prevalence of obesity and the health outcomes linked with it result in billions of dollars spent each year in attempts to lose weight (Cottrell, 1992). Because of the many health benefits, including an increase in daily energy expenditure, associated with regular exercise, professional organizations such as the American College of Sports Medicine and the American Medical Association recommend regular aerobic activity as a part of weight loss and weight maintenance programs (ACSM, 1995; AMA, 1988). However, the characteristics of an exercise program which would maximize the chances of preventing excess fat accumulation need to be determined.

Low-intensity exercise uses primarily fat as a fuel source, whereas high-intensity exercise relies more heavily on muscle glycogen (O'Brien et al., 1993). This is one reason why low intensity, long duration exercise is recommended for weight control (ACSM, 1995). A study by Ballor et al. (1990) examined the effects of eight

weeks of high- vs. low-intensity training on weight loss and body composition changes. Both groups expended the same number of calories per exercise bout and lost similar amounts of fat during the study. The high-intensity group lost 4.5 kg of fat whereas the low-intensity group lost 4.7 kg of fat. Although this study showed similar reductions in body fat, the results are difficult to interpret because subjects were dieting in addition to exercising. In fact, the exercise alone only accounted for 0.8 kg of the weight loss. Although the results of this study are not definitive, it suggests that high intensity exercise may be as beneficial as low-intensity exercise for fat loss.

Excess post-exercise oxygen consumption (EPOC) is an elevation in oxygen consumption above resting values after the cessation of exercise. The magnitude of EPOC depends on both the intensity and duration of the exercise bout, but intensity may be the most important factor (Melton, 1993; Hewitt et al., 1986; Sedlock et al., 1989; Begley et al., 1991; Keleher, 1992; Broeder et al., 1991). The extra energy expenditure during recovery may be beneficial for weight loss and weight maintenance purposes particularly if the primary fuel source during this period is fat.

High-intensity exercise may result in an increase in fat metabolism in the post-exercise period when compared to resting values (Romijn et al., 1993; Treadway and Young, 1990; Bahr et al., 1991). Bahr et al. (1991) exercised subjects for 80 minutes at intensities of 29%, 50%, and 75% VO_2 max. They found a significant linear relationship between exercise intensity and FFA and glycerol concentration two hours post-exercise. They also found after exercise at 75% VO_2 max, glycerol and FFA

concentrations stay elevated for 2.5 and 6 hours, respectively. The authors state that muscle glycogen depletion and the increase in glycerol and FFA concentrations after high-intensity exercise may increase the utilization of fat during the post-exercise period. Treadway and Young (1990) also found fat utilization increased after high-intensity exercise. They exercised subjects for 45 minutes at 34%, 54%, and 75% VO_2 max, and found a significant difference in the R value (0.73 for both) at 54% and 75% VO_2 max compared to the control day (0.82). In contrast, the R value after exercise at 34% VO2 max (0.78) was not significantly different from the control day (0.82). This study indicates that high-intensity, but not low-intensity, exercise elevates fat metabolism in comparison to resting conditions.

The intensity of an exercise bout may also alter the thermic effect of a meal consumed in the post-exercise period. The thermic effect of food (TEF) generally constitutes 10% of an individual's daily energy expenditure. In comparison to low-intensity exercise, high-intensity exercise will elicit a lower R value after consuming a meal indicating a greater reliance on fat metabolism (Treadway and Young, 1990; Broeder et al., 1991; Bahr et al., 1987).

Purpose

Fat metabolism and total caloric expenditure during exercise have been the major foci for researchers investigating the impact of physical activity on weight loss; however, there is little research exploring the utilization of fat in the post-exercise period. The purpose of this study was to examine substrate utilization during and after two exercise bouts of different intensities, but with similar caloric expenditures,

in an attempt to determine which exercise intensity was associated with a greater reliance on fat oxidation.

Hypotheses

1. The high-intensity exercise would elicit a higher degree of fat utilization in the post-exercise period prior to and after food consumption compared to low-intensity exercise.

2. High-intensity exercise would lead to a greater increase in oxygen consumption during the post-exercise period prior to and after food consumption compared to low-intensity exercise.

List of Terms

Excess post-exercise oxygen consumption - Oxygen consumption elevated above resting levels after the cessation of exercise.

Non-protein respiratory quotient - The utilization of fat and carbohydrate (excluding protein) as indicated by the respiratory exchange ratio.

Respiratory exchange ratio (RER) - Calculated by dividing carbon dioxide produced by oxygen consumed. This ratio indicates substrate utilization under steady state conditions. A value of 0.7 would indicate 100% fat utilization where as 100% carbohydrate utilization would have a value of 1.0. Term is used synonymously with R value.

Respiratory quotient - The ratio of carbon dioxide produced to oxygen consumed at the cellular level.

Resting metabolic rate - The energy required to maintain homeostasis within the body at rest.

Substrate cycling - The balance between the use of metabolic pathways involving carbohydrate, fat, and protein in fulfilling the body's energy requirements.

CHAPTER 2

REVIEW OF LITERATURE

Substrate Utilization During Exercise

Substrate utilization during exercise is a complex balance between fat, carbohydrate, and protein metabolism. The use of these substrates is determined by exercise duration and intensity as well as availability of these substances. During prolonged low-intensity exercise, one relies heavily on fat utilization for ATP production. At higher exercise intensities, an individual will rely primarily on carbohydrates. Typically, protein contributes only minimally to ATP production; however, during extended bouts of exercise, protein utilization will become more important due to diminished liver and muscle glycogen stores (Bates et al., 1980). A variety of factors including substrate availability, hormonal influences, and the demand for ATP control substrate utilization.

Carbohydrate

Blood glucose and muscle and liver glycogen are the main sources of carbohydrate. These substrates work together in order to supply the body with energy. Carbohydrates are an important energy source for the phosphorylation of ATP because carbohydrates may be metabolized through either aerobic or anaerobic pathways. When liver and muscle glycogen are depleted through either heavy exercise or dietary restriction, gluconeogenic pathways supply glucose through the metabolism of amino acids or glycerol (McArdle et al., 1996).

At the onset of exercise, muscle glycogen is the dominant source of carbohydrate. As exercise intensity increases, so does the rate of glycogenolysis. This is due to elevated catecholamines and recruitment of type II muscle fibers during high-intensity exercise (Hargreaves, 1990). As exercise continues, the decrease in muscle glycogen is compensated for by an increase in blood glucose utilization to maintain carbohydrate oxidation (Coggan and Coyle, 1992). Hargreaves (1990) and Coggan and Coyle (1992) performed studies which found an inverse relationship between muscle glycogen and blood glucose utilization. As muscle glycogen decreases, blood glucose utilization increases.

Plasma glucose uptake by skeletal muscle is dependent upon exercise intensity. Glucose uptake will increase from 0.3 mmol/min at rest to 8 mmol/min at maximal exercise. This increase in plasma glucose uptake results from an increase in the number of active muscle fibers, a greater demand for glucose by the active muscle fibers, or a combination of both. Plasma glucose utilization also increases with an increase in exercise duration. While performing submaximal cycling, blood glucose utilization will double from minutes 10 to 40. This corresponds with a progressive decrease in muscle glycogen levels (Coggan, 1991).

Although plasma glucose utilization increases proportionately with exercise intensity and duration, training will cause a decrease in glucose oxidation. Coggan et al. (1990) trained seven men for 12 weeks. All subjects performed a two hour cycle ride at 60% VO_2 max before and after training. The authors found that glucose turnover decreased 29% and glucose oxidation fell 33% after training. The R value

decreased from 0.89 in the untrained state to 0.85 in the trained state. Fat oxidation increased from 36.8% to 47.4% of total energy expended after training. The authors concluded that the decrease in glucose uptake was due to the "glucose-fatty acid" cycle. As one becomes trained, fat mobilization increases. This increase exposure to free fatty acids (FFA) causes citrate, which is an intermediary of the Krebs cycle, to accumulate within the muscle causing phosphofructokinase (PFK) to become inhibited therefore decreasing glucose utilization (Coggan et al., 1990).

Both FFA and carbohydrate availability will influence carbohydrate utilization during exercise. Maughan et al. (1978) performed a study in which subjects exercised for one hour at 50% VO_2 max after consuming a low- or high-carbohydrate diet for three days prior to exercise. Before the low-carbohydrate diet, each subject pedaled at 75% VO_2 max until exhaustion. The authors assumed that riding to exhaustion would deplete muscle glycogen stores. The carbohydrate contribution to total energy expenditure following the low- and high-carbohydrate diet was 35.7% and 70.9%, respectively. The R value was significantly lower throughout the low-carbohydrate diet exercise bout when compared to the high-carbohydrate diet exercise bout ($p < 0.01$). Ten minutes into the exercise session, plasma FFA was significantly higher after the low-carbohydrate diet and continued to rise in the post-exercise period. The authors suggest that the rate of glycogen utilization is controlled by availability. Because muscle glycogen was decreased with the low-carbohydrate diet, fat was oxidized at a faster rate and became the dominate fuel source.

Carbohydrate utilization during exercise is dependent upon several factors such as exercise intensity and duration, training status, diet composition, and muscle glycogen availability. These factors also influence fat utilization.

Fat

Fat utilization during exercise increases with exercise duration. Powers et al. (1980) found that after ten minutes of exercise at 65% VO_2 max, fat and carbohydrate metabolism make up approximately 67% and 33% of total energy expended, respectively. However, after 90 minutes of exercise, carbohydrate metabolism decreased to 19% of total energy expended and fat metabolism rose to 81% of the total energy expended. Bielinski et al. (1985) also found fat metabolism increased with as exercise duration. Subjects exercised at 50% VO_2 max for three hours. During the exercise bout, the R value was significantly lower at the end of the exercise compared to the onset of exercise (0.913 vs. 0.869, respectively).

Triglycerides are the main source of fat within the body. Lipolysis is the process in which triglycerides are broken down into FFA and glycerol. Once broken down, FFA can be converted into acetyl-CoA and enter the Krebs cycle to produce energy. Lipolysis is controlled by a enzyme called hormone sensitive lipase. Hormone sensitive lipase is usually inactive unless stimulated by catecholamines or glucagon. Factors which inhibit the utilization of FFA include insulin and lactic acid (Tepperman, 1980).

Fat utilization during exercise has been shown to differ between trained and untrained individuals during exercise. As stated previously, Coggan (1990) showed

that fat utilization, at the same relative workload, was increased with training. Friedmann and Kindermann (1989) also showed that trained males and females release more glycerol during exercise and in the recovery period when compared to untrained subjects. This suggests the trained individuals were relying more on fat as a fuel source.

