THE ELEVATION OF METABOLIC RATE AFTER COMBINED ARM-AND-LEG VERSUS LEG-ONLY EXERCISE

by

Stuart M. C. Lee

Thesis submitted to the faculty of

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN EDUCATION

in

Health and Physical Education

APPROVED BY:

Don R. Sebolt, Chairman

Reed H. Humphrey

Janet Walberg Rankin

Janet L. Walberg-Rankin

January, 1992
Blacksburg, Virginia

THE ELEVATION OF METABOLIC RATE AFTER COMBINED ARM-AND-LEG VERSUS LEG-ONLY EXERCISE

by

Stuart M. C. Lee
Dr. Don R. Sebolt (Chairman)
Division of Health and Physical Education

(ABSTRACT)

Previous investigations have shown that metabolic rate remains elevated for a period of time after the cessation of exercise. While other investigations have examined the effect of intensity and duration of prior exercise, the purpose of this study was to examine the effect of exercise mode and the employment of different muscle masses on the elevation of post-exercise metabolic rate (EPOC). Fifteen non-smoking, physically active females (21.1 ± 1.3 years; 21.4 ± 4.6 %BF) volunteered for this investigation. Each subject completed a graded maximal exercise test (GXT) on the Monark 880 cycle ergometer (Max HR=192.5 ± 2.3 bpm; Max VO_2=2.68 ± 0.11 l/min; Max RPE=19.5 ± 0.1) from which a heart rate corresponding to 70% VO_2max was chosen. Subjects then exercised on either a Monark 880 cycle ergometer (LE) or the Schwinn Airdyne (ALE) in random order for thirty minutes at the prescribed heart rate (HR). Exercise bouts were separated from each other and from the GXT by at least 48 hours. Workloads were monitored in five minute intervals and adjusted to maintain the appropriate heart rate. The mean exercise heart rates were 172.5 ± 2.8 bpm for the LE bout and 170.0 ± 2.8 bpm for the ALE bout, respectively. Two-way repeated measures ANOVA revealed no significant difference ($p > 0.05$) between exercise treatments in terms of HR or VO_2. Repeated measures trend analysis revealed no

significant difference in either EPOC or post-exercise heart rate between the two treatments across a one-hour seated recovery period. There was also no significant difference (p>0.05) in excess post-exercise caloric expenditure during the recovery period as a result of the different exercise treatments. Therefore, this suggests that neither exercise modality nor the distribution of work over a larger muscle mass had an effect on EPOC when exercise intensity and duration were held constant.

ACKNOWLEDGEMENTS

First, I would like to thank Karla Williams in the Research Division at the Schwinn Bicycle Company for her help in securing the Air-Dyne for use in this project, without whose support this investigation could not have been undertaken. Also, thank you to Mike and Chris Betz at East Coasters Bicycle Shop who assembled, and helped deliver, the Air-Dyne to the Human Performance Laboratory at Virginia Tech.

Foremost, I would like to thank my parents for teaching me the value of education and that the responsibility for my life is my own. I would like to thank my sister Jo-Anne who provided me with support and encouragement both as a sibling and as a formidable adversary in a competition for the best grades in the classes we shared. Thank you also to my brothers Andy and Derek who showed me that life was for both enjoyment and growth.

Next, I would like to thank all my professors in both undergraduate and graduate school at Virginia Tech who guided me and tempted me with knowledge. Their inspiration led me to find that there is always more worth learning, but that no one is going to teach it all to me.

Among these professors I was lucky enough to find three outstanding people who agreed to serve on my committee, Drs. Reed Humphrey, Don Sebolt, and Janet Walberg-Rankin. Dr. Humphrey gave me the responsibility to learn what I wanted and the freedom to do it. He started me on the road to the completion of this thesis, but was not able to see me all the way through as my chairman as he moved to Richmond to teach at the Medical College of Virginia.

Dr. Sebolt was brave enough to pick up where Dr. Humphrey left off as my committee chairman. But more than that, he challenged me personally, professionally, and physically. I will always remember the expression on his face as we passed in the rain during the 1990 Tour Da Valley.

And, Dr. Walberg-Rankin saw me all the way through from undergraduate school to the completion of my Masters. It was in my first exercise physiology class with her that I became sincerely committed to studying exercise and cardiac rehabilitation.

Also, I would like to thank Dr. Warren Franke, my cycling and weight lifting partner who, in all this, was my "secret" mentor. He.was patient enough to hear me grumble when I became disconcerted about graduate school and enthusiastic enough provide me with personal and educational guidance.

Next, I would to thank my daughter Anna for her patience and understanding as I completed this part of my education. It has been hard to spend so much time away from you, but I know that this will help me build a better world for both of us.

Also, I would like to thank Robert and Gwen Fraser for their financial and emotional support as I finished the writing of this document.

And the final thank you goes to Lesley Retallick who was my fellow investigator in data collection. But more importantly, she was my support in this undertaking and throughout graduate school. With her help, I have grown as a person and as a professional, and discovered that I am a worthwhile person.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

Introduction

Exercise has been considered to be an important adjunct to weight control programs both as a means to accelerate weight loss and as a means to maintain desirable fat levels. When contrasted to diet-only programs, the caloric expenditure of exercise has been suggested to promote a greater share of body fat loss with the reduction of body weight when used singularly or in combination with dietary restriction (Pavlou, 1985; Pavlou, 1989a; Hill, 1987; Phinney, 1988; Pavlou, 1989b). However, less is known about the contribution of an elevated post-exercise metabolic rate (EPOC) in these weight loss-exercise regimens. Although the number of kilocalories expended above resting values as a result of EPOC is small, estimated at 15% of energy expenditure during exercise (Bahr, 1987), the summation of these kilocalories with chronic exercise may have a significant impact on the total caloric expenditure and thus a greater body fat loss in a long-term program. EPOC may also be important in the maintenance of desirable fat levels among normal weight, physically active individuals.

Statement of the Problem

The majority of studies on post-exercise oxygen consumption have been conducted with cycle ergometry (Hagberg, 1980; Chad, 1985; Maehlum, 1986; Bahr, 1987; Chad, 1988) or running (Bielinski, 1985; Freedman-Akabas, 1985; Brehm, 1986). There has been no discernable research on the effects on the use of other exercise modalities and muscle groups on EPOC. Much work has been conducted on the oxygen kinetics of the arms and the combination of arms and legs (Sechler, 1974) but no information is presently available on EPOC for either exercise modality. It has been reported that the mean maximal oxygen consumption (VO_2) and maximal workload for the arms alone is approximately 70% of that obtained with the legs (Asmussen, 1958; Astrand, 1961; Stenberg, 1967). However, some studies have suggested that subjects can obtain higher maximal VO_2 values and higher workloads in combined arm-and-leg exercise (ALE) than in leg-only (LE) (Sechler, 1974). This is attributed to the involvement of a greater total muscle mass. Therefore, it may be possible to achieve and maintain higher workloads at similar relative exercise intensities with the combination of arms and legs versus legs alone. This may result in a greater metabolic disturbance which would enhance EPOC.

In addition to the limited use of exercise modalities in previous studies, these investigations also are limited in their subject selection. The majority of these EPOC studies have been conducted using a male-only subject population or males with a subset of females. Also, because of the inherently long periods of time necessary for EPOC data collection, the number of subjects in each previous investigation typically has been small.

Therefore, the purpose of this investigation was to expand current knowledge by comparing LE and ALE in a group of 15 college-age, normal weight females.

Research Hypotheses

In order to facilitate this investigation, the ensuing research hypotheses were formulated:

Ho: There was no difference between the excess post-exercise oxygen consumption (EPOC) for the two exercise modalities, leg-only and combined arm-and-leg ergometry, after a fixed duration of exercise of similar intensity as monitored by heart rate response.

Ho: There was no difference in mean whole body oxygen consumption during exercise between the two modalities of fixed duration and similar intensity as monitored by heart rate response.

Significance of the Study

This study was designed to compare the post-exercise responses of oxygen consumption and heart rate in two common exercise modalities, leg-only exercise versus combined arm-and-leg exercise. While some other studies have attempted more rigorous control of the relative contributions of the arms and legs during exercise, this investigation was structured to be as clinically relevant as possible. In everyday situations, persons do not exercise with external control over relative limb contributions to the total work performed, but rather, work within a range of comfort and ease. Although responses in the laboratory are important, it is important to determine the effects of exercise in the field.

As this investigation simulated typical exercise situations, its purpose was to examine the relative effects of the two different exercise modalities on exercise and post-exercise metabolism. In times such as these when efforts for health maintenance are increasingly limited due to increasing demands on lifestyles, it is important to optimize exercise sessions, choosing the exercise modality which provides the greatest overall benefits.

Finally, there is a large body of knowledge concerning the effects of exercise on males, but is somewhat limited for females. It is hoped that this study will broaden the scope of research in this area.

Delimitations

The following delimitations were imposed by the investigator:

1) Subjects were 15 non-smoking, non-obese (<30% body fat) female volunteers aged 18 to 24 and presently attending VPI & SU. Subjects were currently physically active, engaging in at least three exercise sessions per week over the previous six months.

2) Exercise was performed at a prescribed heart rate corresponding to 70% of the maximal oxygen consumption as determined by a graded exercise test.

3) The variables selected for evaluation were:
    a. Post-Exercise VO_2: Oxygen uptake measured for one hour of seated rest after each individual exercise treatment across specific time intervals.
    b. Excess Post-Exercise Oxygen Consumption (EPOC): Oxygen uptake in excess of resting oxygen uptake assessed for one

hour of seated rest after each individual exercise treatment across specific time intervals.

c. Post-Exercise Heart Rate: Heart rate measured for one hour of seated rest after each individual exercise treatment across specific time intervals.

d. Exercise VO_2: Oxygen uptake measured throughout each individual exercise treatment at five minute intervals.

e. Exercise Heart Rates: Heart rates measured throughout each individual exercise treatment at five minute intervals.

f. Mean Achieved Workload: Mean of achieved workload measured throughout each individual exercise treatment at five minute intervals.

Limitations

The following limitations affect the generalization of the findings:

1) The results of this investigation are limited to physically active, non-smoking, non-obese females aged 18 to 24.

2) Application of the results is limited to exercise prescription by heart rate based on a graded exercise test performed on a cycle ergometer.

3) The results of this study are applicable only to the exercise intensities prescribed and maintained by heart rate response.

4) The results are generalizable only to the exercise modalities performed.

Basic Assumptions

1) Subjects gave a maximal effort during the graded exercise test for the determination of functional capacity.
2) Subjects refrained from exercise for a period of at least 48 hours prior to each exercise session.
3) Subjects refrained from eating for a period of at least four hours prior to the exercise session.
4) Subjects adhered to the prescribed diet plan for the pre-exercise meal in order to control for the thermal cost of digestion.
5) Subjects minimized movement and conversation during the pre-exercise and post-exercise rest periods.
6) Subjects exercised at and maintained their relative prescribed exercise intensity level.
7) Subjects refrained from eating at least 12 hours prior to the hydrostatic weighing session.
8) Subjects exhaled maximally during the determination of underwater weight and residual volume.
9) The measurement of functional capacity, metabolic rate, heart rate, total body weight, lean body weight, and percent fat were accurate within the error of the various instruments.

Definitions and Symbols

Terms and symbols requiring clarification for use in this study are as follows:

Arm-and-Leg Exercise (ALE) Exercise performed using some combination of arms and legs. In this investigation, this refers specifically to the use of a Schwinn Air-Dyne.

Excess Post-Exercise Oxygen Consumption (EPOC) The elevation of metabolic rate above resting levels after exercise which decreases in a curvilinear fashion over time (Brooks & Fahey, 1985).

Excess Post-Exercise Caloric Consumption (EPCC) The additional caloric expenditure above resting resulting from previous exercise, and is directly related to and extimated by the measurement of Excess Post-Exercise Oxygen Consumption.

Heart Rate (HR) The number of cardiac cycles measured in one minute, usually expressed as beats per minute (bpm).

Lean Body Weight (LBW) The total weight of an individual minus the fat weight.

Leg-Only Exercise (LE) Exercise performed using the legs only. In this investigation, exercise on the Monark cycle ergometer.

Maximal Oxygen Uptake (VO_2max) A measure of functional capacity taken as the highest attained value achieved during the maximal graded exercise test expressed in L/min.

Oxygen Consumption or Uptake (VO_2) A measure of indirect calorimetry used to express metabolic rate in relation to the oxygen requirements to produce energy for mechanical work, as during exercise. This is expressed in absolute terms as liters per minute (L/min)..

Percent Fat (% fat) Percent of total body weight that is comprised of adipose tissue.

Post-Exercise Metabolic Rate (Post-RMR) The energy expenditure at rest, as determined by indirect calorimetry, measured during specific time intervals after the completion of an exercise session.

Pre-Exercise Metabolic Rate (Pre-RMR) The energy expenditure at rest, as determined by indirect calorimetry, after 15 minutes of rest expressed as an average of the last five minutes of rest and measured prior to each exercise session.

Respiratory Exchange Ratio (RER) The ratio of the volume of carbon dioxide expired to the volume of oxygen inspired. This value is though to be indicative of the substrates used in metabolism during rest and during steady-state exercise (McArdle et al., 1986).

Rotations per Minute (rpm) The number of rotations of the flywheel of an ergometer in one minute. This is used as a means to monitor workload when observed with respect to the resistance applied to the flywheel.

Summary

Obesity is considered to be a risk factor for a large number of health problems, including coronary heart disease and diabetes. Public health efforts emphasize risk factor reduction, which includes regular exercise for the control of excess body fat. The management of desirable fat levels should be a goal of every individual. However, due to the increasing demands placed on lifestyle and available free time, it is important to optimize the time spent during exercise to bring about change and maintain appropriate health parameters. Therefore, the development of an appropriate exercise prescription for health maintenance should include the choice of the most beneficial exercise modality.

While cardiovascular exercise is recommended for the attainment of these goals, leg specific exercise limits overall fitness development (Franklin, 1989). Many individuals view upper body exercise as a compliment to leg exercise. However, time is a limiting factor in including both modalities in a regular exercise regimen. Therefore, it is possible that a modality which combines the limbs for the duration of effort may provide equal or greater health benefits while enhancing performance for both the lower and upper body. It is important to carefully assess the caloric impact of existing exercise modalities so that the consumer and health care practitioner can choose the appropriate goal-specific exercise modalities.