Klein et al. (1994) compared fat utilization between trained and untrained men during exercise at the same absolute workload. During the last 30 minutes of the running protocol (four hours at 20 ml/kg/min), they found the R value to be 0.79 and 0.83 in trained and untrained subjects, respectively. The average rate of fat oxidation during the exercise was 7.51 and 5.67 μmol/kg/min ($p<0.001$) in trained and untrained subjects, respectively. These authors attribute the greater fat oxidation in the trained subjects to an increase in oxidative enzymes and mitochondria, an increase oxidation of intramuscular trigycerides, and an increase in the muscle's ability to uptake plasma FFA. These authors also state that β-adrenergic stimulation is the most important mechanism for stimulating lipolysis during exercise. As one trains, there is an increase in the lipolytic response to catecholamines. In other words, the trained individual's adipose tissue becomes more sensitive to β-adrenergic stimulation, thereby, increasing lipolysis (Klein et al., 1994).

In addition to the work cited above (Klein et al., 1994), Hurley and colleagues (1986) also demonstrated that training enhances the use of intramusclar triglycerides. Nine male subjects were trained for 12 weeks using 6 five-minute bouts of cycling (2 minute rest periods) at 90% to 100% of VO_2 max and using 40 minutes

of running at 75% VO_2 max. The subjects trained 6 days per week using each exercise protocol 3 days per week. After training, β-hydroxyacyl-CoA dehydrogenase, which is a mitochondrial enzyme for fatty acid oxidation, had increased by 90% ($p< 0.01$), providing a greater capacity for FFA metabolism. The R value was significantly lower in the trained state during exercise (0.9 vs. 0.8; $p<0.05$). Muscle biopsies showed muscle glycogen was used 41% less and muscle triglyceride use was two times greater following training. Although plasma FFA and glycerol decreased in the trained state during exercise, the authors credit the increase in fat oxidation to an increase in the utilization of muscle triglyceride.

Romijn et al. (1993) also looked at fat oxidation and exercise intensity. Five trained cyclists rode the cycle ergometer for 120 minutes at 25% and 65% VO_2 max and at 85% VO_2 max for 30 minutes. They measured oxygen consumption as well as glycerol and FFA rates of appearance (Ra) and disappearance (Rd). At 25% VO_2 max, fat oxidation constituted approximately 90% of energy expended with FFA and muscle triglycerides contributing 80% and 10% of the calories, respectively. At 65% VO_2 max, only 60% of energy expended was due to fat metabolism. FFA and muscle triglyceride each made up approximately 30% of the energy expended. At 85% VO_2 max, 32% of the energy expenditure was due to fat metabolism. When comparing all three exercise intensities, the rate of total fat oxidation during exercise was highest at 65% VO_2 max (42.8 μmol/kg/min; $p<0.05$).

Romijn et al. (1993) reported that during the exercise bouts at 25% and 65% VO_2 max FFA Ra increased, whereas FFA Ra at 85% VO_2 max did not increase

above resting values. During recovery, FFA Ra increased after the 85% VO_2 max exercise bout only. The changes seen in FFA Ra after high-intensity exercise was attributed to changes in blood flow and a decrease in fat oxidation by the muscles. Bahr et al. (1991) reported that glycerol and FFA may stay elevated for 2.5 and 6 hours post-exercise, respectively. These authors state that this elevation may enhance lipid oxidation in the post-exercise period due to increased availability of FFA and the preferential use of carbohydrate for the restoration of muscle glycogen levels.

Protein

Protein as a fuel source during exercise does not make a large contribution to an individual's metabolic need. Protein utilization accounts for approximately 4% to 10% of energy expended during exercise (Brooks, 1987; Evans et al., 1983; Lemon and Nagle, 1981). Many researchers have stated that the utilization of protein is dependent upon the amount of carbohydrate present. When the muscles are carbohydrate depleted, protein can provide 10% of the total energy expended. When the muscles are carbohydrate loaded, protein provides approximately 4% of the total energy expended (Dohm, 1983; Lemon and Nagle, 1981).

During exercise bouts, amino acids are released from muscles to be used as gluconeogenic precursors by the liver. Alanine is one particular amino acid that is released by the working muscles. Alanine synthesis increases tremendously during exercise (Evans et al., 1983). This allows the liver to use alanine as a gluconeogenic precursor and restore hepatic glucose levels (Evans et al., 1983).

Leucine is an essential amino acid that can be oxidized and used as a fuel source. Many studies have stated that exercise training will increase the amount of leucine oxidation (Dohm, 1983; Lemon and Nagle, 1981; Brooks, 1987). Leucine oxidation takes place within the mitochondria of the muscles. As one trains, there is an increase in the number of mitochondria; therefore, a greater potential for leucine oxidation exists (Dohm, 1983; Lemon and Nagle, 1981).

As one exercises, protein synthesis decreases (Dohm, 1983; Evans et al., 1983). This decrease in protein synthesis is necessary to allow free amino acids to be used for oxidation and gluconeogenesis. The decline in protein synthesis is related to the intensity and duration of exercise. The higher the intensity and the longer the duration of exercise the greater is the decline in protein synthesis, therefore allowing a higher rate of amino acid oxidation (Dohm, 1983).

During exercise, protein metabolism does not make a large contribution to an individual's energy expenditure. Some amino acids are used as gluconeogenic precursors in the liver while others are oxidized within the exercising muscles (Evans et al., 1983; Dohm, 1983). Protein utilization is largely dependent upon the amount of carbohydrate available within the body. When muscles are carbohydrate depleted, protein contribution can provide approximately 10% of the energy expended during exercise. In contrast, protein metabolism under carbohydrate loaded conditions provides approximately 4% of energy expended during exercise (Dohm, 1983; Lemon and Nagle, 1981).

Oxygen Uptake and Substrate Utilization During Recovery From Exercise

Hewitt et al. (1986) had subjects perform exercise at high and low intensities (79% VO_2 max and 46% VO_2 max, respectively) and found that high-intensity exercise causes a greater increase in EPOC. After low-intensity exercise, the oxygen consumption values returned to baseline after 20 minutes of recovery, whereas the oxygen consumption after high-intensity exercise remained elevated for 60-70 minutes post-exercise. The authors state the increase in energy expenditure after exercise may contribute to fat loss during a training program if the exercise intensity is high enough.

Sedlock et al. (1989) also determined that exercise intensity, and not duration, was the significant factor related to EPOC. Subjects exercised at 70% and 50% VO_2 max until 300 kcal were expended. In a separate exercise bout, subjects exercised at 50% VO_2 max until 600 kcal were expended. After exercise, VO_2 was measured until it returned to baseline levels. The caloric expenditure in the recovery period was significantly higher after performing at 70% VO_2 max (29.4 kcals) than after either exercise bout at 50% VO_2 max (14.3 and 12.1 kcals for short and long duration, respectively).

Begley et al. (1991) examined the effects of exercising at various intensities and durations on recovery energy expenditure. Subjects ran for 20 and 40 minutes at 50% and 70% VO_2 max. Subsequently, recovery VO_2 was measured for 20 minutes. In recovery, there was no significant difference in the number of calories burned between durations, but there was a significant difference in the number of calories

expended between intensity levels. Approximately 11.3 kcal and 17.5 kcal were expended above pre-exercise values for the 20 minute recovery period at 50% and 70% of VO_2 max, respectively.

Additional evidence that exercise intensity is the primary factor associated with the magnitude of EPOC was provided by Gore and Whithers (1990). In this study, subjects performed 9 exercise trials which included running for 20, 50, and 80 minutes at intensities of 30%, 50%, and 70% VO_2 max. After an eight hour recovery period, there was not a significant difference in oxygen consumption values following exercise at 30% VO_2 max compared to the control values. However, VO_2 was significantly elevated above control values after exercise at 50% and 70% VO_2 max. Also at intensities of 50% and 70% VO_2 max, EPOC increased linearly with exercise duration. The authors stated that intensity accounted for 45.5% of the variance in EPOC, while duration only accounted for 8.9% of the variance. When comparing mean values of VO_2 following exercise at 70% VO_2 max to the control values, it was determined that metabolism had increased 11.4% in the recovery period.

Although it appears that exercise intensity affects the magnitude of EPOC, the reason EPOC exists is complex. EPOC may be due to factors which directly or indirectly affect mitochondrial oxygen consumption. Such factors include creatine phosphate (CP) and ADP replenishment, catecholamines, and temperature. CP and ADP resynthesis have been shown to be very similar in length to EPOC (Piiper and Spiller, 1970). However, Brooks et al. (1971) estimated CP and ADP resynthesis

may only account for 10% of the total EPOC volume at maximal exercise; therefore, it is believed that additional factors must be related to EPOC.

Catecholamines have also been shown to influence EPOC. Gladden et al. (1982) infused norepinephrine into canine muscle. VO_2 increased 40% with the NE infusion compared to control groups. It is believed that catecholamines cause cell membranes to become more permeable to Na^+ and K^+ ions. This increase in the Na^+ /K^+ pump activity would cause an increase in ATP production and therefore oxygen consumption (Gaesser and Brooks, 1984).

Temperature is thought to be the most influential factor affecting EPOC (Gaesser and Brooks, 1984). Claremont et al. (1975) compared muscle, rectal, and skin temperatures in recovery after exercising at environmental temperatures at 0°C and 35°C. Eight subjects exercised on a cycle ergometer for 30 or 60 minutes at intensities ranging from 52% and 59% VO_2 max. The time and intensity of each subject was held constant between each trial. After exercising in the heat, the subjects had a higher body temperature and a significantly higher recovery VO_2. Oxygen consumption during recovery was 866 ml greater after exercising in the heat ($p<0.025$).

In addition to the energy expended during recovery, it is also important to consider the substrates utilized during this period. In a review by Van Zant (1992), he stated that energy expenditure following exercise depended upon exercise intensity and duration. The higher the intensity (>70% VO_2 max) and the longer the duration (>60 min), the more muscle glycogen would be depleted. This depletion causes an

increase in fat oxidation during the post-exercise period, reflected by a significant reduction in the R value.