CHAPTER II

REVIEW OF LITERATURE

Phases of EPOC

It is commonly accepted that there are three components of EPOC (Mole, 1990). The first phase, complete within the first two minutes of exercise recovery, is manifested as a sharp decline from exercising metabolic levels and is known as the "fast phase" (Mole, 1990). The magnitude of this phase seems to be dependent upon the intensity of exercise but independent of exercise duration (Hagberg, 1980). However, the rapidity of the decline and its duration appear to be independent of both factors (Mole, 1990).

The second phase of post-exercise recovery begins at approximately two minutes when the decline in VO_2 begins to decrease and plateau (Mole, 1990). This portion of recovery is known as the "slow phase" and appears to be highly dependent upon exercise intensity and duration (Hagberg, 1980; Chad, 1985), although duration seems to be the more important factor. Chad and Wenger (1985) reported that by increasing the duration of exercise at 70% VO_2max from 15 to 30 minutes, the slow component of EPOC was more than doubled. In addition, when subjects exercised at an intensity of 50% VO_2max for approximately 38 minutes so as to match the caloric cost of 30 minutes at 70% VO_2max, the resultant EPOC was more than 1.5 times greater than that for the 30-minute exercise session. The slow phase of EPOC seems to be influenced by the interaction of duration and intensity, and can last from as little as 10 minutes after short, low intensity exercise to as long as 90 minutes following more intense, longer duration exercise (Mole, 1990). The fast and slow phases are believed to include the oxidative resynthesis of CP and ATP used during the exercise bout (Mole, 1990) and the replenishment of oxygen stores in hemoglobin and myoglobin (Brehm & Gutin, 1986)

The final phase of post-exercise recovery has been termed the "ultra-slow phase." This phase seems to begin between 90 and 120 minutes, but its length also seems to be dependent upon the intensity and duration of exercise (Mole, 1990). A threshold of 70% of maximal oxygen consumption has been proposed for consistent metabolic elevations in the ultra-slow phase, and it appears that the duration of the ultra-slow phase is proportional to the duration of the exercise bout (Bahr, 1987, Sullivan, 1984). It seems possible that trained individuals may have a consistently high resting metabolic rate, as has been proposed in the literature, due to repeated bouts of exercise and their associated ultra-slow phase of recovery.

Some cross sectional studies suggest that trained individuals may have elevated RMR/fat free mass (FFM) ratios of 5-19% greater than sedentary persons (Mole, 1990). However, because of lack of controls for genetic differences, nutritional practices, physical activity patterns, and degree of adaptation to training, these results can not be attributed to exercise training. Further, training studies on this ratio have been inconsistent (Poehlman, 1986, Segal, 1989, Lawson, 1987, Treublay, 1986). These studies demonstrated an increase in RMR with training but did not show a concomitant increase in FFM, suggesting that an increase in RMR occurred per unit of FFM tissue.

Lactic Acid in EPOC

Early researchers investigating EPOC concluded that the elevation of metabolic rate was related to the reestablishment of the active cells in the body to pre-exercise conditions (Gaesser, 1984). Their investigations showed that the majority of the lactic acid which had accumulated during exercise was reconverted to glycogen, but a substantial amount, approximately 20%, was required for oxidation to H_2O and CO_2 to supply the energy necessary for glycogen repletion. And therefore, by their calculations, it was the combination of the energy required for glycogenolysis and the replenishment of ATP that was the cause of EPOC.

However, the time course of lactic acid uptake and removal does not seem to follow closely the pattern of EPOC. During steady state exercise, it has been noted that blood lactate levels may reach their peak early in the exercise bout and decline thereafter, approaching resting levels even before the bout is completed. Knuttgen (1970) reported that as the duration of exercise was increased, blood lactate levels at the termination of exercise were actually lower, but that the slow component of EPOC was enhanced. Also, in short duration, high intensity exercise, it has been observed that lactate levels do not reach their maximum until two minutes after the completion of effortwhich is after the time that VO_2 has already sharply declined (Brooks, 1984). This evidence suggests that lactic acid likely does not plays significant role in EPOC. Segal and Brooks (1979) confirmed this hypothesis when they observed that blood lactate levels had no effect on the slopes of the initial and slow exercise recovery curves.

Effect of Heat on EPOC

Subsequent investigations though have suggested that the basic concept of the cell's role in EPOC may have been correct. Many alterations in the body's homeostatic systems occur during exercise. These seem to continue in the post-exercise period until the resting state is e-established. Although the systemic clues of body stress, including elevated heart rate and blood pressure, remain elevated immediately after an exercise bout, a better explanation of EPOC might be viewed from events at the cellular level.

In terms of cell energetics, it is important to examine the possible effects of exercise on post-exercise energy production and utilization. In order for the normal cell processes to be functional and return the cell to its pre-exercise state, energy is needed to drive these metabolic reactions. While a small proportion of energy produced is the result of metabolic pathways active in the cytosol, the greatest proportion of cellular respiration occurs in the mitochondria.

During exercise, the major waste product of metabolic reactions is thermal energy (Brooks, 1984). Because no biologic reaction is 100 percent efficient, when a high energy compound is degraded to a lower energy compound some of the resultant energy is used to charge another reaction while some is lost as heat. In exercise, because the number of reactions in the cell is greatly accelerated to meet the metabolic demands placed upon it, the total amount of heat produced per unit time is greatly elevated. This heat is absorbed by surrounding tissues, including muscles, and stored there until it can be removed by other heat reservoirs, especially blood. However, while this heat is stored in the tissues it has a significant effect on the mitochondria.

Mitochondrial respiration becomes more inefficient due to an uncoupling oxidation and phosphorylation in the electron transport chain. As a result, cellular respiration must be increased to meet the demands of cellular metabolism (Brooks, 1971; Brooks, 1972). In the whole body system, elevated tissue temperatures resulting from this heat transfer after exercise in humans have been associated with EPOC (Claremont, 1975).

The decreased efficiency of the mitochondria as a result of heat is referred to as the Q10 effect. Several studies have attempted to examine the effect of heat on EPOC by measuring changes in core body temperature by rectal (Hagberg, 1980; Bahr, 1987; Maehlum, 1986) or tympanic temperatures (Chad, 1988). All of these studies found a relationship between elevated body temperatures and the magnitude of EPOC, and these both seem to be related to the duration of exercise rather than intensity. Estimated core temperatures returned to normal within 30 minutes after exercise (Maehlum, 1986; Bahr, 1987) which is in close association with the end of the slow phase of EPOC. Thereafter, the relationship between core temperature and EPOC is weak, and one author has suggested that there is no significant elevation of metabolism after this time (Freedman-Akabas, 1985). Hagberg et al. (1980) have suggested that approximately 70% of the slow component of EPOC can be accounted for by the Q10 effect.

Calcium Effects in EPOC

In addition to this heat-induced disturbance of cellular respiration by heat, cellular respiratory efficiency also seems to suffer as a result of increased intracellular calcium levels (Brooks, 1984). Calcium is integrally important in both cardiac and skeletal muscle contractions, and is released into the cell in high relative concentrations with each impulse to initiate shortening of the sarcomeres. In order for relaxation of muscle fibers to occur, intracellular calcium must be removed. Although the majority of the calcium is sequestered into the terminal cisternae of the sarcoplasmic reticulum, some is taken up in the mitochondria (Carafoli, 1971). Not only does this sequestering by the mitochondria require energy, but like heat, the presence of calcium in the mitochondria seems to decrease the efficiency of mitochondrial respiration. It may be that this interference with mitochondrial respiration extends into the post-exercise period since it would require some time for clearance (Brooks, 1984).

Elevated Norepinephrine in EPOC

The high levels of circulating norepinephrine after exercise may also affect EPOC (Chapler, 1980; Gladden, 1982). One of the effects of norepinephrine is to render cell membranes more permeable to sodium and potassium, two integral electrolytes in cellular homeostasis (Brooks, 1984). Therefore, as cells are less resistant to the passage of these electrolytes through their membranes, the sodium-potassium pump must work harder to maintain normal concentration gradients. As a result, more ATP, or energy, is necessary to meet these demands as the activity of the pump increases. More energy production through cellular respiration is then needed which may be reflected in EPOC.

Kjaer et al. (1989) demonstrated that plasma norepinephrine levels increased linearly with the duration of exercise and that the rate of secretion was dependent upon the intensity of exercise. There seemed to be a significant increase in the rise of plasma norepinephrine at intensities greater than 50-60% VO_2max. Hagberg et al. (1979) reported that after five minutes of exercise that the clearance of norepinephrine would not be complete by 19 to 25 minutes post-exercise. These observations are in agreement with those about EPOC in which 70% VO_2max seems to be the threshold intensity for EPOC, suggested by many authors (Bahr, 1987; Chad, 1985; Chad, 1985; Hagberg, 1980; Mole, 1991), and that EPOC seems to be complete by 30 minutes post-exercise (Freedman-Akabas, 1985). The source of the elevated levels of norepinephrine seems to be muscle tissues as they are stimulated by the sympathetic nervous system (Mole, 1990).

Effect of Substrates on EPOC

A final way that exercise may influence EPOC is through the substrates metabolized for energy production. During prolonged steady state exercise, the body typically relies upon the most efficient substrate for energy production and release, fatty acids. There are increases in lipid oxidation rate and plasma levels of free fatty acids and glycerol with prolonged exercise (Bielinski, 1985). In exercise, epinephrine levels in the blood stimulate the release of fatty acids from adipose tissue so that the plasma levels increase dramatically. In this way, working cells are provided with an extracellular energy source to meet the demands of exercise as well as to replenish depleted glycogen stores. The elevation of plasma free fatty acids present during exercise persists after exercise and may result in futile substrate cycling (Brooks, 1984) in which fatty acids are repeatedly broken down and rebuilt

(Bahr, 1987). While circulating plasma catecholamines influence substrate cycling, this effect may be further enhanced by increased body core temperatures (Bahr, 1988).

The increased reliance on fatty acids as a substrate for energy during EPOC has been suggested by a lower RER after exercise than before exercise (Bahr, 1987; Bielinski, 1985; Chad & Wenger, 1988). A lower resting ratio would imply a greater mobilization and oxidation of fats to meet the energy needs of the body's homeostatic mechanisms in the post-exercise period. Chad and Wenger (1988) have suggested that EPOC is more related to metabolic substrate utilization after exercise. They observed that a lower RER accounts for approximately 75% of the variance of EPOC while they reported that the Q10 effect accounted for only 41-56% of the variance.

Exercise Studies on EPOC

Early investigations of the effect of exercise on EPOC have been plagued by inconsistencies in exercise modality, intensity, duration, and procedures of measurement. Because little control was exercised in these studies, they are not considered in this review of relevant literature. What follows is a description of more closely controlled investigations since 1970. A summary of these studies and their findings can be found in Table 1.

In 1970, Knuttgen recruited 12 subjects to participate in a three-part investigation which examined several different aspects of EPOC. All subjects, seven males and five females, participated in this first portion of the experiment by completing 15-minute exercise bouts at intensities ranging from 45% to 98% VO_2max on a cycle ergometer. Knuttgen observed that there

Table 1 Summary of Previous Investigations

Investigation	Subjects	Treatment	Modality	Results of Investigation
Knuttgen 1970 Part A	7 males & 5 females	Intensities ranged from 45% to 95% VO2 max. Duration set at 15 minutes.	Cycle	Small increases in EPOC with increasing intesity at lower levels. Increase exponentially at greater than 66% VO2 max. Continues to increase exponentially as approach max. Both fast and slow increase but slow contributes more to total.
Knuttgen 1970 Part B	4 males & 3 females	60% VO2 max for 15, 35, & 55 minutes.	Cycle	Total debt greater with longer durations. Slow component solely responsible for increase. Significantly greater EPOC after longer durations than after 15 minute exercise but no significant difference between 35 & 55 minutes.
Knuttgen 1970 Part C	3 males & 2 females	Intensities ranged from 55% to 83% VO2 max for either 15 or 55 minutes of exercise.	Cycle	Significantly greater EPOC after 55 minutes than 15 minutes at all intensities. Magnitude of fast component lower after 55 minutes than 15 minutes. No consistent pattern between lactate levels and EPOC.
Hagberg et al. 1980	18 males	50,65, & 80% VO2max, 5 & 20 min	Cycling	Can effect fast component magnitude with intensity but not duration. Threshhold to effect slow component >65% VO2 max. Q10 effect accounts for 60-70% EPOC.
Chad et al. 1985 Part A	3 males & 3 females	70% VO2 max for 15 & 30 min	Cycling	Significant increase in EPOC with increase in duration.
Chad et al. 1985 Part B	6 males	70% VO2 max for 30 minutes; 50% VO2 max for equivalent energy expenditure	Cycling	EPOC greater at 50% for longer duration than at 70% for 30 minutes. Duration of exercise may be more important.
Bielinski et al. 1985	10 males	3 hours at 50% VO2 max	Treadmill walking with control	Significant increase in VO2 after exercise when compared with control condition. No significant difference after 8 hours. Increased utilization of fat after exercise.
Freedman-Akabas et al. 1985 Part A	10 males & 13 females	20 min at ventilatory threshhold	Treadmill walking with control	No significant difference from control condition after 40 min. No significant difference across fitness groups.

Table 1 (Continued)

Freedman-Akabas et al. 1985 Part B	4 males & 3 females	2 mph greater than ventilatory threshhold for 20 min. 40 min at ventilatory threshhold	Treadmill walking with control	No significant difference from control condition after 40 min in either exercise treatment.
Maehlum et al. 1986	4 males & 4 females	80 min of intermittent exercise at 70% VO2 max	Cycling with control	VO2 remained significantly elevated up to 12 hours post-exercise. No significant difference in rectal temperature after 30 minutes. Lower respiratory exchange ratio after exercise than before.
Brehm et al. 1986	4 male & 4 female runners; 4 male & 4 female sed.	Absolute intensities and set distances	Treadmill walking & running	No difference in recovery VO2 between trained and untrained subjects at low intensities. EPOC increases with intensity. Significant correlation between core temperature and EPOC.
Bahr et al. 1987	6 males	70 % VO2 max for 20, 40, & 80 min	Cycling	EPOC increased significantly with increases in duration. No significant elevation of VO2 after 12 hours. Estimated total EPOC at 15% of exercise energy expenditure. Significant difference in rectal temperature as duration increased, but no significant elevation after 30 min for all durations.
Chad et al. 1988	2 males & 3 females	70% VO2 max for 30, 45, & 60 min	Cycling	EPOC increased significantly with increasing exercise duration. High correlation between EPOC and core temperature (0.64-0.75) and between EPOC and respiartory exchange ratio (0.86-0.89)

were small increases in EPOC as the intensity of exercise increased at lower intensities, but EPOC was exponentially increased at intensities greater than two-thirds of functional capacity. Further, these exponential increases continued as the intensity approached maximum. The magnitude of both the fast and slow components increased with increasing intensity, but the largest contribution to total EPOC was made by the slow component.