Bielinski et al. (1985) compared exercising on a treadmill at 50% VO_2 max for 3 hours to a sedentary control day and found a 9% increase in energy expenditure 4.5 hours after exercise. Even the morning after exercise, energy expenditure was elevated by 4.7% compared to the control day. The R value, 18 hours post-exercise, was significantly lower after exercise compared to the control day. The authors concluded that lipid oxidation was increased up to 18 hours post-exercise and that approximately 27 grams of "extra" fat was used during the post-exercise period

Maehlum et al. (1986) performed a study which examined 24 hour energy expenditure after high-intensity exercise. The eight subjects were required to cycle at 70% VO_2 max for 90 minutes. Oxygen consumption was monitored continuously for the first hour post-exercise and then hourly for the following 11 hours. A final measurement was taken 24 hours post-exercise. This study showed there was a significant difference in oxygen consumption 12 hours post-exercise when comparing the exercise day to the control day (211 L vs 185 L; $p < 0.001$). At 24 hours post-exercise, there again was a significant difference between the exercise and control day ($p<0.05$). The authors also reported a significantly lower R value after exercise compared to the control day during the first nine hours of recovery (with the exception of hours five and seven) and at 12 and 24 hours post-exercise.

Treuth et al. (1996) also examined 24 hour energy expenditure following low- and high-intensity exercise. This study involved eight females who cycled at

50% VO_2 max for 60 minutes and at 100% VO_2 max for two minutes with two minute recovery periods for a total of 30 minutes of exercise. The energy used during the exercise bouts was included in the total 24-hour energy expenditure. The authors found a 699 kJ/day significant increase in energy expenditure following high-intensity exercise compared to the low-intensity exercise. Although exercise R values were lower during low-intensity exercise, the average 24 hour R values were not different between exercise bouts. The authors speculate that the similarity in average 24 hour R values was due to greater lipid oxidation during recovery from high-intensity exercise.

Broeder et al. (1991) had subjects perform treadmill exercise at 30% and 60% VO_2 max until 720 kcals were expended. VO_2 was measured for three hours post-exercise. Throughout the entire three-hour recovery period, oxygen consumption following exercise at 60% VO_2 max stayed significantly higher than pre-exercise VO_2 values, whereas exercise at 30% VO_2 max did not produce a significant difference in oxygen consumption compared to pre-exercise VO_2 values. When comparing R values after 30% and 60% VO_2 max exercise (0.78 and 0.73, respectively) to pre-exercise R values (0.81 and 0.79, respectively), both exercise intensities produced significantly lower R values in the recovery period.

Treadway and Young (1990) had five subjects perform cycling exercise for 45 minutes at 34%, 54%, and 75% VO_2 max. Recovery VO_2 was measured until pre-exercise VO_2 values had been achieved. There was a significant decrease in the R

value at 54% and 75% VO_2 max compared to the control day (0.73 for both exercise intensities vs. 0.82 for the control; $p<0.01$).

Muscle glycogen depletion may cause an increase reliance on fat and protein in the recovery period. Alanine is one of the major precursors for gluconeogenesis. During recovery from exhaustive exercise, alanine may help restore muscle glycogen levels, especially if carbohydrate is not available (Brooks, 1987). Gaesser and Brooks (1980) exercised rats to exhaustion and then monitored blood glucose and glycogen levels for four hours post-exercise. During the four-hour recovery, the rats were not given any food. The authors found heart glycogen to be supercompensated above pre-exercise values, blood glucose increased to pre-exercise levels, muscle glycogen had slightly increased from exhaustion levels, yet liver glycogen did not increase. The authors believe that in conjunction with Form I glycogen synthase, precursors for gluconeogenesis (amino acids, glycerol, etc.) may increase the muscle's ability to restore muscle glycogen levels when carbohydrate intake is limited.

Although the factors responsible for EPOC are difficult to quantify, it appears that the magnitude of EPOC is related primarily to the intensity of the exercise performed. Substrate utilization is also influenced by exercise intensity. The amount of carbohydrate depleted during exercise affects which substrate will be used in the recovery period. A greater reliance on fat as a fuel source during recovery from exercise was particularly prominent when muscle glycogen was depleted during exercise.

Thermic Effect of Food

It has been shown that the ingestion of food increases oxygen consumption above baseline values (Bahr et al., 1987; Maehlum et al., 1986; Gore and Whithers, 1989). This phenomenon is known as the thermic effect of food (TEF). The R value after meal consumption reflects the composition of the diet consumed. If a high-fat diet is ingested, the R value will decrease from baseline values. In contrast, a high-carbohydrate diet will cause an increase in the R value when compared to baseline values (Satabin et al., 1987). Exercise prior to meal consumption will cause one to utilize more fat during the post-meal recovery period (Bahr et al.,1987; Bielinski et al., 1985).

Broeder et al. (1991) found VO_2 increased by 14.7% after subjects consumed 720 calories on a control day. On separate days, subjects performed treadmill exercise at 30% and 60% VO_2 max until 720 calories had been expended. The subjects were then refed 720 calories. After meal ingestion, oxygen consumption increased 21.7% and 22.2% for 30% and 60% VO_2 max trials, respectively. Exercise prior to feeding significantly lowered the R values and increased fat utilization compared to the control day. The authors attribute this shift in metabolism after exercise to muscle glycogen resynthesis.

Treadway and Young (1990) also observed TEF after various exercise intensities. Subjects performed exercise at 34%, 54%, and 75% VO_2 max for 45 minutes each. After subjects recovered to pre-exercise VO_2 values, they consumed 100 grams of carbohydrate and VO_2 was measured for 3 hours. VO_2 increased 9.9%

after consuming a meal on the control day (no exercise). This was not significantly different than after performing the low- (34% VO_2 max) and moderate-intensity (54% VO_2 max) exercise prior to consuming the meal (10.2% and 12.6%, respectively). The high-intensity exercise (75% VO_2 max) did elicit a significant increase in VO_2 (18%; $p<0.05$) as well as a significantly lower R value compared to the control day. There was no significant difference in post-meal R values between the control day and after exercise at 34% and 54% VO_2 max.

These studies (Broeder et al., 1991; Treadway and Young, 1990) show post-meal oxygen consumption will significantly increase after high-intensity exercise compared to a control day. Also, the R values after meal ingestion were significantly lower post-exercise when compared to the control day, therefore post-exercise fat utilization is greater.

Impact of Different Exercise Intensities on Weight Loss

Ballor et al. (1990) performed a study in which 27 obese female subjects were divided into a high (85% VO_2 max for 25 minutes) and low (51% VO_2 max for 50 minutes) intensity exercise groups. Caloric expenditure per session was not significantly different between groups. This study showed that the high-intensity and low-intensity groups reduced their body fat by 3.4% and 3.7%, respectively. The subjects were also on a 1200 calorie diet throughout the eight week training period.

Leutholtz et al. (1995) also investigated the influence of exercise intensity on body composition changes in obese subjects. Subjects were randomly assigned to exercise at 40% or 60% VO_2 max until 300 kcal had been expended. The subjects

were also on a severely restricted diet of 420 kcal/day. After 12 weeks of training, there was no significant difference between exercise groups in body weight and body fat percentage. The 40% and 60% VO_2 max exercise groups lost 15 kg and 15.7 kg of body weight and 8.3% and 9.6% body fat, respectively.

The fact subjects in these studies were on restricted calorie diets may cloud the ability to interpret the results. The exercise sessions only allowed the subjects to burn approximately 800-900 calories per week. This may not have been sufficient caloric expenditure to examine the effects of exercise on fat loss.

Tremblay et al. (1994) divided subjects into two groups which consisted of an endurance group and a high-intensity intermittent group. Training lasted for 20 weeks. The results showed that although the high-intensity group burned less calories per session than the endurance group (57.9 MJ and 120.4 MJ, respectively), the reduction in the sum of skinfolds was greater in the high-intensity exercise group. When comparing the two groups, the decrease in skinfolds showed the high-intensity group to have a nine-fold greater fat loss per calorie expended ($p< 0.01$). The authors attributed the greater fat loss to the high-intensity exercise. It should be noted that the authors did not control the subjects' food intake throughout the study and this may have contributed to the greater fat loss observed within the high-intensity group.

Gaesser and Rich (1984) performed a study in which subjects exercised 3 days a week for 18 weeks at 80-85% or 45% VO_2 max until 350 kcal had been expended. They found percent body fat was not significantly different between groups after

training; however, there was a significant decrease in percent body fat between pre- and post-training measures with both the high-and low-intensity bouts (18.0% and 19.0% vs. 15.9% and 17.2%, respectively).

The effect of exercise intensity on fat loss is still unclear. When comparing studies, factors such as subjects' body fat, diet restrictions, exercise intensity and duration, and total caloric expenditure need to be taken into consideration before conclusions can be drawn about the "best" type of exercise intensity for fat reduction.

Summary

Weight control and obesity are significant health problems in the United States (Kuczmarski et al., 1994). ACSM has recommended regular aerobic activity to help lose and maintain weight. The studies cited within this review of literature have suggested that fat utilization may increase in the recovery period after high-intensity exercise. The potentially greater glycogen depletion with high-intensity exercise causes a greater reliance on fat as an energy source during recovery. On the other hand, the percentage of calories from fat oxidation during exercise is greater with low-intensity exercise.

More research is needed to determine the exact changes in substrate metabolism during the post-exercise period. Many studies suggest that post-exercise fat utilization may increase with high intensity exercise, but few studies have actually measured this variable. If fat metabolism does in fact increase with exercise intensity

in conjunction with the increase that is seen in EPOC and TEF, then weight control guidelines may need to be altered to support high intensity exercise for weight loss.

CHAPTER 3

METHODS

Subjects

Ten males between the ages of 22 and 35 years volunteered as subjects for this study. Only healthy subjects who had performed aerobic exercise three times per week for at least 30 minutes each session for six months prior to testing were allowed to participate. An informed consent form (Appendix A), approved by the Institutional Review Boards at the University of Tennessee Medical Center and the University of Tennessee-Knoxville, was signed prior to testing. Also, a health and training questionnaire (Appendix B) was completed by each subject to ensure that they met the training criteria and that they were categorized as "Apparently Healthy" according to the American College of Sports Medicine guidelines (ACSM, 1995). All subjects completed a maximal exercise test followed by two submaximal bouts on subsequent days. All testing took place at the Pulmonary Function Laboratory at the University of Tennessee Medical Center.

Maximal Cycle Test

Before reporting to the laboratory, subjects had avoided exercise for at least 24 hours and had not consumed food 3 to 4 hours prior to testing. Subjects performed an incremental protocol on a SensorMedics electronically braked cycle ergometer in order to determine maximal oxygen consumption (VO_2 max). Each subject started at a work rate of 30 watts. Subjects maintained a pedal frequency

between 70 and 90 rpm. The work rate increased 30 watts every minute. The test was terminated when the intensity could not be maintained or at the subject's request. The subjects breathed through a rubber facemask and expired air was channeled to the SensorMedics 2900 Metabolic Cart for analysis of oxygen consumption and carbon dioxide production. A Polar Favor heart rate watch was used to record heart rate every stage throughout the test. The criteria used to signify that VO_2 max had been achieved were: a plateau of oxygen consumption values, a R value above 1.1, a score of 10 on Borg's revised RPE scale, and a heart rate within ± 10 beats of the age predicted heart rate. All subjects met at least two of the criteria listed above.

Submaximal Exercise Session

After determining maximal aerobic capacity, each subject performed two submaximal exercise bouts in random order on the SensorMedics cycle ergometer. These tests took place on different days and were separated by at least four days (not exceeding two weeks). Subjects reported to the lab at 7:00 a.m. for the submaximal tests. Subjects were asked to refrain from alcohol consumption for 24 hours and strenuous exercise 12 hours prior to exercise testing and to consume at least two meals since their last exercise session prior to testing. One test consisted of riding the ergometer at 33% of VO_2 max for 90 minutes. The other test lasted 45 minutes with the subject cycling at 66% of VO_2 max. The SensorMedics 2900 Metabolic Cart described above was used to measure VO_2 and VCO_2 during these tests and a Polar heart rate watch was used to measure heart rate.

Post-Exercise Recovery Period

After each exercise session, subjects continued to breathe through the rubber facemask for approximately 15 minutes to allow the measurement of VO_2 and VCO_2. After the 15 minute period, a five-minute transition period was used to obtain a urine collection, after which subjects were transferred underneath the SensorMedics plastic canopy (see below) and remained in the laboratory until six hours of post-exercise oxygen consumption had been collected. During this six-hour period, the subjects remained supine in a recliner and were allowed to watch television or read.

The hooded flow-through system of the SensorMedics 2900 Metabolic Cart consists of a hard plastic canopy used to cover the subject's head for collection of expired gases. The system was "sealed" by weighing down the soft plastic sides of the canopy. Room air was pulled through this canopy by the SensorMedics 2900 Metabolic Cart at a flow rate which maintains the fraction of carbon dioxide between 0.7% and 0.9%. SensorMedics software calculated VO_2, VCO_2, and R values based on the known flow rate and the measurement of oxygen and carbon dioxide fractions in expired air. See Calibrations for further discussion of the system.

Two hours after exercise ended, subjects were given approximately 15 minutes to consume a standard meal consisting of two peanut butter and jelly sandwiches, one apple, one banana, one Snackwell's cereal bar, and one cup of 2% milk. This meal contained approximately 960 calories with 66%, 11%, and 23% of the calories derived from carbohydrates, protein, and fat, respectively. After the meal, subjects returned to the plastic canopy for the remainder of the six hours of recovery.

RMR

Prior to one of the submaximal exercise bouts, RMR was measured on each subject. The subjects reported to the laboratory in the same condition as described in the submaximal exercise section, and the hooded flow-through system of the SensorMedics 2900 Metabolic Cart was used for analysis of oxygen consumption and carbon dioxide production. Subjects remained under the SensorMedics canopy in a reclined position for 45 minutes, but only the last 15 minutes was used to calculate RMR.

Urine Collection

In order to quantify the protein contribution to energy expenditure, urine collection took place during the recovery period of each submaximal exercise bout. Subjects voided prior to exercise, but this sample was not collected. Urine collections took place after exercise, prior to eating, and as needed during the recovery period. The samples were analyzed for urea nitrogen levels in order to quantify the protein contribution to energy expenditure (Sigma, 1991). A fan was placed in front of each subject during the exercise bouts to decrease the amount of urea nitrogen lost through sweat. Subjects were weighed before and after each test and water intake was measured in order to measure the amount of water lost through sweating.

One milliliter of acetic acid was added to each urine sample, and samples were kept on ice in an attempt to inhibit bacterial growth. At the end of the testing session, the urine samples were transported to the Exercise Physiology Laboratory at The University of Tennessee-Knoxville where the volume was measured and samples were

frozen. Urea nitrogen was measured using Sigma Diagnostics kit # 640. In the reaction utilized by this kit, urea is broken down by urease to ammonia and carbon dioxide. The chemical reagents alkaline hypochlorite and phenol react with the ammonia to form indophenol. Absorbance of indophenol, which is directly proportional to ammonia concentration, was measured with a Spectronic 21 spectrophotometer.

Dietary Records

Each subject kept a three-day diet record prior to each test. The foods were analyzed with the computer program Nutritionist IV version 3.5.2 to determine diet composition as well as total caloric intake prior to each test. The purpose was to verify that subjects consumed a similar diet prior to each submaximal test.

Calibrations

Before testing took place, the SensorMedics Metabolic Cart was calibrated to ensure accurate data collection. Oxygen consumption measured by the hooded flow-through system was compared with values obtained after capturing expired air in a Douglas bag. The gas sample collected in the Douglas bag was analyzed at the University of Tennessee Exercise Physiology Laboratory. The volume was measured using a Collins 120 Liter Tissot Spirometer. Oxygen and carbon dioxide fractions were measured using the Applied Electrochemistry Model S-3A Oxygen Analyzer and the Beckman LB-2 Carbon Dioxide Analyzer, respectively. The hooded flow through system calculated a VO_2 of 0.189 L/min whereas the Douglas bag procedure calculated a VO_2 of 0.192 L/min. Also, a methanol burn (see Appendix C) was

completed with the flow through system to measure the accuracy of the R value. A methanol burn should yield a R value of 0.67. The SensorMedics system reported a R value of 0.65 during this procedure.

Prior to every test, the SensorMedics 2900 Metabolic Cart was calibrated by gases of a known concentration, and the flow system was checked by a three liter syringe. In all tests lasting longer than 30 minutes, the gas calibrations were repeated every 30 minutes. The cycle ergometer was also calibrated prior to testing to ensure that the power output was accurately controlled.

Statistics

A two-way repeated measures ANOVA and contrast analysis was utilized to compare variables (VO_2 and R) over time and between treatments. Paired t-tests were used to evaluate differences in total calories expended, as well as fat, carbohydrate, and protein consumed for the exercise bouts. The significance level for all tests was established *a priori* at $p<0.05$.

CHAPTER 4

RESULTS

Subjects Characteristics

Ten male subjects volunteered to participate in this study. Mean (± SD) age, height, and weight were as follows: 26.9 ± 4.8 years, 181.1 ± 4.8 cm, and 75.7 ± 8.8 kg. Average VO_2 max and resting metabolic rate (RMR) were 51.2 ± 4.8 ml/kg/min and 234.4 ± 38.3 ml/min, respectively. During exercise at 33% and 66% VO_2 max, subjects lost an average of 0.68 and 0.73 kg, respectively. Subjects did not consume water during exercise. After exercise, body weight was recorded and subjects were given approximately 250 ml of water.

Total Caloric Expenditure and Substrate Utilization

When comparing total caloric expenditure during exercise and recovery combined, this study showed no significant difference between low- and high-intensity exercise (1056 ± 193 kcal and 1068 ± 168 kcal, respectively). Figure 1 illustrates the total grams of substrate oxidized throughout exercise and recovery. The total amount of carbohydrate oxidized during and after the high-intensity bout (188.8 ± 45.2g) was significantly ($p<0.05$) greater than that metabolized during the low-intensity exercise and recovery period (142.5 ± 28.5 g). Total fat utilization was significantly greater ($p<0.05$) in the low-intensity bout compared to the high-intensity bout (42.4 ± 13.6 g vs. 24.0 ± 12.2 g, respectively). Total protein utilization was

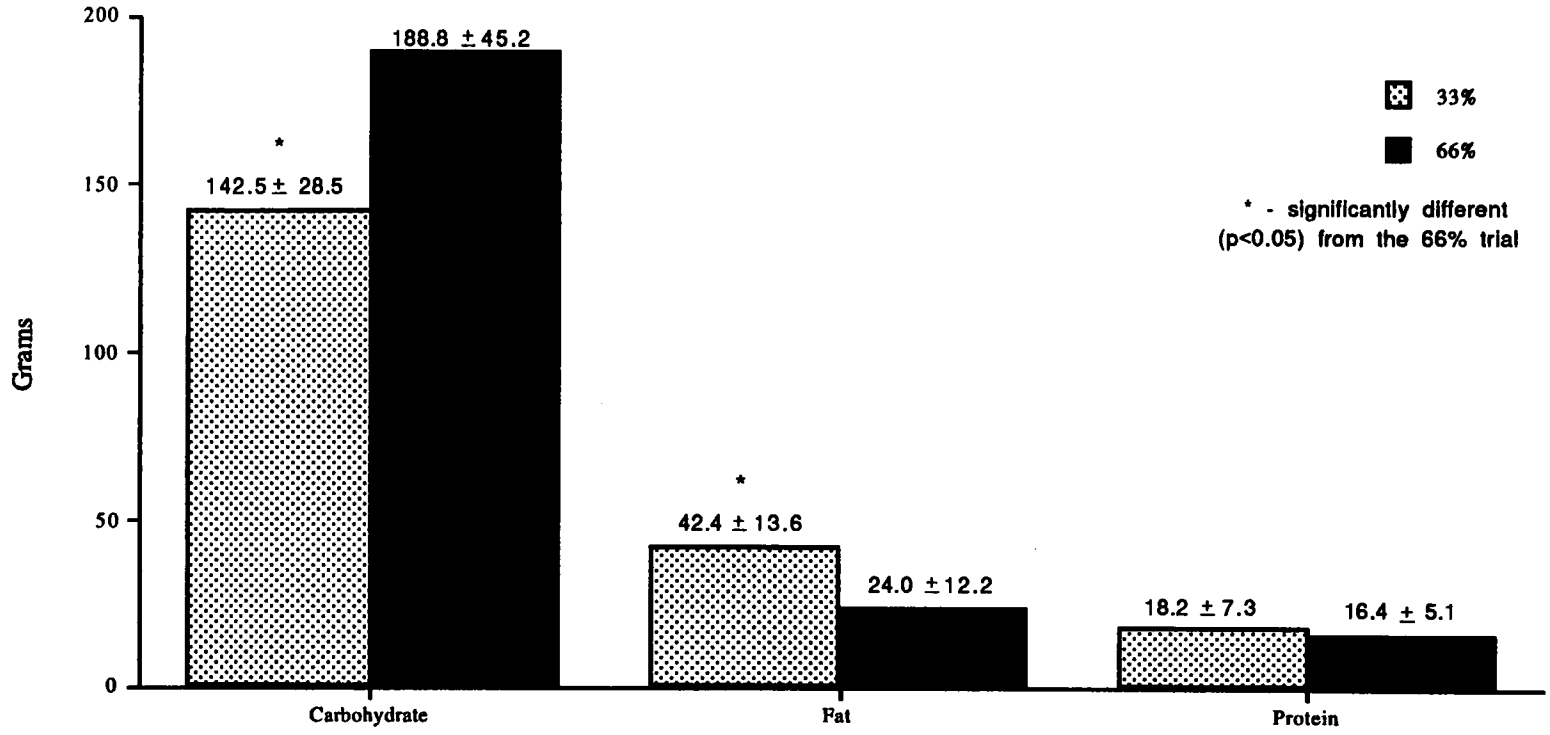


Figure 1: Total Grams of Substrate Oxidized throughout Exercise and Recovery

similar for the low- and high-intensity trials (18.2 ± 7.3 g and 16.4 ± 5.1 g , respectively).