Three females and four males completed the second section of this investigation by Knuttgen (1970) by exercising at 60% VO_2max on a cycle ergometer for periods of 15-, 35-, and 55-minutes. The total magnitude of EPOC was greater as the duration of effort increased. The slow component of EPOC was reported to be primarily responsible.for this increase as the fast component was not significantly affected by duration. A significantly greater EPOC was found after the longer durations of work than after the 15-minute exercise bout, but there was no statistically significant difference in EPOC between the 35- and 55-minute bouts.

The final portion of the study (Knuttgen, 1970) involved the remaining three males and two females. They exercised on a cycle ergometer at exercise intensities ranging from 55% to 83% VO_2max for time periods of 15 and 55 minutes. Again, investigators reported a significant increase in EPOC and the slow component across duration when intensity was held constant, and across intensity as duration was held constant. However, the magnitude of the fast component was significantly less after 55 minutes of exercise as compared to exercise at the same intensity for 15 minutes. Also, a consistent pattern between plasma lactate levels and EPOC was not observed.

From the summation of this investigation, several important factors contributing to EPOC can be ascertained. First, both increasing intensity and increasing duration have a positive effect on the slow component and total EPOC. The fast component may be negatively influenced by increasing durations, but due to its limited contribution to total EPOC is insignificant. Second, both intensity and duration appear to have thresholds of effect. Intensities greater than 66% VO_2max have a significantly greater impact on EPOC than lesser intensities, and durations greater than 30 minutes have no additional significant positive contribution to the total EPOC. Finally, there was no relationship between EPOC and plasma lactate levels, a theory which has been used in the past as a method of explanation.

In 1980, Hagberg et al. continued the investigation of EPOC when they exercised 18 male subjects at 50%, 65%, and 80% VO_2max on a cycle ergometer for periods of 5 and 20 minutes. These investigators observed a significant increase in the magnitude of the fast component of EPOC with increasing intensity but not duration. Presumably, the fast component related most directly to intensity since this has been proposed to be the time period when resynthesis of ATP and CP occurs which would more greatly depreciated by high intensity work. There was no effect of duration on the slow component observed at either 50% or 65% VO_2max, but the magnitude of EPOC was approximately five times greater after 20 minutes of exercise than after 5 minutes when subjects exercised at 80% VO_2max. From this, there appeared to be a threshold intensity and duration which the investigators explained by differences in core temperature resulting from the exercise bout. There was also a significant difference in core temperature across all durations when intensity was held constant, and across all intensities when duration was held constant. Therefore, there also would seem to be a threshold value of elevated core temperature which significantly effects EPOC. These investigators suggested that 60 to 70% of the variation in EPOC could be explained by variations in core temperature.

Chad et al. (1985) used a two-part study design to further elucidate the roles of duration and intensity of exercise in EPOC. The first portion of the study employed three males and three females who cycled at 70% VO_2max for periods of 15- and 30-minutes. As in previous investigations, the longer duration of exercise resulted in an enhanced magnitude of EPOC. The total post-exercise oxygen consumption for the 30-minute exercise session was approximately two fold greater than that after the 15-minute exercise bout.

In the second portion of the investigation (Chad et al., 1985), six males cycled for 30 minutes at 70% VO_2max and again at 50% VO_2max until the metabolic cost was equivalent to that of the 30-minute exercise bout. The resulting EPOC after the 50% VO_2max exercise was significantly greater than that of the exercise session at 70% VO_2max . These results contradict previous studies (Knuttgen, 1970; Hagberg, 1980) which suggested that 70% VO_2max represented a threshold value for a significant EPOC. Rather than a threshold value for intensity alone, there seems to be an interplay between intensity and duration which influence EPOC. Chad et al. (1985) suggested that previous studies had utilized intensities and durations that together were too low to yield any significant results. They suggested that this was probably due to core temperatures not rising to a sufficient level to elicit any changes in EPOC.

In 1985, Bielinski et al. reported on an investigation that also utilized lower intensities but for greater durations than any previous study. This study included 10 male subjects exercising for three hours at 50% VO_2max versus a control condition in which no exercise was performed. There was a significant increase in oxygen consumption after exercise when compared to the control condition, but there was no difference at the end of eight hours of rest. These investigators reported depressed RER values after exercise as compared to the control condition which they contended suggested a greater utilization of fats as a substrate for energy after the exercise session in comparison to the control. These results, like Chad et al. (1985), suggest that duration alone can not be examined to determine the effect of previous exercise on the subsequent EPOC and that substrate utilization after exercise may play an important role.

Like Bielinski et al. (1985), Freedman-Akabas et al. (1985) exercised subjects and compared the EPOC to a resting control condition. In the first part of the study, 10 male and 13 female subjects of varying states of conditioning exercised for 20 minutes at their ventilatory threshold by exercising on a treadmill. The results indicate that there was no significant difference between fitness level groups, and that the elevated post-exercise metabolism was no different from the control condition by forty minutes after the completion of exercise.

In the second portion of the investigation (Freedman-Akabas et al., 1985), four males and three females again exercised on a treadmill. However, the first exercise treatment in this portion was exercise at a speed 2 miles per hour greater than that at which they reached their ventilatory threshold for twenty minutes. The second exercise session involved exercising at their ventilatory threshold for 40 minutes. There was no significant difference between exercise treatments, and there was no significant difference in metabolic rate by minute 40 post-exercise in comparison to a control condition. Although no specific relative intensities were reported, this investigation confirmed that there is an interrelationship between duration and intensity of exercise in the determination of EPOC.

Although previous investigations employed continuous exercise, Maehlum et al. (1986) exercised four males and four females at 70% VO_2max for 80 minutes of intermittent exercise. Subjects exercised on a cycle ergometer and their oxygen consumptions after exercise were compared with a non-exercising control condition. These investigators found that EPOC continued to be significantly elevated up to 12 hours post-exercise but not greater than 24 hours. No significant difference in core temperature was observed after 30 minutes post-exercise, and lower RER values were observed after exercise in comparison to the control condition in agreement with other investigations. These results appear to suggest that elevated core temperatures and free fatty acid utilization at the completion of exercise have a role in at least the slow phase of EPOC.

The investigation by Brehm et al. (1986) attempted to determine differences in EPOC between trained and untrained states. These investigators utilized four trained males, four trained females, four untrained males, and four untrained females walking at absolute workloads for set distances. Subjects either walked or jogged on a treadmill. These investigators observed no significant difference in recovery oxygen consumption between the trained and untrained subjects. However, they postulated that the relative exercise intensities for this comparison were too low and did not result in a significant EPOC for either group. This investigation, as did previous studies, confirmed that EPOC increased with exercise intensity, and that there was a significant correlation between core temperature and EPOC.

Bahr et al. (1987) had six male subjects exercise at 70% VO_2max for bouts of 20, 40, and 80 minutes. As had been confirmed by previous studies, EPOC increased significantly with increasing exercise durations. There appeared to be a relationship between EPOC and core temperature as core temperature also rose significantly with increasing exercise duration. However, there was no significant elevation of core temperature in any condition after 30 minutes post-exercise although metabolism continued to be elevated up to 12 hours post-exercise. The total EPOC for each condition was estimated to be equivalent to 15% of the energy expended during the exercise bout.

Finally, Chad et al. (1988) had two males and three females work at 70% VO_2max for durations of 30-, 45-, and 60-minutes. EPOC was increased approxiamtely two-fold between the 30- and 45-minute exercise bouts and approximately five-fold between the 30- and 60-minute exercise bouts. Although core temperature was observed to reach resting levels before the end of EPOC, there was a significant high correlation between core temperature and EPOC. Depressed RER values post-exercise were also significantly correlated with EPOC. Although depressed RER values have been observed with hyperventilation and low blood pH, Chad et al. contend that this was not the case since it is improbable hyperventilation could be sustained with the task duration involved and because previous studies have shown little blood lactate accumulation at the chosen intensity of exercise.

From a review of these investiagtions, several points can be ascertained. First, that the magnitude of EPOC is strongly related to an interrelationship between exercise intensity and duration (Chad, 1985; Bielinski, 1985). However, several investigators contend that for shorter-duration exercise 70% VO_2max seems to be a threshold for significant effect on EPOC ((Knuttgen, 1970; Hagberg, 1980). Second, although it is also dependent on the relationship between intensity and duration, the duration of EPOC itself is generally no longer than 12 hours (Maehlum, 1986; Bahr, 1987), but has been reported to be short as 40 minutes (Freedman-Akabas, 1985). Differences here may be related to the methods of measurement, the posture of resting subjects, and the allowances for food consumption after exercise. Last, there seems to be a strong relationship between EPOC and both core temperature (Hagberg, 1980; Maehlum, 1986; Brehm, 1986; Bahr, 1987; Chad, 1988) and depressed RER values (Bielinski, 1985; Maehlum, 1986; Chad, 1988) after exercise which may be related to changes at the cellular level.

Leg-Only Versus Arm-and-Leg Exercise

From previous investigations it has been generally accepted that there is a limited degree of crossover benefits between limbs when training one set of limbs exclusively (Franklin, 1989). This information opposes the practice of emphasizing legs-alone training because overall body fitness development would be limited. Additionally, many vocational and recreational activities are dependent on the arms alone or in some combination with other body parts.

Some investigations have reported the achievement of 5-10% greater maximal oxygen capacity with the combination of arms and legs versus the legs-alone in graded exercise tests (Bergh, 1976). The variations in the reported findings are primarily due to the differences in the relative contributions of the limbs employed by different investigators (Secher, 1974), but also may be related to the efficiency of muscular work. Milesis (1991) reported that there was a greater mechanical efficiency in combined arm-and-leg work as compared to leg-only efforts. This difference in level of efficiency might help explain the attainment of higher work outputs achieved with combined arm-and-leg exercise. However, Telford (1982) reported an increase in maximal oxygen consumption of 4.4% during arm-and-leg over leg-only exercise, but observed that the leg-only exercise was more efficient. Although maximal oxygen uptake was different, there was no reported difference in maximal heart rates during graded exercise tests between the two exercise modalities (Nagle, 1974; Secher, 1974).

Although the achievement of higher oxygen uptakes and workloads is important, exercise prescription needs to take into consideration the effects of exercise modality on steady state, submaximal exercise. When subjects are compared at the same absolute workload between leg-only and combined arm-and-leg exercise, heart rates, oxygen consumption, and respiratory exchange ratio were all lower for arm-and-leg exercise (Milesis, 1991). Similarly, in a training study by Mostardi et al. (1981), subjects were able to train at the same relative workloads with a lower heart rate when exercising with arms and legs yet achieve the same benefits as those exercising with legs-alone. Therefore during submaximal exercise it appears that arm-and-leg exercise may result in less physiologic stress at the same workloads, and that higher workloads could be attained with less physiologic stress than with leg-only exercise.

Summary

It is generally accepted that there are three phases of EPOC which have been described by Mole (1990). Each phase's magnitude and duration seem to be influenced directly by the exercise session that proceeds it. Therefore, because different investigators have attempted to examine EPOC with different exercise protocols, their individual descriptions of EPOC have varied. However, quantitatively Bahr et al. (1987) have suggested that the total magnitude of EPOC is approximately equal to 15% of the caloric expenditure of the preceding exercise bout. Although several investigators have suggested that 70% VO_2max is threshold intensity for EPOC (Hagber, 1980; Brehm ,1988), the more important factor in the exercise session that most positively influences EPOC seems to be the interaction of intensity and duration of the exercise bout (Bahr, 1987; Chad, 1985; Chad,1988).

Previous investigations have suggested that the major mechanisms influencing EPOC are those which directly effect the "powerhouse" of the cell, the mitochondria. It appears that the efficiency of the mitochondria to supply the body's metabolic needs to maintain homeostasis are compromised resulting in a greater number of energy stores used to produce adequate amounts of energy. The production and retention of heat appears to have a significant effect on EPOC, and has been observed both at the cellular level (Brooks, 1971; Brooks, 1972) and at the level of whole body system (Claremont, 1975) and correlated with longer duration exercise bouts (Hagberg, 1980; Bahr, 1987; Maehlum, 1986; Chad, 1988). Other factors which may influence EPOC include the uptake and retention of calcium by the mitochondria (Carafoli, 1971; Brooks, 1984), elevated levels of circulating norepinephrine (Chapler, 1980; Gladden, 1982), and futile substrate cycling (Brooks, 1984).

Since it appears that EPOC may be strongly related to whole-body physiologic stress, there should be some consideration for choice of exercise modalities. Submaximal combined arm-and-leg exercise seems to result in a lower heart rate response and oxygen uptake at similar absolute intensities when compared to leg-only exercise (Milesis, 1991; Mostardi, 1981). Therefore, if exercise intensity is maintained by heart rate and oxygen uptake response, although higher workloads may be achieved with combined arm-and-leg exercise, EPOC may not be positively influenced.