Exercise Oxygen Consumption and R Values

As specified by the study design, the total oxygen consumption for the low- and high-intensity exercise (119.9 ± 29.8 L and 114.7 ± 23.9 L, respectively) was not significantly different ($p>0.05$). Average exercise intensity completed by each subject was 33.1% and 65.3% VO_2 max for the low- and high-intensity exercise bouts, respectively. As shown in Figure 2, the R value was significantly lower during low-intensity exercise compared to the high-intensity exercise (0.85 vs. 0.93, respectively).

The amount of substrate utilized in each exercise bout was significantly different. Carbohydrate utilization was significantly ($p<0.05$) greater during high-intensity exercise compared to low-intensity exercise (106.0 ± 27.8 g vs. 68.7 ± 20.0 g, respectively). In contrast, fat utilization was significantly greater ($p<0.05$) during the low-intensity exercise than the high-intensity bout (30.0 ± 11.0 g vs. 13.6 ± 6.6 g, respectively). Protein utilization was also significantly greater ($p<0.05$) during low-intensity exercise when compared to high-intensity exercise (4.9 ± 2.9 g vs. 1.6 ± 0.6 g, respectively); however, the rate of urinary nitrogen excretion (0.4 g/hr vs. 0.37 g/hr) was not significantly different between low- and high-intensity exercise bouts at any time point throughout exercise and recovery, respectively.

Post-Exercise Oxygen Consumption

There was no significant difference in the six hour recovery period R value or oxygen consumption for the two exercise bouts (Figure 2 and 3); however, when the

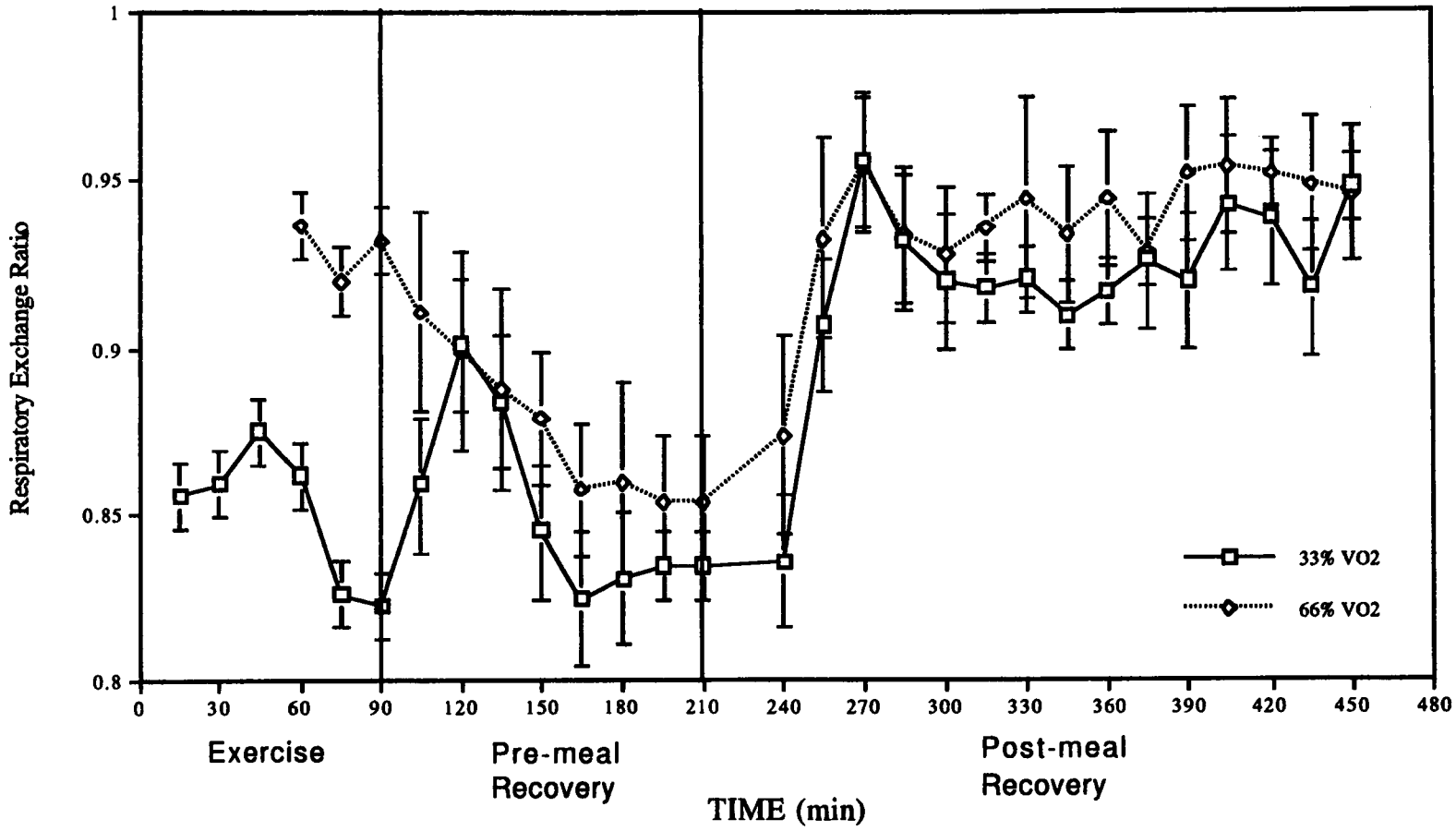


Figure 2: Respiratory Exchange Ratio during Exercise and Recovery at 33% and 66% VO2 Max

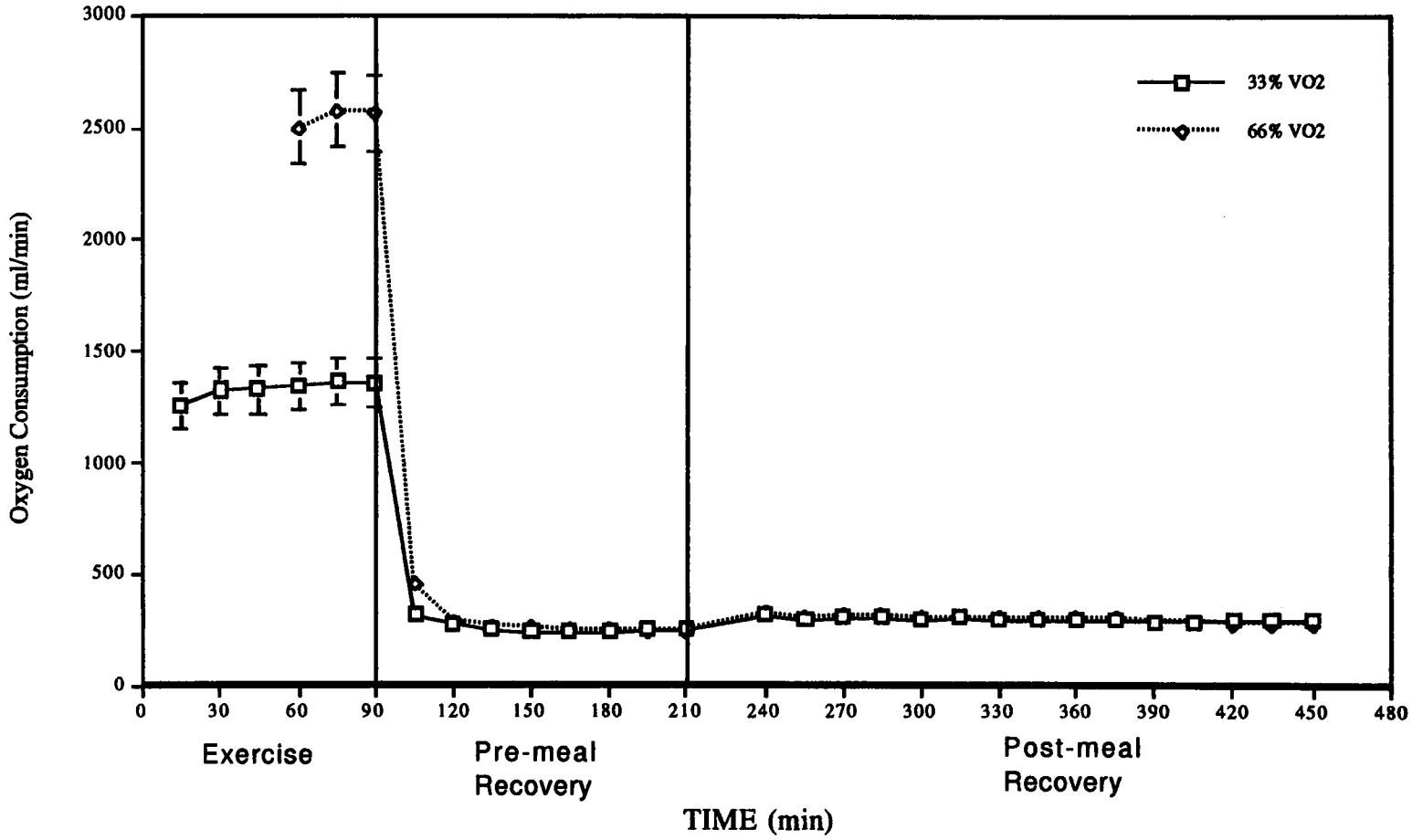


Figure 3: Oxygen Consumption during Exercise and Recovery at 33% and 66% VO2max

recovery period was divided into pre-meal and post-meal recovery periods, the average pre-meal oxygen consumption was significantly higher following high-intensity exercise compared to low-intensity exercise (288 ± 91.3 ml/min and 264 ± 48.6 ml/min, respectively; Figure 4). Total oxygen consumption throughout the entire two hour pre-meal recovery period averaged 34.6 L vs. 31.7 L for 66% and 33% VO_2 max, respectively. This produced a caloric expenditure of 169 kcals vs. 154 kcals during the pre-meal recovery period (66% VO_2 max vs. 33% VO_2 max, respectively). When compared to the expected resting energy expenditure during a two-hour period (140 kcals), the EPOC after high-intensity exercise accounted for an extra 29 kcals whereas EPOC after low-intensity exercise added an extra 14 kcals. Oxygen consumption remained significantly elevated above RMR until 60 minutes post-exercise for both exercise bouts. Pre-meal recovery R values were not significantly different for high- vs. low-intensity exercise (0.87 vs. 0.85, respectively). Substrate utilization during the pre-meal recovery period was not significantly different between exercise trials.

There was no significant difference in post-meal oxygen consumption between exercise trials (304.6 ± 35.2 ml/min vs. 301.5 ± 36.7 ml/min after low- and high-intensity exercise, respectively). After meal ingestion, oxygen consumption never returned to resting values for either trial. Post-meal recovery R values were not significantly different after low- or high-intensity exercise (0.92 vs. 0.94, respectively). Substrate utilization during the post-meal recovery period was not significantly different between exercise bouts.

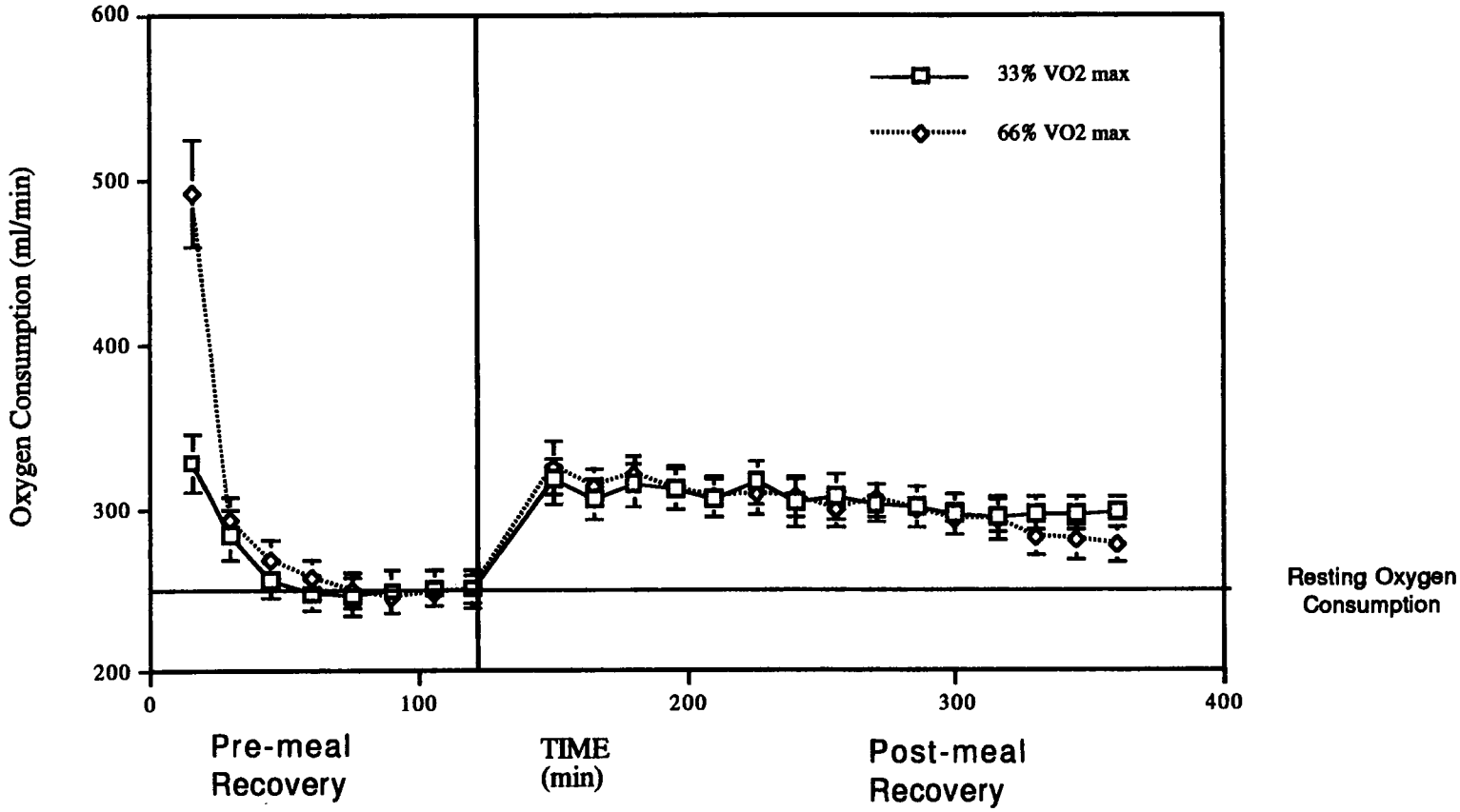


Figure 4: Comparison of Oxygen Consumption Values during Recovery at 33% and 66% VO2 Max

Figure 5 shows the percent contribution of each substrate at 33% and 66% VO_2 max during exercise, pre-meal recovery, and post-meal recovery. This figure shows significantly ($p<0.05$) more fat is utilized during 33% VO_2 max exercise than at 66% VO_2 max exercise (47.3% vs. 22.4% of total kcal, respectively). However, carbohydrate utilization was significantly greater throughout the 66% VO_2 max bout compared to the 33% VO_2 max trial (76.4% vs. 49.2% of total kcal, respectively). Protein utilization was greater during 33% VO_2 max exercise compared to 66% VO_2 max exercise (3.5% vs. 1.3% of total kcal, respectively), but total protein utilization for the combined exercise and recovery period was not significantly different. Substrate utilization during the pre- and post-meal recovery periods was similar for both exercise trials.

Dietary Analysis

Prior to each submaximal exercise bout, each subject recorded his diet for three days for dietary analysis. This was to document caloric intake and percentage of kcal from carbohydrate, fat, and protein prior to the submaximal exercise bouts. There was no significant difference in the number of calories consumed for three days (7036 ± 1871 kcal vs. 7962 ± 2144 kcal), percentage of carbohydrate (65 ± 17% vs. 61 ± 8%), fat (20 ± 10% vs. 24 ± 8%), and protein (15 ± 5% vs. 14 ± 3%) when comparing low- and high-intensity trials, respectively.

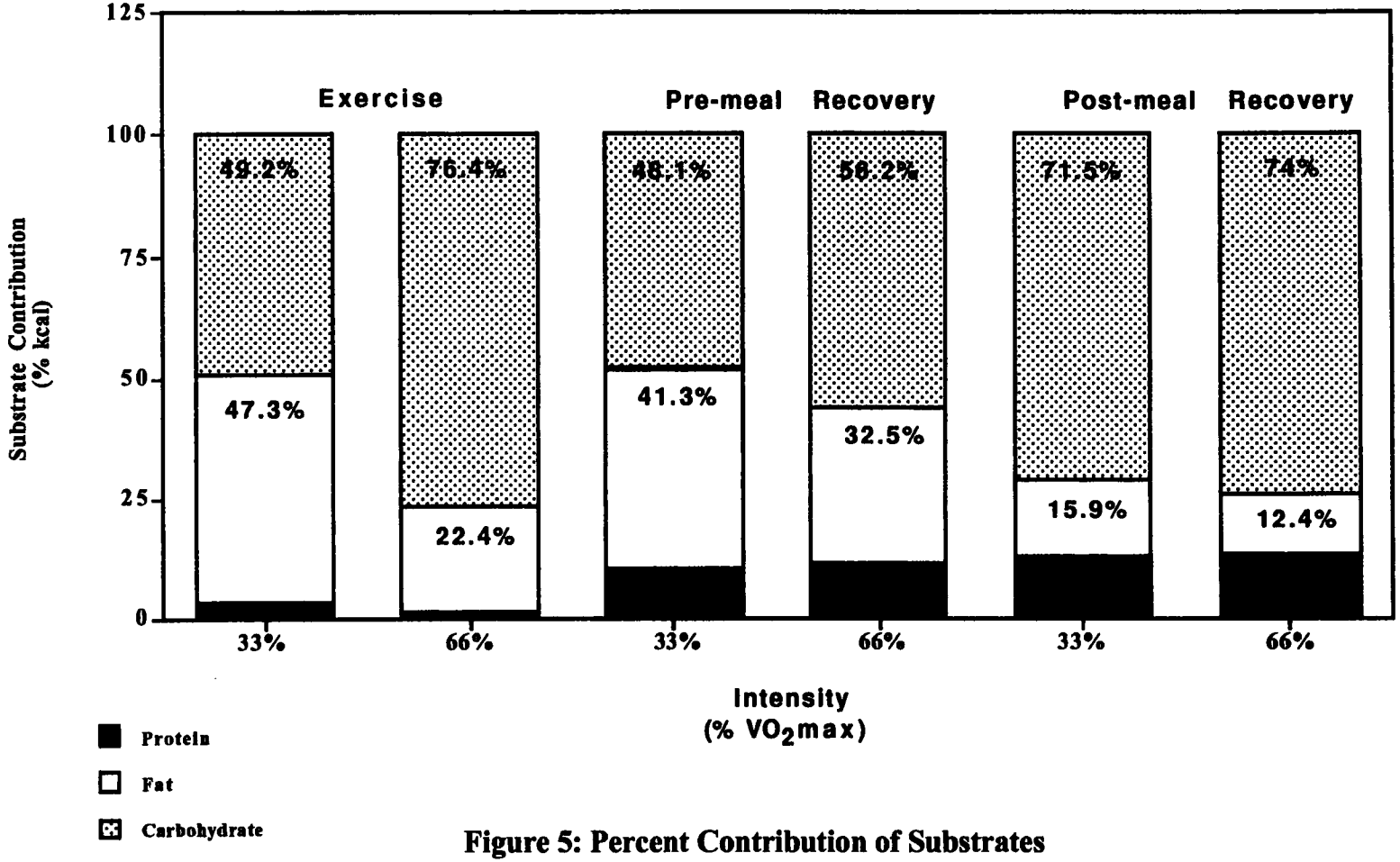


Figure 5: Percent Contribution of Substrates

CHAPTER 5

DISCUSSION

Total oxygen consumption during exercise at 33% and 66% VO_2 max was shown not to be significantly different (119.9 ± 29.8 L and 114.7 ± 23.9 L, respectively); however, substrate utilization was different between exercise bouts. Carbohydrate utilization was significantly greater during high-intensity exercise compared to low-intensity exercise (106.0 ± 27.8 g vs. 68.7 ± 20.0 g, respectively). Fat and protein utilization was significantly greater during low-intensity exercise compared to high-intensity exercise (30.0 ± 11.0 g vs. 13.6 ± 6.6 g and 4.9 ± 2.9 g vs. 1.6 ± 0.6 g, respectively). Additionally, an examination of the exercise period revealed that the low-intensity trial resulted in a greater reliance on fat compared to the high-intensity bout (47.3% vs. 22.4% of total kcal, respectively).