CHAPTER III

JOURNAL MANUSCRIPT

THE ELEVATION OF METABOLIC RATE AFTER COMBINED ARM-AND-LEG VERSUS LEG-ONLY EXERCISE

Stuart M.C. Lee, Reed H. Humphrey, Don R. Sebolt, Janet L. Walberg-Rankin

(abbreviated title for running head)
Effect of Exercise Modality on Excess Post-Exercise Metabolic Rate

Stuart M.C. Lee
159 Boxfield Road
Pittsburgh, PA 15241
(412)831-3834

ABSTRACT

Previous investigations have shown that metabolic rate remains elevated for a period of time after the cessation of exercise. While other investigations have examined the effect of intensity and duration of prior exercise, the purpose of this study was to examine the effect of exercise mode and the employment of different muscle masses on the elevation of post-exercise metabolic rate (EPOC). Fifteen non-smoking, physically active females (21.1 ± 1.3 years; 21.4 ± 4.6 %BF) volunteered for this investigation. Each subject completed a graded maximal exercise test (GXT) on the Monark 880 cycle ergometer (Max HR=192.5 ± 2.3 bpm; Max VO_2=2.68 ± 0.11 l/min; Max RPE=19.5 ± 0.1) from which a heart rate corresponding to 70% VO_2max was chosen. Subjects then exercised on either a Monark 880 cycle ergometer (LE) or the Schwinn Airdyne (ALE) in random order for thirty minutes at the prescribed heart rate (HR). Exercise bouts were separated from each other and from the GXT by at least 48 hours. Workloads were monitored in five minute intervals and adjusted to maintain the appropriate heart rate. The mean exercise heart rates were 172.5 ± 2.8 bpm for the LE bout and 170.0 ± 2.8 bpm for the ALE bout, respectively. Two-way repeated measures ANOVA revealed no significant difference ($p>0.05$) between exercise treatments in terms of HR or VO_2. Repeated measures trend analysis revealed no significant difference in either EPOC or post-exercise heart rate between the two treatments across a one-hour seated recovery period. There was also no significant difference ($p>0.05$) in excess post-exercise caloric expenditure during the recovery period as a result of the different exercise treatments. Therefore, this suggests that neither exercise modality nor the distribution of

work over a larger muscle mass had an effect on EPOC when exercise intensity and duration were held constant.

INTRODUCTION

Exercise has been considered to be an important adjunct to weight control programs both as a means to accelerate weight loss and as a means to maintain desirable fat levels. When contrasted to diet-only programs, the caloric expenditure of exercise has been suggested to promote a greater share of body fat loss with the reduction of body weight when used singularly or in combination with dietary restriction (Pavlou, 1985; Pavlou, 1989a; Hill, 1987; Phinney, 1988; Pavlou, 1989b). However, less is known about the contribution of an elevated post-exercise metabolic rate (EPOC) in these weight loss-exercise regimens. Although the number of kilocalories expended above resting values as a result of EPOC is small, the summation of these kilocalories over the course of a chronic training regimen may have a significant impact on total caloric expenditure and/or a higher percentage of body fat loss in a long-term program. EPOC may also be important in the maintenance of desirable fat levels among normal weight, physically active individuals.

It is generally accepted that there are three phases of EPOC which have been described by Mole (1990). Each phase's magnitude and duration seem to be influenced directly by the exercise session that proceeds it. Therefore, because different investigators have attempted to examine EPOC with different exercise protocols, their individual descriptions of EPOC have varied. However, quantitatively Bahr et al. (1987) have suggested that the total magnitude of EPOC is approximately equal to 15% of the caloric expenditure of the preceding exercise bout. Although several investigators have suggested that 70% VO_2max is threshold intensity for EPOC (Hagberg, 1980; Brehm ,1988), the more important factor in the exercise session that most positively influences EPOC seems to be the interaction between intensity and duration of the exercise bout (Bahr, 1987; Chad, 1985; Chad,1988)

Previous investigations have suggested that the major mechanisms influencing EPOC are those which directly effect the "powerhouse" of the cell, the mitochondria. It appears that the efficiency of the mitochondria to supply the body's metabolic needs to maintain homeostasis are compromised, resulting in a greater number of energy stores used to produce adequate amounts of energy. The production and retention of heat appears to have a significant effect on EPOC as well, and have been observed both at the cellular level (Brooks, 1971; Brooks, 1972) and at the level of whole body system (Claremont, 1975) and correlated with longer duration exercise bouts (Hagberg, 1980; Bahr, 1987; Maehlum, 1986; Chad, 1988). Other factors which may influence EPOC include the uptake and retention of calcium by the mitochondria (Carafoli, 1971; Brooks, 1984), elevated levels of circulating norepinephrine (Chapler, 1980; Gladden, 1982), and futile substrate cycling (Brooks, 1984).

Since it appears that EPOC may be strongly related to whole body physiologic stress, there should be some consideration for choice of exercise modalities. Submaximal combined arm-and-leg exercise seems to result in a lower heart rate response and oxygen uptake at similar absolute intensities when compared to leg-only exercise (Milesis, 1991; Mostardi, 1981). Therefore, if exercise intensity is maintained by heart rate and oxygen uptake response, higher workloads may be achieved with combined arm-and-leg exercise so as to positively influence EPOC.

It was the purpose of this investigation to examine whether one exercise modality was superior to another in terms of metabolic cost both during and after exercise when intensity was monitored by heart rate.

METHODS

SUBJECTS

Prior to subject selection, permission to conduct this investigation was obtained from the Institutional Review Board for Research Involving Human Subjects. Criteria used for subject selection included: 1) female, 2) non-smoking, 3) non-obese (<30 percent body fat), 4) physically active, engaging in regular physical exercise at least three times per week over the last six months, and 4) aged 18-24 years old. Subjects were given both written and oral explanation of the investigation including risks, benefits, and procedures. Subjects completed a medical history questionnaire and appropriate informed consents for participating in the study. Fifteen subjects met the criteria for the investigation. Subjects met with the principal investigator prior to any procedures to familiarize them with all equipment used during the investigation and the methods to be employed for data collection.

GRADED EXERCISE TEST

Subjects completed a maximal graded exercise test on a Monark 880 cycle ergometer for the determination of functional capacity. Subjects were connected to a three-lead EKG for monitoring heart rate. The volume of inspired gas was measured using a Parkinson-Cowan Gas Flow Meter, and expired gases were collected and analyzed with an Ametek S3A Oxygen Analyzer and an Ametek CD3A Carbon Dioxide Analyzer (Applied Electrochemistry, Sunnyvale, CA). Subjects were allowed to warm-up at a resistance of 25 watts at cadence of 50 rpm for two minutes. Thereafter, resistance was set at 50 watts and was increased in 25 watt increments in two minute stages until volitional fatigue or the subject could no longer maintain the 50 rpm cadence. Subjects were strongly encouraged to give a maximal effort.

Oxygen consumption was assessed at one-minute intervals throughout the test; heart rate was plotted against oxygen consumption. Seventy percent of the absolute oxygen consumption and its corresponding heart rate was determined to monitor the intensity of exercise for treatments

BODY COMPOSITION

After the completion of the maximal exercise capacity test, body density was determined using the hydrostatic weighing technique with residual lung volume correction (Katch et al., 1967). Twelve repeated trials were performed to allow learning and improved performance of the technique. The heaviest four trials were chosen, the highest was eliminated, and the remaining three values were averaged. Residual lung volume measurements were made out of water using the oxygen rebreathing technique with the subjects in the same seated posture used during hydrostatic weighing (Wilmore et al., 1980). Percent body fat was calculated from body density using the Siri equation (Siri, 1961). Fat weight was determined by multiplying percent fat times body weight and fat free mass was determined by subtracting fat weight from body weight.

PRE-EXERCISE CONTROLS

After completion of the graded exercise test, subjects were randomly assigned to order of exercise treatments. Treatments consisted of two 30-minute exercise sessions at an average heart rate corresponding to 70% of maximal oxygen consumption. One exercise session was conducted using legs only on the Monark cycle ergometer and the other on a combined arm-and-leg ergometer, the Schwinn Air-Dyne.

Efforts were made to control the measurement conditions for the pre-exercise metabolic rate. Exercise treatments were separated by at least 48 hours but not more than one week. Sessions were scheduled at approximately the same time of day to control for possible diurnal variations in metabolic rate. In order to minimize the thermal effect of digestion, subjects were not permitted to eat less than 4 hours prior to an exercise session and the pre-exercise meal was prescribed to contain 300 kcal with fixed percentages of foodstuffs (47% bread exchange, 25% meat exchange, 15% fat exchange, and 13% fruit exchange).

PRE-EXERCISE METABOLIC RATE

Prior to each exercise session, subjects were seated on the appropriate ergometer for a period of at least 15 minutes after they were fitted with EKG monitoring leads and the Hans Rudolph one-way non-rebreathing valve and mouthpiece. Subjects were requested to minimize movement and activity.

Inspired volumes were measured by a Parkinson-Cowan Gas Flow Meter. The Parkinson-Cowan Gas Flow Meter was calibrated with known volumes using a three liter syringe. Volumes utilized to determine accuracy of these measurements included 30, 60, 90, and 120 liters. Gases expired through the non-rebreathing valve were collected in a 20 liter mixing bag and analyzed with an Ametek S3A Oxygen Analyzer and an Ametek CD3A Carbon Dioxide Analyzer (Applied Electrochemistry, Sunnyvale, CA). This expired gas system was calibrated to room air and to sample gas of known concentrations of oxygen and carbon dioxide (18% O_2 and 3% CO_2). During the last five minutes of the seated rest period, inspired volumes, percent 0_2 , and percent CO_2 were measured in one minute intervals. A high intraclass stability-reliability was shown for these measurements (R=0.92). These values were averaged and accepted as the pre-exercise resting metabolic rate for that day of testing.

EXERCISE TREATMENTS

Subjects were allowed to warm-up for a period of two minutes at approximately 25 watts immediately prior to the beginning of the exercise session. Initial resistance for the exercise sessions was chosen to elicit theappropriate target heart rate based on the graded exercise test for each individual. Resistances were modified during the exercise sessions to maintain the desired heart rate response as monitored by a three-lead EKG at five-minute intervals. The average of these heart rates was accepted as the mean heart rate for the exercise session.

During each exercise session subjects breathed through a Hans-Rudolph one-way non-rebreathing valve so that inspired volumes could be measured and expired gases analyzed, as above, at five-minute intervals. These measures were averaged to determine the the mean oxygen consumption for the exercise treatment.

POST-EXERCISE METABOLIC RATE

At the completion of the 30 minutes of exercise, subjects were instructed to immediately cease exercise and remain seated quietly on the ergometer with a minimum of movement. Measurements for oxygen consumption were recorded as before at one-minute intervals for the first five minutes post-exercise. Subjects then were disconnected from tubing to the gas flow meter and expired gas analyzers and transferred to a comfortable chair directly behind the ergometer for an additonal 55 minutes.

Post-exercise expired gases were collected in a 60-liter Douglas bag for analysis. Collections by this method were conducted at five time intervals: 10-12, 12-15, 25-30, 40-45, and 55-60 minutes post-exercise. Gases were extracted from the Douglas bag for analysis of oxygen and carbon dioxide content for one-minute at a fixed rate so that the total volume was reduced by one liter. The volume of the remaining gas was determined by expelling it into a Tissot tank. The measured displacement of water in centimeters was converted to a volume expressed in liters. The one liter extracted for analysis was added for the total volume of expired gas over the time period. Post-exercise oxygen consumption was determined to reflect an average consumption per minute over the collection interval. Oxygen consumption was expressed as a net value of increase greater than resting levels and is referred to as excess post-exercise oxygen consumption (EPOC).

CALORIC EXPENDITURE

An estimation of caloric expenditure during and after exercise was made for comparison of practical importance of the results of the investigation. Caloric consumption during exercise was estimated by multiplying the oxygen uptake at the end of each five minute period by the appropriate conversion factor as determined by the measured respiratory exchange ratio (RER) (McArdle et al., 1986) This amount was then multiplied by five minutes and accepted as to represent the caloric expenditure for that period of time. Total caloric expenditure during exercise was estimated by summing all of the five minute estimations for each exercise session.

Caloric expenditure after exercise was estimated by the area under the curve describing the decline of metabolic rate. The average oxygen consumption between two time intervals was multiplied by the time interval and by 5 kcal/liter/minute. Caloric expenditure after exercise could not be estimated by the means previously described because of the influence of hyperventilation on RER immediatley after exercise and because RER fell below 0.70 by 10 minutes post-exercise, a value for which there is no expressed conversion factor (McArdle et al., 1986).

STATISTICAL ANALYSIS

Repeated measures trend analysis was used to detect differences in post-exercise heart rates, excess post-exercise oxygen consumptions, and recovery RER between exercise sessions. A paired t-test was used to detect differences in post-exercise caloric expenditures.

Two-way repeated measures ANOVA's were utilized to determine whether exercise treatments were significantly different from each other in terms of exercise HR's and VO_2's. Paired t-tests were used to detect significant differences between mean achieved workload and caloric expenditure. All statistical analysis was performed on the Statistical Analysis System (SAS).

RESULTS

A description of subject characteristics , the results of their GXT's, and their exercise prescriptions can be found in Table 2. Also, the description of exercise treatments can be found in Table 3. A two-way repeated measures ANOVA found no significant differences ($p>0.05$) between the two exercise sessions for either heart rate or oxygen uptake. Similarly, paired t-tests performed to compare the caloric cost of exercise between the two treatments did not reveal any significant difference ($p>0.05$). However, paired t-tests performed to examine the mean workload maintained during exercise did reveal that subjects worked at a significantly greater ($p<0.05$) mean workload during ALE when compared to LE.

Repeated measures trend analysis revealed a significant decrease in mean excess post-exercise oxygen consumption (Figure 1), mean heart rate (Figure 2), and mean RER (Figure 3) across time ($p<0.0001$). However, there was no significant difference in any of the variables between treatments across the entire one-hour rest period($p>0.05$).

Table 2 Subject Characteristics

	Mean	Standard Deviation
Age	21.1	1.3
Max VO_2 (L/min)	2.68	0.43
Target VO_2 (L/min)	1.88	0.08
Target HR (bpm)	169.1	2.7
Body Weight (kg)	58.8	5.8
Percent Body Fat	21.4	4.6
Lean Body Mass (kg)	46.2	3.6
Fat Mass (kg)	12.6	3.4
Residual Volume (L)	1.03	0.20
Resting Metabolic Rate (ml/min)	201.7	7.6
Resting Metabolic Rate (ml/kg/min)	3.44	0.38

Table 3 Description of Exercise Sessions

	Leg-Only	Arm-and-Leg	Difference
Mean HR [1] (bpm)	172.5 ± 11.0	170.9 ± 10.8	1.6 ± 2.6
% THR [2]	103.0 ± 2.8	102.0 ± 2.3	0.99 ± 0.39
Mean VO_2 [3](L/min)	1.82 ± 0.24	1.79 ± 0.19	0.03 ± 0.09
%TVO_2 [4]	97.1 ± 8.8	96.0 ± 7.7	1.09 ± 1.27
Mean Wkld [5] (Watts)	119.1 ± 4.0	126.8 ± 4.3	-7.6 ± 1.9
Caloric Cost (kcal)	268.8 ± 10.1	261.0 ± 9.0	7.9 ± 6.4

[1] Mean HR: The mean of all five minute heart rate measurements during individual exercise treatment.

[2] %THR: The achieved mean percentage of the target heart rate as determined by the GXT.

[3] Mean VO_2: The mean all five minute VO_2 measurements during the individual exercise treatment.

[4] %TVO_2: The achieved mean percentage of the target VO_2 as determined by the GXT.

[5] Mean Wkld: The mean workload achieved as monitored at the five minute intervals during the individual exercise treatment.

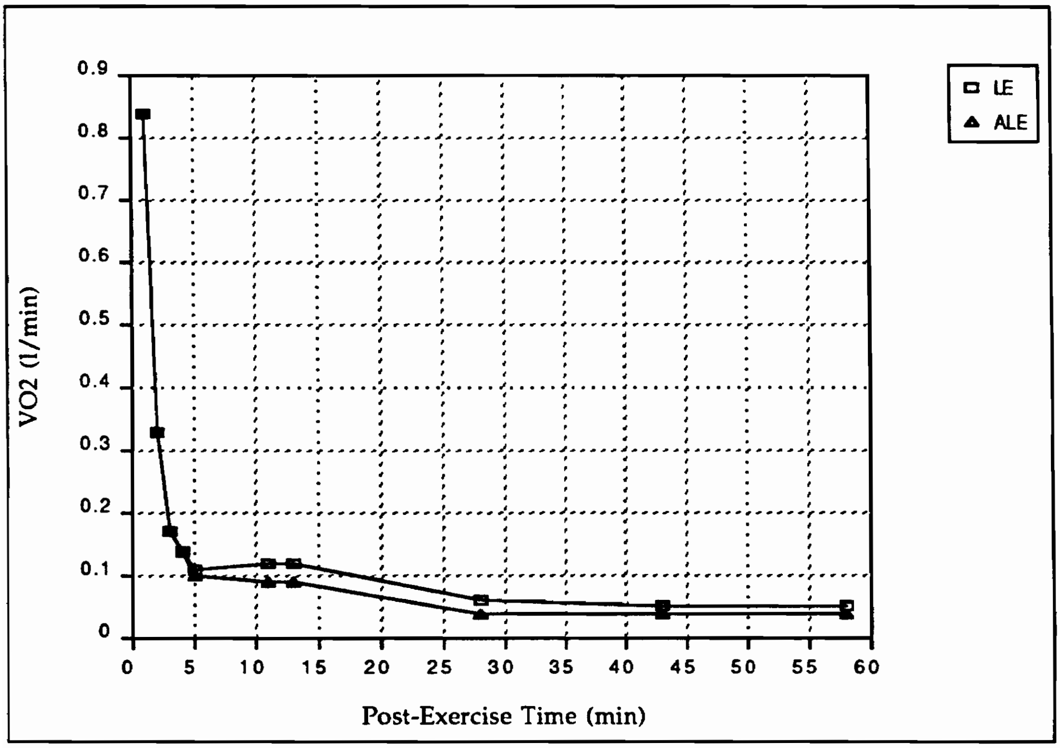

Figure 1 Mean Post-Exercise Excess Oxygen Consumption Response

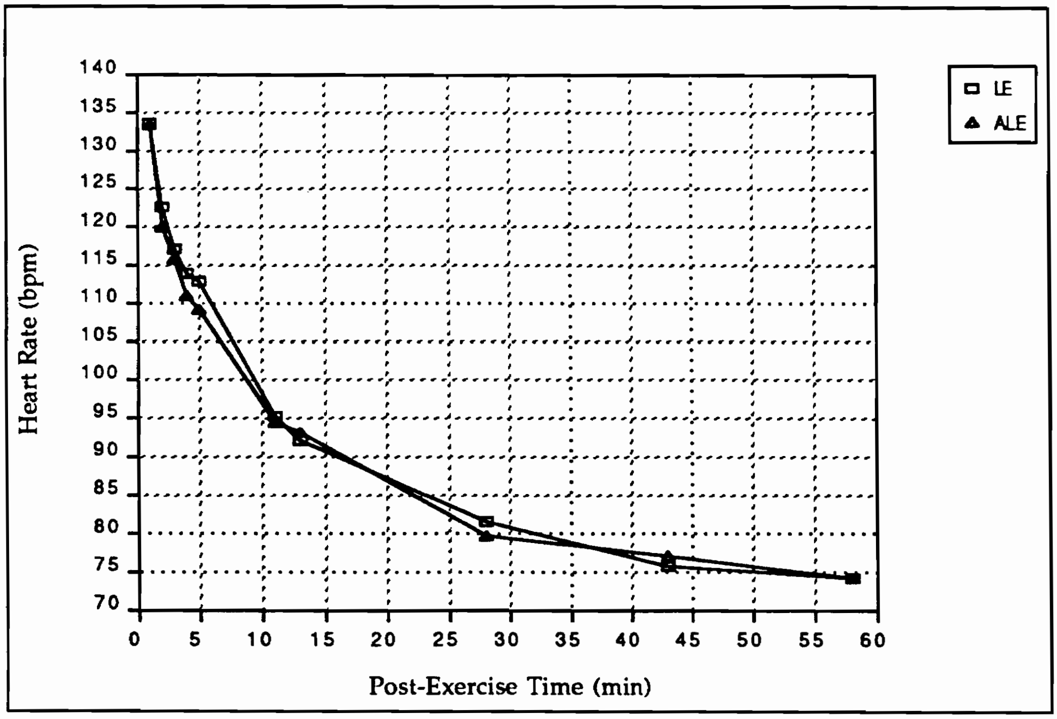

Figure 2 Mean Post-Exercise Heart Rate Response

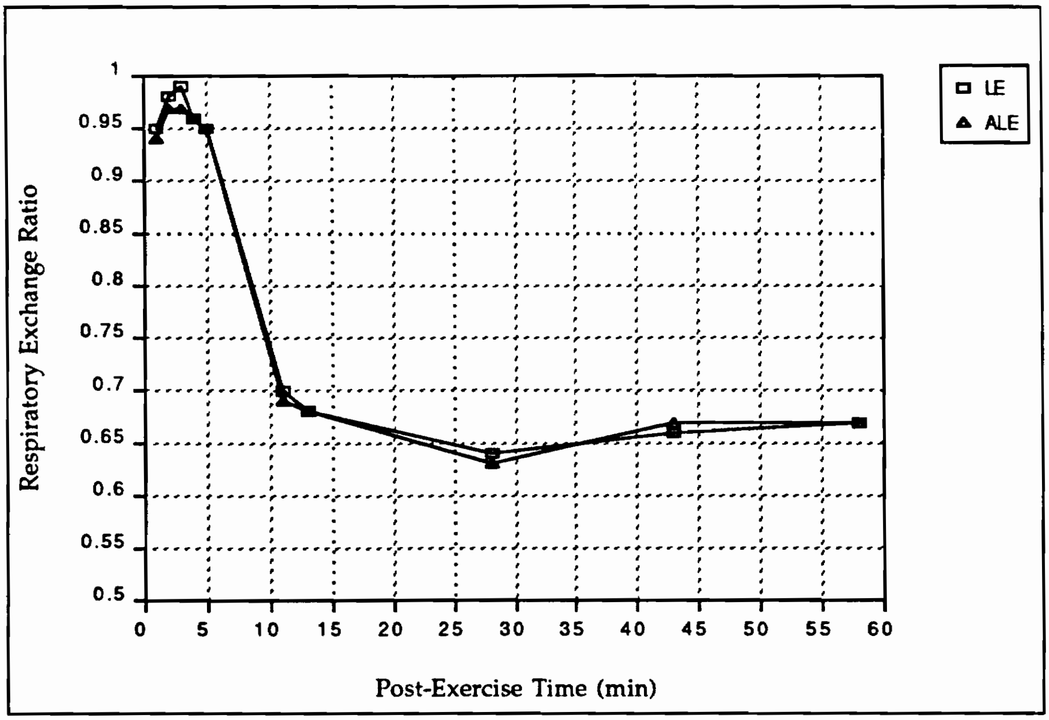

Figure 3 Mean Post-Exercise Respiratory Exchange Ratio Response

Separate trend analyses were performed on each post-exercise variable, excess post-exercise VO_2, heart rate, and RER for time periods 0-5 minutes and 5-60 minutes post-exericse. There was no siginificant difference detected for any of the variables between the two conditions for the full one hour period or for 0-5 minutes , but LE was found to result in a significantly greater ($p<0.05$) excess post-exercise VO_2 than ALE when these two variables were compared across 5-60 minutes post-exercise.

Paired T-tests were conducted comparing the two exercise modalities in terms of excess post-exercise caloric consumption. There was no significant difference detected across any of the intervals examined in terms of excess caloric cost. However, a trend towards significantly greater excess caloric consumption after LE was noted across the one hour period ($p=0.12$) and across minutes 5-60 ($p=0.10$), but not across minutes 0-5 ($p=0.83$). Mean values for each of the post-exercise caloric expenditure variables are presented in Table 4.

DISCUSSION

Previous investigations have demonstrated that the intensity and duration of exercise preceding post-exercise metabolic measurements are highly significant in their impact on EPOC. Several studies have shown that the magnitude of EPOC is enhanced by increasing the prior exercise intensity (Knuttgen, 1970; Hagberg, 1980; Brehm, 1986), and that EPOC is exponentially enhanced at intensities greater than 70% VO_2max. (Knuttgen, 1970) Additionally, other investigators have determined that duration of exercise also elevates EPOC (Knuttgen, 1970; Hagberg, 1980; Chad, 1985; Bahr, 1987;

Table 4 Excess Post-Exercise Caloric Expenditure (kcal)

	Leg Only	Arm-and-Leg	Difference
EPCC Total	30.3 ± 1.9	26.9 ± 2.9	3.4 ± 2.0
EPCC, 0-5 min	11.2 ± 0.6	11.4 ± 0.4	-0.1 ± 0.6
EPCC,5-60 min	19.1 ± 1.8	15.6 ± 2.7	3.5 ± 2.0

Chad, 1988). However, Chad et al. (1985) found that a lesser exercise intensity could result in an enhanced EPOC if it equaled the total energy expenditure at a higher intensity but was necessarily longer. It seems that an interaction between intensity and duration is necessary to bring about the desired effects. However, Brehm (1988) suggested that 70% of functional capacity represented a threshold of exercise intensity to result in a significant EPOC within a moderate amount of exercise time. For these reasons, 70% VO_2max was chosen for the intensity of exercise treatments with a predertermined duration of 30 minutes to maintain constancy of exercise treatments.

In order for the information from this experiment to be properly considered, the prescription of exercise is the first matter to be discussed. The data obtained from the graded exercise sessions suggested that each subject performed a maximal effort. Subjects attained a mean maximal heart rate in excess of their predicted maximal heart rate, reported a mean maximal rating of perceived exertion greater than 17, and RER values were observed in excess of 1.1 (ACSM, 1991). Therefore, the prediction of 70% VO_2max for the intensity of exercise treatments was assumed to represent an effort of 70% of the subject's functional capacity.

After assuring the proper exercise prescription had been determined, there was an inherent importance in the design of this study to control the exercise sessions preceding post-exercise measurements to retain continuity of treatments. Heart rate was chosen as the method to monitor exercise intensity since it is the method of choice in the majority of settings. There was a strong positive correlation (r=0.97) between the mean heart rates of the two exercise sessions. In both exercise sessions, subjects attained a mean of

102.5 ± 0.6% of their target heart rate, although subjects averaged only 96% of their target VO_2 across the two exercise sessions. This was probably the result of cardiovascular drift. There was also no significant difference in caloric expenditure during exercise between the two exercise bouts. Therefore, it can be assumed that the two exercise bouts resulted in similar whole body physiologic stress even though subjects were able to maintain a significantly higher ($p<0.05$) mean workload during ALE exercise than during LE exercise, in agreement with previous investigations (Mostardi, 1981; Milesis, 1991).

The timing of post exercise measurements was chosen to primarily examine the fast and slow phases of EPOC. It was hoped that by focusing on these segments of recovery that small differences between the exercise modalities might be revealed. However, there was no significant difference ($p>0.05$) in either heart rate or oxygen uptake across the entire on hour resting recovery period observed with repeated measures trend analysis. However, after analyzing the mean excess post-exercise oxygen uptakes graphically, it seemed possible that a difference in post-exercise response occurred after the first five minutes of rest. Therefore, all data was re-analyzed by dividing the data into two subsets: immediate post-exercise to five minutes and five to 60 minutes.

The analysis of these two time periods revealed two important considerations. First, there continued to be no significant difference ($p>0.05$) between the two exercise bouts in any of the variables in the first five minutes of recovery. Neither modailty had an impact during this phase of recovery. Therefore it can be maintained that prior exercise volume is the primary factor at work in determining the magnitude of the fast phase of EPOC

(Hagberg, 1980; Chad, 1985). However, examination of the time period lasting from five to 60 minutes post-exercise revealed a significantly greater ($p<0.05$) excess post-exercise VO_2 for LE exercise that is reflected in a trend towards significantly greater excess caloric expenditure ($p=0.10$) for LE exercise. Disappointingly, the difference is probably not clinically significant because the mean difference was only 3.6 ± 2.0 kcal. The difference may be greater if the resting subject were observed over a greater peiod of post-exercise time than one hour, although previous investigations (Brehm & Gutin, 1986; Pacey et al., 1985) have suggested that EPOC was complete within one hour.

RER values were observed to be in general agreement with previous investigations (Bahr, 1987; Bielinski, 1985; Chad & Wenger, 1988). The contention of these investigators was that the low RER values suggested a greater dependence on free fatty acids in recovery, and that this mat be an indication of futile substrate cycling. The mean RER values in this investigation declined to approximately 0.70 by minute 10 and remained depressed for the remainder of the recovery session. There was no significant difference ($p>0.05$) detected by repeated measures trend analysis between the RER values for each of the exercise treatments.