The present finding of greater reliance on fat during low-intensity exercise is consistent with previous reports (Romijn et al., 1993; Broeder et al., 1991; Treuth et al., 1996). In a study by Romijn et al. (1993), subjects exercised at 25% and 65% VO_2 max for 120 minutes and at 85% VO_2 max for 30 minutes. At 25% VO_2 max, fat oxidation constituted approximately 90% of the calories expended during exercise. Fat metabolism contributed approximately 60% and 32% of the calories expended during 65% and 85% VO_2 max exercise, respectively. Broeder et al. (1991) found that at the same caloric expenditure, exercise at 30% VO_2 max produced a

significantly lower R value compared to exercise at 60% VO_2 max (0.79 vs. 0.88, respectively). Treuth et al. (1996) performed a study in which subjects exercised at 50% VO_2 max for 60 minutes and two minute intervals of exercise at 100% VO_2 max followed by rest intervals for a total exercise time of 30 minutes. Although caloric expenditure was different between exercise bouts, the R value was significantly lower during the low-intensity trial compared to the high-intensity trial (0.85 vs. 0.93, respectively). The lower R value during low-intensity exercise seen in these studies indicates a greater utilization of fat when compared to high-intensity exercise.

The present study showed similar substrate utilization in the recovery period for both exercise trials. Several researchers have reported an increased reliance on fat after high-intensity exercise due to muscle glycogen depletion (Romijn et al., 1993; Maehlum et al., 1986; Bahr et al., 1991); however, these studies were not equal in terms of exercise energy expenditure. In most of the studies in which an increase reliance on fat was observed during the post-exercise period, the exercise intensity was >70% VO_2 max or the exercise duration was substantially longer than in the present study perhaps causing a greater deficit in muscle glycogen (Treadway and Young, 1990; Bielinski et al., 1985).

However, Quinn et al. (1994) found similar R values during a three hour recovery period from exercise at 70% VO_2 max for durations of 20, 40, and 60 minutes. Treuth et al. (1996) had subjects exercise at 50% VO_2 max for 60 minutes and two minute intervals at 100% VO_2 max for a total exercise time of 30 minutes. During the 12 hour rest period, sleep, and at the end of the 24 hour recovery period,

the authors found no significant difference in substrate utilization between exercise trials. Perhaps exercising at a constant exercise intensity or at similar caloric expenditures does not cause a large difference in muscle glycogen depleted between exercise bouts, therefore fat utilization is not different.

Most of the previous studies examining exercise and recovery substrate utilization failed to account for protein oxidation. In the present study, the contribution of protein to total energy expenditure during the combined exercise and recovery period was not significantly different (18.2 ± 7.3 g vs. 16.4 ± 5.1 g) for low- and high-intensity bouts, respectively. The rate of urinary nitrogen excretion was 0.4 and 0.37 g/hr for low- and high-intensity bouts, respectively. These values are consistent with the previous reports of urinary nitrogen excretion rate of approximately 0.5 g/hr. The greater protein utilization during the low-intensity bout can be explained by that bout's longer duration.

Carbohydrate, fat, and protein utilization are important, but separate, components in maintaining energy balance. Carbohydrate and protein balance are precisely regulated within the body whereas fat balance is not. Nutrient balance is maintained when the composition of the food oxidized is closely related to the diet composition consumed. In order to maintain energy balance, the food quotient (FQ) must equal the mean respiratory quotient (RQ). When this ratio is greater than 1.0, fat accumulation is indicated. Several studies have shown that de novo lipogenesis is a minor pathway in humans, therefore carbohydrate ingested is either oxidized or stored as muscle glycogen. In contrast, fat intake does not influence fat oxidation,

therefore, when individuals take in more fat than what is oxidized by the body, a positive fat balance exists and weight is gained. In order to lose fat, one must expend more fat calories than are consumed (Jequier, 1993). Therefore, the combination of a low fat diet and exercise which utilizes primarily fat as a fuel source would be most beneficial for preventing fat gain and/or reducing body fat.

When comparing oxygen consumption after exercise at 33% and 66% VO_2 max, the present study found no significant difference between the exercise bouts throughout the entire six hour recovery period (278.4 ± 72.8 L vs. 283.2 ± 82.5 L, respectively). However, when the recovery period was divided into pre- and post-meal recovery, average pre-meal recovery VO_2 was significantly different between exercise trials (264 ml/min vs. 288 ml/min at 33% and 66% VO_2 max, respectively). These results show that during the 2 hour pre-meal recovery period, 15 more calories were expended in recovery from high-intensity compared to low-intensity exercise. There was no significant difference in oxygen consumption when comparing exercise trials in the post-meal recovery period.

Most researchers find post-exercise oxygen consumption to be significantly higher after high-intensity exercise compared to low-intensity exercise (Hewitt et al., 1985; Begley et al., 1991). The increase in EPOC has been attributed to increases in catecholamine levels and core temperature related to high-intensity exercise. Catecholamines have been shown to increase Na^+/K^+ pump activity which will elicit an increase in oxygen consumption (Gaesser and Brooks, 1984). An increase in core temperature decreases phosphorylative coupling efficiency which will cause an

increase in oxygen consumption in order to met the demands for ATP synthesis (Gaesser and Brooks, 1984).

Sedlock et al. (1989) also examined caloric expenditure in the post-exercise period. Subjects performed cycling exercise at 50% and 70% VO_2 max until 300 kcal had been expended. The subjects then stayed in recovery until oxygen consumption had returned to baseline values (approximately 30 minutes for both exercise trials). Consistent with the present study, they found high-intensity exercise expended more calories in the recovery period when compared to low-intensity exercise (29.4 ± 8.4 kcal vs. 14.3 ± 6.4 kcal, respectively). Likewise, Broeder et al. (1991) had subjects perform treadmill exercise at 30% and 60% VO_2 max for equivalent energy expenditures. During a three hour recovery period, oxygen consumption was significantly higher after 60% VO_2 max when compared to RMR (250 ml/min vs. 237 ml/min, respectively). There was no significant difference in oxygen consumption during recovery from 30% VO_2 max exercise and RMR. No comparisons were made between VO_2 and R values during exercise at 30% and 60% VO_2 max.

In contrast to the studies mentioned above (Sedlock et al.,1989; Broeder et al., 1991), Kaminsky et al. (1987) found no significant difference in post-exercise oxygen consumption when subjects exercised at 35% VO_2 max for 60 minutes (297 ml/min) or 70% VO_2 max for 30 minutes (292 ml/min). VO_2 returned to baseline levels 10 and 15 minutes after exercise at 70% and 35% VO_2 max, respectively. Chad and Wenger (1985) found post-exercise oxygen consumption to be significantly higher after low-intensity exercise compared to high-intensity exercise. These authors

had subjects perform exercise at 50% and 70% VO_2 max for similar energy expenditures. The subjects remained in recovery until baseline oxygen consumption values had been reached. The authors determined that recovery oxygen consumption was 1.6 times greater after 50% VO_2 max exercise when compared to 70% VO_2 max exercise.

The differences seen in the studies dealing with the magnitude of EPOC may reflect the methodology of the studies. Kaminsky et al. (1987) found no difference in post-exercise oxygen consumption between exercise intensities. This may have resulted because subjects did not perform both exercise trials. Although both groups were not significantly different in maximum aerobic capacity, intra-individual differences in VO_2 between exercise bouts were not investigated. Chad and Wenger (1985) found low-intensity exercise produced a significant increase in VO_2 compared to high-intensity exercise and the authors speculated this may have been due to differences in body temperature. Previous studies (Hagberg et al., 1980) determined core temperature will significantly increase with a longer exercise duration (20 min vs. 5 min) at exercise intensities between 50%-80% VO_2 max. The effect of temperature on metabolism alone accounts for 60-70% of the slow component of recovery oxygen consumption. Also, Chad and Wenger (1985) gave each subject the option of covering up during the recovery period. This could have altered the core body temperature over time and subsequently impacted EPOC.

In the present study, VO_2 in recovery was elevated above RMR until 60 minutes post-exercise for both submaximal trials. Sedlock et al. (1991) performed a

study in which subjects were to exercise at 40% and 60% VO_2 max until 850 kJ were expended. These authors also found EPOC duration (27 min vs. 18 min) was not significantly different between exercise bouts (40% and 60% VO_2 max, respectively). In contrast, Treadway and Young (1990) exercised subjects at 34%, 54% and 75% VO_2 max for 45 minutes. They found EPOC duration increased as exercise intensity increased (28 min vs. 68 min vs. 85 min, respectively). Bahr et al (1987) found after exercising subjects at 70% VO_2 max for durations of 20, 40, and 80 minutes, VO_2 stayed significantly elevated above control values 12 hours post-exercise with all exercise durations.

EPOC is a complex phenomenon in which a precise explanation of its causes has yet to be determined. EPOC has been shown to remain elevated for as little as 10 minutes (Kaminsky et al., 1987) and as long as 24 hours (Bielinski et al, 1985). When comparing studies, factors such as subject's state of training and exercise duration and intensity should be taken into consideration since these factors influence EPOC (Kaminsky et al., 1987). The present study indicates that, in the 2-hour post-exercise period, 15 more kcals were burned after high-intensity compared to low-intensity exercise. This difference was due to a greater elevation in VO_2 during the first 15 minutes following high-intensity exercise. When the entire recovery period (pre- and post-meal) was considered, no difference in energy expenditure was observed.

The present study showed oxygen consumption after meal ingestion was not significantly different between exercise bouts (304.6 ± 35.2 ml/min vs. 301.5 ± 36.7 ml/min at 33% and 66% VO_2 max exercise, respectively). The TEF kept VO_2

elevated above RMR throughout the entire 4 hour post-meal recovery period following each exercise trial. There was no significant difference in R values throughout the post-meal recovery period between exercise bouts (0.92 vs. 0.94 at 33% and 66% VO_2 max exercise, respectively). The elevation in R values compared to pre-meal values reflects the carbohydrate content of the ingested meal.

In support of the present study, Broeder et al (1991) had subjects perform exercise at 30% and 60% VO_2 max until 720 kcal had been expended. The subjects were then refed 720 kcals and remained in the laboratory for three hours. The authors found that oxygen consumption had increased 21.7% and 22.2% above RMR values throughout the recovery period (30% vs. 60% VO_2 max exercise, respectively).