The exercise modalities chosen for this investigation were thought to be two of the more common exercise modalities used in both clinical and non-clinical settings. Additionally, the different relative distributions of work across muscle mass were hoped to elicit different metabolic responses, both during exercise and afterward. The larger muscle mass involved during the combined arm-and-leg exercise treatment did not seem to result in any positive influences to further elevate EPOC.

From observation of the results of this investigation it appears that the determinants of exercising whole body oxygen consumption and EPOC are not dependent on the size of muscle mass incorporated in physical work. Instead, they are related to the whole body metabolic disturbance of exercise and the measures required to return the body to resting levels. This point is reinforced by the observation that subjects in this investigation were able to maintain a significantly greater ($p<0.05$) mean workload during ALE than LE, but this did not result in a significantly greater VO_2 or oxygen consumption during or after work. However, to more adequately examine the effects of combined arm-and-leg exercise, it will be necessary to examine different externally controlled relative combinations of arm-and-leg work as they relate to heart rate and VO_2 responses during and after exercise. Future research should also focus on other exercise modalities, including weight training and swimming (Brehm, 1988).

Based on the results of this investigation, it may be accepted that there is no need to alter exercise prescriptions based on a cycle ergometer when a subject is exercising on a combined arm-and-leg ergometer. Especially when working within a target heart rate range, there appears to be no significant difference between physiologic responses measured by VO_2 either during or after exercise. Therefore in the presciption of exercise for metabolic expenditure or the purchase of exercise equipment, the choice of modality between the cycle ergometer and the Air-Dyne need only be based upon personal preference of the participant. However, the Air-Dyne may provide additional upper body exercise resulting in the enhancement of total body fitness which the cycle cannot.

REFERENCES

American College of Sports Medicine (1991) Guidelines for Exercise Testing and Prescription. 4th ed., Philadelphia: Lea and Febiger.

Bahr,R., Ignes, I., Vaage, O., Sejersted, O.E., Newsholme, E.A. (1987). Effect of duration of exercise on excess postexercise O_2 consumption. Journal of Applied Physiology, 62(2): 485-490.

Bergh, U., Kanstrup, I.-L., Ekblom, B. (1976). Maximal oxygen uptake during exercise with various combinations of arm and leg work. Journal of Applied Physiology, 41(2): 191-196.

Bielinski, R., Schutz, Y., Jequier, E. (1985). Energy metabolism during postexercise recovery in man. The American Journal of Clinical Nutrition, 42: 69-82.

Brehm, B.A. (1988). Elevation of metabolic rate following exercise: implications for weight loss. Sports Medicine, 6: 72-78.

Brehm, B.A. & Gutin, B. (1986). Recovery energy expenditure for steady state exercise in runners and nonexercisers. Medicine and Science in Sports and Exercise, 18(2): 205-210.

Brooks, G.A. & Fahey, T.D. (1985). Exercise Physiology: Human Bioenergetics and Its Applications. New York: Macmillan.

Brooks, G.A., Hittelman, K.J., Faulkner, J.A., Beyer, R.E. (1971). Temperature, liver mitochondrial respiratory functions, and oxygen debt. Medicine and Science in Sports, 3(2): 72-74.

Brooks, G.A., Hittelman, K.J., Faulkner, J.A., Beyer, R.E. (1971a). Temperature, skeletal muscle mitochondrial functions, and oxygen debt. American Journal of Physiology, 220(4): 1053-1059.

Brooks, G.A., Hittelman, K.J., Faulkner, J.A., Beyer, R.E. (1971b). Tissue temperatures and whole-animal oxygen consumption after exercise. American Journal of Physiology, 221(2): 427-431.

Chad, K.E., & Wenger, H.A. (1985). The effects of duration and intensity on the exercise and post exercise metabolic rate. Australian Journal of Science and Medicine in Sport, 17(4): 14-18.

Chad, K.E., & Wenger, H.A. (1988). The effect of exercise duration on the exercise and post-exercise oxygen consumption. Canadian Journal of Sports Science, 13(4):204-207.

Claremont, A.D., Nagle, F., Reddan, W.D., Brooks, G.A. (1975). Comparison of metabolic, temperature, heart rate, and ventilatory responses at extreme ambient temperatures. Medicine and Science in Sports, 7:150-154.

Devlin, J.T., Barlow, J., Horton, E.S. (1989). Whole body and regional fuel metabolism during early postexercise recovery. American Journal of Physiology, 256: E167-172.

Franklin, B.A. (1989). Aerobic exercise training programs for the upper body. Medicine and Science in Sports and Exercise, 21(5): S141-S148.

Freedman-Akabas, S., Colt, E., Kissileff, H.R., Pi-Sunyer, F.X. (1985). Lack of sustained increase in VO_2 following exercise in fit and unfit subjects. The American Journal of Clinical Nutrition, 41: 545-549.

Gaesser, G.A., & Brooks, G.A. (1984). Metabolic bases of post-exercise oxygen consumption: a review. Medicine and Science in Sports and Exercise, 16(1): 29-43.

Hagberg, J.M., Mullin, J.P., Nagle, F.G. (1980). Effect of work intensity and duration on recovery 02. Journal of Applied Physiology, 48(3): 540-544.

Knuttgen, H.G. (1970). Oxygen debt after submaximal physical exercise. Journal of Applied Physiology, 29(5): 651-657.

Maehlum, S., Grandmontagne, M., Newsholme, E.A., Sejersted, O.M. (1986). Magnitude and duration of excess postexercise oxygen consumption in healthy young subjects. Metabolism, 35(5): 425-429.

McArdle, W.D., Katch, F.I., & Katch, V.L. (1986). Exercise Physiology: Energy, Nutrition, and Human Performance. Philadelphia: Lea & Febiger.

Milesis, C.A., Sprecker, T.B., and Chumbley, R.A. (1991). Physiological and perceptual responses to friction-braked vs. air-braked ergometer cycling. Clinical Kinesiology: 3-8.

Mole, P.A. (1990). Impact of energy intake and exercise on resting metabolic rate. Sports Medicine, 10(2): 72-87.

Mostardi, R.A. & Gandee, R.N. (1981). Exercise training using arms and legs versus legs alone. Archives of Physical Medicine and Rehabilitation, 62: 332-336.

Nagle, F.J., Richie, J.P., and Giese, M.D. (1984). VO_2 max responses in separate and combined arm and leg air-braked ergometer exercise. Medicine and Science in Sports and Exercise, 16(6): 563-566.

Pavlou, K.N., Krey, S., Steffee, W.P. (1989a). Exercise as an adjunct to weight loss and maintenance in moderately obese subjects. The American Journal of Clinical Nutrition, 49: 1115-1123.

Pavlou, K.N., Steffee, W.P., Lerman, R.H., Burrows, B.A. (1985). Effects of dieting and exercise on lean body mass, oxygen uptake, and strength. Medicine and Science in Sports and Exercise, 17(4): 466-471.

Pavlou, K.N., Whaley, J.E., Jannace, P.W., DiBartolomeo, J.J., Burrows, B.A., Duthie, E.A.M., Lerman, R.H. (1989b). Physical activity as a supplement to weight-loss dietary regimen. The American Journal of Clinical Nutrition, 49: 1110-1114.

Phinney, S.D., LaGrange, B.M., O'Connell, M., Danforth, E. Jr., (1988). Effects of aerobic exercise on energy expenditure and nitrogen balance during very low calorie dieting. Metabolism, 37: 758-765.

Poehlman, E.T., Melby, C.L., Badylak, S.F. (1988). Resting metabolic rate and postprandial thermogenesis in highly trained and untrained males. The American Journal of Clinical Nutrition, 47: 793-798.

SAS Institute, Inc. (1985). SAS user's guide: Statistics version 5 edition. Cary, NC: SAS Institute, Inc.

Secher, N.H., Ruberg-Larsen, N., Binkhorst, R.A., Bonde-Petersen, F. (1974). Maximal oxygen uptake during arm cranking and combined arm plus leg exercise. Journal of Applied Physiology, 36(5): 515-518.

Segal, K.R. & Gutin, B. (1983). Thermic effects of food and exercise in lean and obese women. Metabolism, 32(6): 581-589.

Segal, S.S., & Brooks, G.A. (1979). Effects of glycogen depletion and workload on postexercise O_2 consumption and blood lactate. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, 47(3): 514-521.

Shah, M., Giessler, C.A., Miller, D.S. (1988). Metabolic rate during and after aerobic exercise in post-obese and lean women. European Journal of Clinical Nutrition, 42: 455-464.

Siri, W.E. (1961). Body composition from fluid spaces and density: an analysis of methods. In Techniques for Measuring Body Composition. Washington, D.C.: National Academy of Sciences.

Stainsby, W.N. & Barclay, J.K. (1970). Exercise metabolism: O_2 deficit, steady level O_2 uptake, and O_2 uptake for recovery. Medicine and Science in Sports, 2(4): 177-181.

Stenberg, J., Astrand, P.O., Ekblom, B., Royce, J., Saltin, B. (1967). Hemodynamic response to work with different muscle groups, sitting and supine. Journal of Applied Physiology, 22: 61-70.

Telford, R.D. (1982). Specific performance analysis with air-braked ergometers. Journal of Sports Medicine, 22: 340-348.

Wilmore, J.H., Vodak, P.A., Parr, R.B., Girandola, R.N., and Billing, J.E. (1980). Further simplification of a method for the determination of residual lung volume. Medicine and Science in Sports and Exercise, 12(3): 216-218.

CHAPTER IV

Summary and Research Recommendations

The purpose of this investigation was to determine if one exercise modality was superior to another in terms of metabolic expenditure during and after exercise. Because this study was designed to be clinically relevant, the intensity of exercise was monitored and maintained by heart rate as is the practice in non-laboratory settings. In addition, the exercise modalities, cycle ergometry and combined arm-and-leg exercise, were also chosen for their practical application to both preventive and rehabilitative environments. Both the Monark 880 cycle ergometer and the Schwinn Air Dyne are common pieces of equipment in most exercise programs.

Fifteen non-obese, non-smoking physically active females completed two 30-minute exercise sessions, one using the Monark and the other combining arm-and-leg work on the Schwinn Air Dyne. The exercise intensity was chosen as 70% of VO_2max and the corresponding heart rate was determined from a graded maximal function test performed on a Monark 880 Cycle ergometer. The appropriate intensity was maintained by adjusting exercise workloads based upon the constancy of heart rate response. Heart rate and oxygen uptake were monitored throughout the exercise session, averaged, and taken as the mean exercise heart rate and oxygen consumption, respectively, for that exercise session.

Prior to each exercise session subjects were seated upon the appropriate exercise ergometer for pre-exercise baseline measurements. Subjects rested for at least 15 minutes after being connected to 3-lead EKG and oxygen uptake monitoring systems. Resting VO_2 measures were taken the last five minutes of this rest period, averaged, and taken as the resting value for that day.

At the completion of the exercise session, subjects remained seated on the ergometer for the first five minutes of post-exercise measurements. Heart rate and oxygen uptake were measured at one-minute intervals. Thereafter, subjects were transferred to a comfortable chair directly behind the ergometer for the remainder of the measurements taken in the one hour after exercise. Heart rate and oxygen uptake were measured at time intervals of 10-12, 12-15, 25-30, 40-45, and 55-60 minutes. Oxygen uptakes were expressed as an excess post-exercise value, gross oxygen consumption minus the pre-exercise resting oxygen consumption.

A simple correlation was performed to examine the relationship between mean exercise heart rates for each exercise session; a strong positive correlation ($r=0.97$) was observed. Additionally, paired t-tests were performed to detect differences between exercise sessions on mean exercise VO_2 and caloric expenditure. There was no significant difference ($p>0.05$) between bouts in mean exercise VO_2 or caloric consumption. Subjects achieved an average of 102% of their target heart rate for both modalities and 96% of their target VO_2.

Repeated measures trend analysis revealed a significant difference ($p<0.05$) between exercise treatments during recovery for heart rates and excess VO_2 across time. Their decline reflected the curvilinear response described by Brooks (1985). There was no significant difference ($p>0.05$) for any of these variables during recovery between exercise treatments across the full hour of recovery. However, when considered in two different time periods, immediate post-exercise to five minutes and five minutes to 60 minutes post-exercise, a significantly greater ($p<0.05$) excess VO_2 for LE exercise and a trend towards significance ($p=0.10$) for excess caloric consumption were observed. However, these differences were not clinically significant since they resulted in a mean excess caloric difference of 3.6 ± 2.0 kcal.

The respiratory exchange ratio after exercise has been reported in other literature to be depressed after exercise (Bahr, 1987; Bielinski, 1985; Chad & Wenger, 1988) possibly reflecting an increased reliance upon fatty acids as an energy substrate. The RER values were similarly depressed by 10 minutes post-exercise in this investigation. Repeated measures trend analysis did not reveal a significant difference ($p>0.05$) between recovery RER between the two exercise treatments.

Observation of the results of this study seem to suggest that there was no significant effect of exercise treatment on either exercise or post exercise VO_2 or heart rates. Although subjects were instructed and strongly encouraged to distribute the work across the arms and the legs during the Air-Dyne session, because there was no direct control over the relative amounts of work that the arms and legs performed during ALE on the Air Dyne, it is possible that subjects used the arms minimally. If this is the case, then the ALE session could be viewed as yet another LE treatment, and therefore would yield similar results. This study was designed to simulate non-laboratory exercise sessions, and may accurately reflect common exercise practice. Future research may focus, however, on the effect of strict control of relative workloads on the muscle masses involved.

Research Implications

The results of this study contribute information regarding the effect of two different exercise modalities on the exercise and post-exercise VO_2 and heart rate in non-smoking, non-obese, physically active college age women. Although this information may be generalizable also to males (Brehm & Gutin, 1986), it is not clear as to whether it can be implied that untrained subjects will have a similar response (Brehm & Gutin, 1986; Freedman-Akabas, 1985; Hagber, 1980).

From the information obtained in this study, it appears that when exercise physiologists are prescribing exercise for either the Monark 880 cycle ergometer or the Schwinn Air Dyne, the same prescription can be applied to each modality without concern for differences in metabolic rate during or after exercise.

Recommendations for Future Research

Although EPOC represents a relatively small amount of total caloric expenditure in comparison to exercise (Bahr, 1987), over a chronic training program it has the potential to be a significant factor in both weight maintenance and weight loss. For this reason, future research be directed to determining the optimal exercise modality to maximize EPOC responses.

One of the weaknesses of this investigation by design was the lack of strict control over the relative work of the muscle masses involved during ALE. A natural progression from this point would be to examine a spectrum of different combinations of arm-and-leg work from legs alone to arms alone.

Separate ergometers would necessarily be employed for greatest control of the work performed.

Most of the previous work has focused on the effect of aerobic exercise on EPOC. The primarily modalities have been walking, jogging, and cycling. Other exercise treatments to be investigated include swimming, rowing, canoeing, stair-climbing, ladder-climbing, jump roping, and aerobic dance.

In addition to experimentation with aerobic exercise, another area of investigation might be the effect of resistance training on EPOC. Isotonic, isometric, and isokinetic exercise bouts could be contrasted with each other for EPOC as well as different intensities and durations of work. Also, because of the discontinuatious nature of these exercises, different rest periods between sets of exercise bouts could be investigated. These each, of course, could be contrasted with different aerobic exercise modalities.

Another weakness of this investigation is that there was no attempt examine the effect of stored thermal heat from exercise (Q10 effect) on the post-exercise period. Future investigations could examine the effects of the Q10 effect during a similar exercise bout as the one employed in this investigation as well as other varying degrees of intensity and duration with ALE. This same concept of different intensities and durations could also be applied to each of the other exercise modalities suggested above. Because Chad et al. (1985) were able to produce a greater volume of EPOC at an exercise intensity of 50% VO_2max and a duration equal to that of 70% VO_2max for 30 minutes, it seems that the optimal combination of intensity and duration has not been clarified.

The majority of the subjects examined thus far in these EPOC investigations have been healthy, young adults who are accustomed to exercise. An area of research that needs to be addressed includes work with those people who are obese, older, or suffer from some metabolic disease which alter energy production and utilization.

This investigation and those previous have examined EPOC under restful, thermoneutral environments. Other investigations may attempt to discern uncomfortable, noisy, cold, hot, or other stressful environments may further elevate metabolic rate after exercise to enhance EPOC.

REFERENCES

American College of Sports Medicine (1991) Guidelines for Exercise Testing and Prescription. 4th ed., Philadelphia: Lea and Febiger.

Asmussen, E, & Hemmingsen, I.(1958). Determination of maximum work capacity at different ages in work with legs or with the arms. Scandinavian Journal of Clinical Laboratory Investigation, 10: 67-71.

Astrand, P.O., & Saltin, B. (1961). Maximal oxygen uptake and heart rate in various types of muscular activity. Acta Physiologica Scandinavia, 38: 1-21.

Bahr,R., Ignes, I., Vaage, O., Sejersted, O.E., Newsholme, E.A. (1987). Effect of duration of exercise on excess postexercise O_2 consumption. Journal of Applied Physiology, 62(2): 485-490.

Bergh, U., Kanstrup, I.-L., Ekblom, B. (1976). Maximal oxygen uptake during exercise with various combinations of arm and leg work. Journal of Applied Physiology, 41(2): 191-196.

Bielinski, R., Schutz, Y., Jequier, E. (1985). Energy metabolism during postexercise recovery in man. The American Journal of Clinical Nutrition, 42: 69-82.

Brehm, B.A. (1988). Elevation of metabolic rate following exercise: implications for weight loss. Sports Medicine, 6: 72-78.

Brehm, B.A. & Gutin, B. (1986). Recovery energy expenditure for steady state exercise in runners and nonexercisers. Medicine and Science in Sports and Exercise, 18(2): 205-210.

Brooks, G.A. & Fahey, T.D. (1985). Exercise Physiology: Human Bioenergetics and Its Applications. New York: Macmillan.

Brooks, G.A., Hittelman, K.J., Faulkner, J.A., Beyer, R.E. (1971). Temperature, liver mitochondrial respiratory functions, and oxygen debt. Medicine and Science in Sports, 3(2): 72-74.

Brooks, G.A., Hittelman, K.J., Faulkner, J.A., Beyer, R.E. (1971). Temperature, skeletal muscle mitochondrial functions, and oxygen debt. American Journal of Physiology, 220(4): 1053-1059.

Brooks, G.A., Hittelman, K.J., Faulkner, J.A., Beyer, R.E. (1971). Tissue temperatures and whole-animal oxygen consumption after exercise. American Journal of Physiology, 221(2): 427-431.

Carafoli, E. & Lehninger, A.L. (1971). A survey of the interation of calcium ions with mitochondria from different tissues and species. Biochemistry Journal, 122: 681-690.

Chad, K.E., & Wenger, H.A. (1985). The effects of duration and intensity on the exercise and post exercise metabolic rate. Australian Journal of Science and Medicine in Sport, 17(4): 14-18.

Chad, K.E., & Wenger, H.A. (1988). The effect of exercise duration on the exercise and post-exercise oxygen consumption. Canadian Journal of Sports Science, 13(4):204-207.

Chapler, C.K., Stainsby, W.N., Gladden, L.B. (1980). Effect of changes in blood flow, norepinephrine, and pH on oxygen uptake by resting skeletal muscle. Canadian Journal of Physiology and Pharmacology, 58: 93-96.

Claremont, A.D., Nagle, F., Reddan, W.D., Brooks, G.A. (1975). Comparison of metabolic, temperature, heart rate, and ventilatory responses at extreme ambient temperatures. Medicine and Science in Sports, 7:150-154.

Devlin, J.T., Barlow, J., Horton, E.S. (1989). Whole body and regional fuel metabolism during early postexercise recovery. American Journal of Physiology, 256: E167-172.

Freedman-Akabas, S., Colt, E., Kissileff, H.R., Pi-Sunyer, F.X. (1985). Lack of sustained increase in VO_2 following exercise in fit and unfit subjects. The American Journal of Clinical Nutrition, 41: 545-549.

Gaesser, G.A., & Brooks, G.A. (1984). Metabolic bases of post-exercise oxygen consumption: a review. Medicine and Science in Sports and Exercise, 16(1): 29-43.

Gladden, L.B., Stainsby, W.N., MacIntosh, B.R. (1982). Norepinephrine increases canine skeletal muscle VO_2 during recovery. Medicine and Science in Sports and Exercise, 14(6): 471-476.

Hagberg, J.M., Mullin, J.P., Nagle, F.G. (1980). Effect of work intensity and duration on recovery 02. Journal of Applied Physiology, 48(3): 540-544.

Hill, J.O., Sparling, P.B., Shields, T.W., Heller, P.A. (1987). Effects of exercise and food restriction on body composition and metabolic rate in obese women. American Journal of Clinical Nutrition, 46: 622-630.

Knuttgen, H.G. (1970). Oxygen debt after submaximal physical exercise. Journal of Applied Physiology, 29(5): 651-657.

Maehlum, S., Grandmontagne, M., Newsholme, E.A., Sejersted, O.M. (1986). Magnitude and duration of excess postexercise oxygen consumption in healthy young subjects. Metabolism, 35(5): 425-429.

McArdle, W.D., Katch, F.I., & Katch, V.L. (1986). Exercise Physiology: Energy, Nutrition, and Human Performance. Philadelphia: Lea & Febiger.

Mole, P.A. (1990). Impact of energy intake and exercise on resting metabolic rate. Sports Medicine, 10(2): 72-87.

Mostardi, R.A. & Gandee, R.N. (1981). Exercise training using arms and legs versus legs alone. Archives of Physical Medicine and Rehabilitation, 62: 332-336.

Pavlou, K.N., Krey, S., Steffee, W.P. (1989a). Exercise as an adjunct to weight loss and maintenance in moderately obese subjects. The American Journal of Clinical Nutrition, 49: 1115-1123.

Pavlou, K.N., Steffee, W.P., Lerman, R.H., Burrows, B.A. (1985). Effects of dieting and exercise on lean body mass, oxygen uptake, and strength. Medicine and Science in Sports and Exercise, 17(4): 466-471.

Pavlou, K.N., Whaley, J.E., Jannace, P.W., DiBartolomeo, J.J., Burrows, B.A., Duthie, E.A.M., Lerman, R.H. (1989b). Physical activity as a supplement to weight-loss dietary regimen. The American Journal of Clinical Nutrition, 49: 1110-1114.

Phinney, S.D., LaGrange, B.M., O'Connell, M., Danforth, E. Jr., (1988). Effects of aerobic exercise on energy expenditure and nitrogen balance during very low calorie dieting. Metabolism, 37: 758-765.

Poehlman, E.T., Melby, C.L., Badylak, S.F. (1988). Resting metabolic rate and postprandial thermogenesis in highly trained and untrained males. The American Journal of Clinical Nutrition, 47: 793-798.

SAS Institute, Inc. (1985). SAS user's guide: Statistics version 5 edition. Cary, NC: SAS Institute, Inc.

Secher, N.H., Ruberg-Larsen, N., Binkhorst, R.A., Bonde-Petersen, F. (1974). Maximal oxygen uptake during arm cranking and combined arm plus leg exercise. Journal of Applied Physiology, 36(5): 515-518.

Segal, K.R. & Gutin, B. (1983). Thermic effects of food and exercise in lean and obese women. Metabolism, 32(6): 581-589.

Segal, S.S., & Brooks, G.A. (1979). Effects of glycogen depletion and workload on postexercise O_2 consumption and blood lactate. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, 47(3): 514-521.

Shah, M., Giessler, C.A., Miller, D.S. (1988). Metabolic rate during and after aerobic exercise in post-obese and lean women. European Journal of Clinical Nutrition, 42: 455-464.

Siri, W.E. (1961). Body composition from fluid spaces and density: an analysis of methods. In Techniques for Measuring Body Composition. Washington, D.C.: National Academy of Sciences.

Stainsby, W.N. & Barclay, J.K. (1970). Exercise metabolism: O_2 deficit, steady level O_2 uptake, and O_2 uptake for recovery. Medicine and Science in Sports, 2(4): 177-181.

Stenberg, J., Astrand, P.O., Ekblom, B., Royce, J., Saltin, B. (1967). Hemodynamic response to work with different muscle groups, sitting and supine. Journal of Applied Physiology, 22: 61-70.

Wilmore, J.H., Vodak, P.A., Parr, R.B., Girandola, R.N., and Billing, J.E. (1980). Further simplification of a method for the determination of residual lung volume. Medicine and Science in Sports and Exercise, 12(3): 216-218.

APPENDIX A

METHODOLOGY

SELECTION OF SUBJECTS

Permission to carry out this investigation was obtained from the Human Subjects Committee of the Division of Health and Physical Education and from the Institutional Review Board for Research Involving Human Subjects of Virginia Polytechnic Institute and State University.

The subjects were 15 normal weight females currently attending Virginia Polytechnic Institute and State University. Subjects were recruited from various activity classes of the Division of Health and Physical Education and the Recreational Sports Department. Additional interested subjects also were accepted.

Criteria used for subject selection included: 1) female, 2)non-smoking, 3) non-obese (<30 percent body fat), 4) physically active, engaging in regular physical exercise at least three times per week over the last six months, and 4) age 18-24 years old. Subjects were given a written and oral explanation of the investigation including risks, benefits, and procedures. Subjects completed a medical history questionnaire and read and signed for understanding an informed consent form prior to participating in any segment of the study.

EXPERIMENTAL PROCEDURES

MAXIMAL GRADED EXERCISE TEST

Subjects completed a maximal graded exercise test on a Monark 880 cycle ergometer for the determination of functional capacity. Subjects were first familiarized with the testing procedures, the ergometer, and methods for reporting ratings of perceived exertion. Then the subjects were connected to 3-lead EKG for monitoring heart rate, and fitted with a blood pressure cuff for hemodynamic measurements. Subjects were also be fitted with mouthpiece and nose clip. The mouthpiece was attached to a Hans-Rudolph one-way non-rebreathing valve so that inspired volumes from room air could be measured by a Parkinson-Cowan Gas Flow Meter. The Parkinson-Cowan Gas Flow Meter was calibrated with known volumes using a three liter syringe. Volumes utilized to determine accuracy of these measurements included 30, 60, 90, and 120 liters. Gases expired through the non-rebreathing valve were collected in a 20 liter mixing bag and analyzed with an Ametek S3A Oxygen Analyzer and an Ametek CD3A Carbon Dioxide Analyzer (Applied Electrochemistry, Sunnyvale, CA). This expired gas system was calibrated to room air and to sample gas of known concentrations of oxygen and carbon dioxide (18% O_2 and 3% CO_2).

After a two-minute warm-up at a resistance of 25 watts at 50 rpm, the testing began with the subject working at 50 watts at a cadence of 50 rpm. Stages lasted two minutes in duration, and increased in increments of 25 watts until volitional fatigue or the subject could no longer maintain the required 50 rpm cadence. Heart rate and expired gases were analyzed at each minute, however rate of perceived exertion and blood pressure responses were monitored at the completion of each stage. Subjects were strongly encouraged to give a maximal effort.

Maximum oxygen consumption, or functional capacity, was taken as the highest attained value for absolute oxygen uptake in liters per minute. Oxygen consumptions were plotted against their corresponding heart rates, and a line of best fit was drawn for linearity. From this graph, the experimenter was able to determine 70% of maximal capacity and its corresponding heart rate to be maintained during the exercise sessions.

ESTIMATE OF BODY COMPOSITION

After the completion of the maximal exercise capacity test, body density was determined using the hydrostatic weighing technique with residual lung volume correction (Katch et al., 1967). Twelve repeated trials were performed to allow learning and improved performance of the technique. The heaviest five trials were chosen, the highest and the lowest were eliminated, and the remaining three averaged. Residual lung volume measurements were made out of water utilizing the oxygen rebreathing technique with the subjects in the same seated posture used during hydrostatic weighing (Wilmore et al., 1980). Percent fat was calculated from body density using the Siri equation (Siri, 1961). Fat weight was determined by multiplying percent fat times body weight and lean body weight was determined by subtracting fat weight from body weight.