Treadway and Young (1990) exercised subjects at 34%, 54%, and 75% VO_2 max for 45 minutes. After subjects had returned to baseline RMR values, each subject consumed 100 grams of carbohydrate. Post-meal recovery lasted for three hours. Unlike our study, these authors found that high-intensity exercise produced a significant increase in energy expenditure during the post-meal period (146 kJ) when compared to control (85 kJ) and low-intensity exercise (100 kJ). Moderate-intensity exercise (119 kJ) was not significantly different from any of the other exercise intensities or control value. The R value after high-intensity exercise was significantly lower in the post-meal recovery period when compared to the control day (0.79 vs. 0.86, respectively), indicating in an increased fat utilization after meal consumption.

In summary, this study showed that total caloric expenditure (exercise and recovery combined) was similar between the exercise trials. However, the total amount of substrate utilized was different between exercise bouts. High-intensity exercise resulted in a significant increase in the total amount of carbohydrate used compared to low-intensity exercise. Conversely, total fat utilization was significantly elevated at low-intensity exercise when compared to high-intensity exercise. Throughout the entire six hour recovery period, there was no significant difference in substrate utilization between exercise trials. The difference in total substrate utilization is due to the exercise bout itself. These results imply that for weight loss or weight management, low-intensity exercise is more beneficial for "fat burning" compared to high-intensity exercise at the same caloric expenditure; however, exercise duration must be substantially longer if low intensity is used.

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APPENDICES

APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

TITLE OF THE STUDY: Substrate Use During and Following High and Low Intensity Exercise: Implications for Weight Control.

PURPOSE:

You are invited to participate in a study, the purpose of which is to examine what types of food are burned during and after two different exercise intensities.

PROCEDURES:

If you choose to participate in this study, you will complete a health history and training questionnaire prior to any testing. This is to ensure that the testing is safe for you as well as allow you to contribute information about your aerobic activity. Your participation in this project will involve 3 exercise tests performed on different days. The first test will measure your maximal exercise capacity. The two subsequent tests will require that you ride the cycle ergometer for an extended period and then remain in the laboratory for an additional 6 hours. The specifics of these tests are outlined below.

The first day of testing will consist of performing a cycle ergometer test to measure your maximal aerobic capacity. You will begin pedaling at a very light resistance (30 watts). After one minute the resistance will be increased slightly (30 watts). Each subsequent minute the resistance will be increased until you reach your maximal capacity and feel you can no longer continue. The test will be stopped at this point. During this test, you will be required to breathe through a rubber face mask so that expired gases may be analyzed. You will also be connected to an electrocardiograph which will monitor and record your heart rate. Electrodes (similar to sticky pieces of tape attached to wires) will be placed on your chest. Before this test you will be required to report to the lab in a rested condition not having consumed food for 3-4 hours prior to testing. This visit to the laboratory will take about 45 minutes.

On another day of testing, you will perform a low intensity exercise session that consists of riding the ergometer at 33% VO_2 max for 90 minutes. During the exercise session , you will wear a rubber face mask that will allow us to analyze your expired gases. After the exercise test, you will lie in bed for 6 hours so that we can determine what type of foods are important for energy during this period of time. While in bed, you will wear a mask made of see-through plastic which will surround your entire head. This mask provides a comfortable environment throughout the entire testing period. You will be given 1 meal during your 6 hour recovery period. Also, urine will be collected prior to exercise, after exercise, prior to eating, and as needed throughout the recovery period to examine how much protein is burned for energy. On another day of testing, you will perform a high intensity exercise session that will consist of riding the ergometer at 66% VO_2 max for 45 minutes. The same procedures used for the low intensity exercise session will be followed. Both of these tests will begin at 7:00 a.m. in the Pulmonary Function Laboratory at UT Medical Center. You should not eat on the morning of these tests. These visits to the laboratory will take about 8 hours each.

The testing will be supervised by students and faculty from the Exercise Science Unit of the University of Tennessee, Knoxville. The testing will take place in the Pulmonary Function Laboratory at UT Medical Center. For all tests, you will also

Initials _____

be asked to refrain from alcohol consumption for 24 hours and strenuous exercise 12 hours prior to testing. Also, you should have consumed at least 2 meals since your last exercise session. For 3 days prior to the exercise tests, you will be asked to record everything you eat and drink so that your diet can be analyzed for fat, carbohydrates, protein, and total calories.

BENEFITS OF PARTICIPATION

The findings of this study will provide vital information to exercise physiologists, as well as others, about what types of foods are burned during varying exercise intensities.
The benefits to you include knowing your maximal aerobic capacity and your "fat burning" abilities at various exercise intensities. This can be helpful for training purposes as well as knowing what type of intensity benefits you most for "fat burning".

RISK OF PARTICIPATION

The risks involved in the exercise tests in this study are those normally associated with any exercise: injury to muscles and/or joints, dizziness, headaches, irregular heart beats, and in rare cases, heart attack. Every effort will be made to minimize these risks. Personnel trained in CPR will be present at every session. Warm-up and cool-down exercises consisting of static stretches and light aerobic activity will be performed prior to and after each testing session to minimize the risks of sore or pulled muscles.

RIGHT TO ASK QUESTIONS AND/OR TO WITHDRAW FROM THIS INVESTIGATION

If you have questions or concerns at any time during the course or after the study, you may contact Karen Townsend, David Bassett Ph.D, or Dixie Thompson Ph.D. at (423) 974-5111. Karen's office number is 144, Dr. Bassett's office number is 346, and Dr. Thompson's office number is 347, all of which is located in the Health, Physical Education, and Recreation (HPER) building. Also, you may contact the Institutional Review Board (423) 544-9781 if you have any questions regarding your rights as a volunteer in this study. If at any time during this study events occur that will impact your ability to participate (i.e., you become injured or sick, etc.), you should inform Karen Townsend, Dr. Bassett, or Dr. Thompson immediately.

As a volunteer in this study, it is your right to withdraw from this investigation at any time. If you decide to withdraw from this study, you will in no way be penalized or suffer a loss of benefits.

PRIVACY OF RECORDS

Only you, Karen, Dr. Bassett, and Dr. Thompson will have access to your results. All data collected will be kept on file by Dr. Thompson and will be coded by subject number rather than name. The results of the study will be published; however, no publication will contain information which will allow you to be identified.

Initials_____

AUTHORIZATION

I understand that I am not waiving any legal rights or releasing the hospital or its agents from liability for negligence. I understand that in the event of physical injury resulting from the research procedures, The University of Tennessee does not have the funds budgeted for compensation either for last wages or for medical treatment. Therefore, the University does not provide for reimbursements for such injuries. I have read the description of the substrate use study and I have freely volunteered to participate in it. I have had possible side effects and adverse reactions explained to me and have had alternatives explained. I have had an opportunity to ask questions from Karen Townsend, Dr. Bassett, and Dr. Thompson (423) 974-5111 and the Institutional Review Board (423) 544-9781 and have received acceptable answers. I understand that I may withdraw from this study at any time and I will still receive standard treatment for my condition.

Participant's Signature	Date
Investigator	Date
Witness	Date

APPENDIX B

HEALTH AND TRAINING QUESTIONNAIRE

HEALTH HISTORY AND TRAINING QUESTIONNAIRE

Name:_____ Date:_____

Address:_____

Date of Birth:_____

Past History/Present Symptoms Review:
Have you ever had the following symptoms (check all that apply)?

	YES	NO	Don't Know
Free or easy bleeding	( )	( )	( )
Rheumatic fever	( )	( )	( )
Heart murmur	( )	( )	( )
High blood pressure	( )	( )	( )
Any heart problems	( )	( )	( )
Varicose veins	( )	( )	( )
Lung Disease	( )	( )	( )
Seizures	( )	( )	( )
Irregular heart beat	( )	( )	( )
Bronchitis	( )	( )	( )
Emphysema	( )	( )	( )
Diabetes	( )	( )	( )
Asthma	( )	( )	( )
Kidney Disease	( )	( )	( )
Liver Disease	( )	( )	( )
Hay Fever	( )	( )	( )
Orthopedic problems	( )	( )	( )
Hyper or Hypothyroidism	( )	( )	( )
AIDS	( )	( )	( )
Claustrophobia	( )	( )	( )

Present symptoms Review:
Have you recently had any of the following symptoms (check all that apply)?

Chest pain	( )	Frequent urination	( )
Shortness of breath	( )	Blood in urine	( )
Heart palpation	( )	Burning sensation	( )
Leg or ankle swelling	( )	Severe headache	( )
Coughing of blood	( )	Blurred vision	( )
Low blood sugar	( )	Difficulty walking	( )
Faint feeling or dizziness	( )	Weakness in arms	( )
Leg numbness	( )	Back pain	( )
Significant emotional problems	( )		

Do you smoke?_____ If yes, how many per day?_____
Are you taking medication?_____ If yes, please describe:_____
Do you have allergies?_____ If yes, please describe:_____
Have you ever had an allergic reaction or skin intolerance to latex, rubber, or plastic?_____ If yes, please describe:_____

Activity Level

How many days per week do you perform aerobic exercise?_____

In what type of aerobic exercise do you participate in?_____

How long do your exercise sessions last (minutes)?_____

How many consecutive months have you participated in this aerobic training?_____

Emergency Information

In case of an unexpected emergency, please provide us with a person with whom to contact.

Name:

Address:

Phone #:

Physician's Name and Office Location:

APPENDIX C

METHANOL BURN PROCEDURE

Methanol Burn Procedure

A methanol lantern was used to calibrate the SensorMedics 2900 Metabolic Cart. A hole was cut into the bottom of a 5 gallon plastic water jug. This allowed the entry of the methanol lantern. A hose was connected between the plastic jug and the metabolic cart. This allowed the flow through system of the metabolic cart to pull air through the apparatus and test the R value measurement. In order to keep the plastic jug from melting due to the heat from the flame of the methanol burn, a plastic bag full of ice was placed on the water jug.

The flow through system of the metabolic cart measured the amount of carbon dioxide produced by the methanol burn for approximately 10 minutes. The metabolic cart calculated a R value of 0.65. This compares favorably to the expected value of 0.67.

VITA

Karen Michelle Townsend was born in Knoxville, TN. She lived in Oliver Springs, TN until she graduated from Oliver Springs High School in June, 1991. She then attended East Tennessee Sate University in Johnson City, TN. Here, she graduated in May, 1995 with a Bachelor of Science degree in Exercise Science. In August of 1995, she entered the Exercise Physiology Department at the University of Tennessee, Knoxville where she received her Master of Science degree in May, 1997.