PRE-EXERCISE CONTROLS

After completion of the graded exercise test, subjects were randomly assigned to order of exercise treatments. Treatments consisted of two 30-minute exercise sessions at an average heart rate corresponding to 70% of maximal absolute oxygen consumption. One exercise session was conducted using legs only on the Monark cycle ergometer and the other on a combined arm-and-leg ergometer, the Schwinn Air-Dyne.

Efforts were made to control pre-exercise metabolic rate. Exercise treatments were separated by at least 48 hours but not more than one week. Sessions were scheduled at approximately the same time of day to control diurnal variations in metabolic rate. In order to minimize the thermal effect of digestion, subjects were not allowed to eat less than 4 hours prior to an exercise session and the pre-exercise meal was prescribed to contain 300 kcal with fixed percentages of carbohydrates, fats, and proteins.

PRE-EXERCISE METABOLIC RATE

Prior to each exercise session, subjects were seated on the appropriate ergometer for a period of at least 15 minutes after they were fitted with EKG monitoring leads and the Hans Rudolph one-way non-rebreathing valve and mouthpiece. Subjects were requested to minimize movement and activity. Inspired volumes were measured by a Parkinson-Cowan Gas Flow Meter. The Parkinson-Cowan Gas Flow Meter was calibrated with known volumes using a three liter syringe. Volumes utilized to determine accuracy of these measurements included 30, 60, 90, and 120 liters. Gases expired through the non-rebreathing valve were collected in a 20 liter mixing bag and analyzed with an Ametek S3A Oxygen Analyzer and an Ametek CD3A Carbon Dioxide Analyzer (Applied Electrochemistry, Sunnyvale, CA). This expired gas system was calibrated to room air and to sample gas of known concentrations of oxygen and carbon dioxide (18% O_2 and 3% CO_2). During the last five minutes of the seated rest period, inspired volumes, percent 0_2, and percent CO_2 were measured in one minute intervals. A high intraclass consistency-reliability was shown for these measurements ($R=0.92$). These values were averaged and accepted as the pre-exercise resting metabolic rate for that day of testing.

EXERCISE TREATMENTS

Subjects were again connected to 3-lead EKG for monitoring heart rate, and fitted with a blood pressure cuff. Instructions were given as to appropriate rpm maintenance for the required workload for the respective ergometer. The investigator also repeated instructions for the monitoring of RPE. The subjects were familiarized with the timing of experimental measures to be taken. Prior to the start of the exercise session, subjects will be allowed to exercise at approximately 25 watts for two minutes as a warm-up.

Initial resistance for the exercise sessions was chosen to elicit the appropriate target heart rate for each individual. Resistances were modified during the exercise sessions to maintain the desired heart rate response as monitored by a three-lead EKG at five-minute intervals. When performing work on the Monark ergometer, subjects were required to maintain a 50 rpm cadence throughout the exercise bout. The cadence using the Schwinn Air-dyne corresponded to the desired workload. Subjects will be advised to use both arms and legs comfortably throughout the exercise session, but being sure that each limb makes a contribution to the total work performed. The average of the heart rates obtained during the session was accepted as the mean heart rate for the exercise session. Subjects also were monitored for blood pressure and RPE responses to exercise.

During each exercise session subjects breathed through a Hans-Rudolph one-way non-rebreathing valve so that inspired volumes could be measured and expired gases analyzed, as above, at five-minute intervals. The gas analysis system was calibrated prior to each exercise session as described above. The average of the absolute oxygen consumption values was accepted as the average oxygen consumption for the exercise treatment.

POST-EXERCISE METABOLIC RATE

At the completion of the 30 minutes, subjects were instructed to immediately cease exercise and remain seated quietly on the ergometer with a minimum of movement. Measurements for oxygen consumption were recorded as before at one-minute intervals for the first five minutes post-exercise. Subjects then were disconnected from tubing to the gas flow meter and expired gas analyzers and transferred to a comfortable chair directly behind the ergometer for the remainder of an hour post-exercise.

Thereafter, expired gases were collected in a 60 liter Douglas bag for analysis. Collections by this method were conducted at five time intervals: 10-12, 12-15, 25-30, 40-45, and 55-60 minutes post-exercise. In addition to expired gases, heart rate and blood pressure responses were monitored in time intervals congruent with gas collection.

Gases were extracted from the Douglas bag for analysis of oxygen and carbon dioxide content for one minute at a fixed rate so that the total volume was reduced by one liter. The volume of the remaining gas was determined by expelling it into a Tissot tank and converting the a measured change in centimeters to a volume in liters. The one liter extracted for analysis was added for the total volume of expired gas over the time period. Post-exercise oxygen consumption was determined to reflect an average consumption per minute over the collection interval. Oxygen consumption was expressed as a gross value and as a net value, gross oxygen consumption minus pre-exercise resting oxygen consumption.

STATISTICAL ANALYSES

EXTERNAL VALIDITY

The characteristics of the subjects, non-smoking, non-obese physically active females between the ages of 18 and 24, allow the experimental findings from this investigation to be generalizable only to a population possessing similar characteristics.

INTERNAL VALIDITY

Variance of measurements was minimized by: 1) familiarizing subjects with testing protocols and procedures, 2) calibrating all equipment prior to all testing, 3) conducting all testing at approximately the same time of day, 4) limiting participant's physical activity 48 hours prior to testing, and
5) limiting subject's caloric intake prior to exercise treatments, including a four hour fast and prescribing a pre-exercise meal with a consistent proportion of carbohydrate, protein, and fat.

DATA ANALYSIS

Repeated measures trend analysis was used to detect differences in post-exercise heart rates, excess post-exercise oxygen consumptions, and recovery RER between exercise sessions. A paired t-test was used to detect differences in post-exercise caloric expenditures.

Two-way repeated measures ANOVA's were utilized to determine whether exercise treatments were significantly different from each other in terms of exercise HR's and VO_2's. Paired t-tests were used to detect significant differences between mean achieved workload and caloric expenditure. All statistical analysis was performed on the Statistical Analysis System (SAS).

Significance was set apiori at an alpha level of 0.05. All statistical analysis was performed on the Statistical Analysis System (SAS). The summary results for these measures are located in Appendix B.

No significant differences were observed between exercise treatments using the repeated measures trend analysis in the following ($p>0.05$):

1. Excess oxygen consumption response after exercise, total
2. Excess oxygen consumption response after exercise, minutes 0-5
3. Heart response after exercise
4. Post-exercise RER, total
5. Post-exercise RER, minutes 0-5
6. Post-exercise RER, minutes 5-60

Significant differences were observed between exercise treatments using the repeated measures trend analysis in the following ($p<0.05$):

1. Excess oxygen consumption response after exercise, minutes 5-60

Paired t-tests revealed no significance between the exercise treatments in the following ($p>0.05$):

1. Mean exercise absolute oxygen consumption
2. Caloric cost of exercise
3. Excess caloric consumption after exercise, total
4. Excess caloric consumption after exercise, minutes 0-5
5. Excess caloric consumption after exercise, minutes 5-60

Two-way repeated measures ANOVA revealed no significant difference between exercise treatments in the following ($p<0.05$)

1. Exercise heart rates
2. Exercise VO_2

Paired t-tests revealed a significant between the exercise treatments in the following ($p<0.05$):

1. Mean exercise workloads achieved

CONCLUSIONS

Based on the results of this study, the researcher retained the following null hypotheses:

1. There was no difference in post-exercise oxygen consumption for the two exercise modalities, leg-only and combined arm-and-leg ergometry, after a fixed duration of exercise at similar intensity as monitored by heart rate response.

2. There was no difference in actual whole body oxygen consumption during exercise between the two modalities at a similar intensity as monitored by heart rate.

APPENDIX B
RAW DATA /STATISTICAL ANALYSIS

Resting Metabolic Rate
(L/min)

Subject	Leg-Only	Arm-and-Leg
1	0.19	0.22
2	0.19	0.22
3	0.19	0.19
4	0.17	0.17
5	0.18	0.19
6	0.19	0.19
7	0.24	0.21
8	0.20	0.22
9	0.27	0.20
10	0.17	0.22
11	0.18	0.16
12	0.17	0.16
13	0.21	0.24
14	0.26	0.26
15	0.19	0.20
Mean	0.20 ± 0.008	0.20 ± 0.007

Mean Heart Rate Response During Exercise (bpm)

Subject	Leg-Only	Arm-and-Leg
1	179.3	174.7
2	182.2	181.1
3	156.6	155.1
4	177.9	174.1
5	177.8	175.6
6	184.9	183.6
7	169.9	168.1
8	153.8	151.8
9	184.5	186.9
10	175.2	170.3
11	161.2	161.8
12	176.1	179.0
13	174.2	169.1
14	181.3	177.6
15	153.3	155.1
Mean	172.5 ± 2.8	170.9 ± 2.8

Mean Oxygen Consumption During Exercise (L/min)

Subject	Leg-Only	Arm-and-Leg
1	1.68	1.78
2	1.67	1.60
3	1.68	1.72
4	1.83	1.80
5	1.74	1.70
6	1.71	1.81
7	2.16	2.12
8	1.86	1.81
9	2.34	2.22
10	1.69	1.72
11	1.83	1.79
12	1.57	1.54
13	2.05	1.83
14	2.05	1.91
15	1.41	1.54
Mean	1.82 ± 0.06	1.79 ± 0.05

Estimated Caloric Cost of Exercise
(kcal)

Subject	Leg-Only	Arm-and-Leg
1	247.6	266.4
2	251.3	209.7
3	254.8	222.7
4	240.4	266.8
5	261.6	223.7
6	260.6	271.9
7	322.5	321.0
8	280.4	266.2
9	354.6	333.8
10	224.0	255.2
11	277.0	267.2
12	240.0	230.4
13	302.5	268.7
14	307.6	281.7
15	207.7	228.9
Mean	268.8 ± 10.0	261.0 ± 9.0

Mean Workload for Each Exercise Session (Watts)

Subject	Leg-Only	Arm-and-Leg
1	112.7	126.7
2	112.3	110.0
3	108.3	128.3
4	123.5	137.5
5	108.3	124.2
6	120.8	126.7
7	147.2	152.5
8	112.3	106.7
9	143.0	156.7
10	111.2	119.2
11	129.3	132.5
12	101.3	105.0
13	130.5	130.0
14	134.8	144.2
15	91.7	101.7
Mean	119.1 ± 4.0	126.8 ± 4.3

Post-Exercise Excess Oxygen Consumption for Leg-Only Exercise, Minutes 0 through 5 (L/min)

Subject	0	1	2	3	4	5
1	1.35	0.73	0.25	0.19	0.17	0.08
2	1.26	0.71	0.34	0.17	0.14	0.10
3	1.41	0.81	0.31	0.16	0.12	0.12
4	1.42	0.78	0.26	0.12	0.08	0.08
5	1.46	0.83	0.33	0.20	0.17	0.12
6	1.30	0.71	0.20	0.14	0.12	0.11
7	1.60	0.82	0.22	0.11	0.11	0.09
8	1.62	1.42	0.63	0.26	0.22	0.14
9	1.85	1.10	0.39	0.21	0.11	0.15
10	1.40	0.78	0.32	0.17	0.12	0.13
11	1.42	0.79	0.37	0.13	0.13	0.10
12	1.19	0.69	0.35	0.17	0.14	0.12
13	1.53	1.11	0.45	0.28	0.17	0.17
14	1.42	0.76	0.36	0.20	0.17	0.06
15	1.12	0.56	0.17	0.07	0.07	0.05
Mean	1.42 ± 0.05	0.85 ± 0.06	0.33 ± 0.03	0.17 ± 0.01	0.14 ± 0.01	.011 ± 0.01

Post-Exercise Excess Oxygen Consumption for Leg OnlyExercise, Minutes 10 through 60 (L/min)

Subject	10-12	12-15	25-30	40-45	55-60
1	0.11	0.09	0.07	0.08	0.08
2	0.10	0.12	0.04	0.06	0.06
3	0.11	0.11	0.08	0.07	0.06
4	0.13	0.13	0.05	0.07	0.08
5	0.13	0.12	0.08	0.03	0.01
6	0.10	0.08	0.08	0.07	0.03
7	0.17	0.20	0.03	0.08	0.06
8	0.11	0.10	0.05	0.01	0.00
9	0.12	0.06	0.06	0.07	-0.01
10	0.16	0.16	0.09	0.09	0.10
11	0.10	0.09	0.03	0.03	0.02
12	0.12	0.08	0.08	0.05	0.04
13	0.16	0.25	0.09	0.10	0.13
14	0.09	0.07	0.03	0.02	0.05
15	0.05	0.10	-0.01	-0.02	0.02
Mean	0.12 ± 0.01	0.12 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	0.05 ± 0.01

Post-Exercise Excess Oxygen Consumption for Arm-and-Leg Exercise, Minutes 0 through 5 (L/min)

Subject	0	1	2	3	4	5
1	1.34	0.74	0.21	0.12	0.06	0.07
2	1.29	0.68	0.35	0.16	0.15	0.11
3	1.38	0.79	0.30	0.18	0.13	0.10
4	1.74	1.02	0.36	0.22	0.19	0.09
5	1.35	0.72	0.31	0.14	0.12	0.09
6	1.47	0.73	0.23	0.19	0.12	0.09
7	1.70	0.95	0.27	0.11	0.11	0.08
8	1.20	0.85	0.40	0.16	0.14	0.09
9	1.82	0.88	0.42	0.19	0.22	0.12
10	1.52	0.89	0.34	0.19	0.10	0.10
11	1.55	0.79	0.38	0.20	0.14	0.09
12	1.27	0.70	0.35	0.19	0.15	0.14
13	1.50	0.96	0.38	0.21	0.18	0.14
14	1.74	1.08	0.35	0.20	0.13	0.09
15	1.35	0.79	0.26	0.14	0.12	0.07
Mean	1.48 ± 0.05	0.84 ± 0.03	0.33 ± 0.02	0.17 ± 0.01	0.14 ± 0.01	0.10 ± 0.01

Post-Exercise Excess Oxygen Consumption for Arm-and-Leg Exercise, Minutes 10 through 60 (L/min)

Subject	10-12	12-15	25-30	40-45	55-60
1	0.02	0.08	0.03	0.04	0.03
2	0.02	0.03	0.04	0.00	0.03
3	0.10	0.10	0.01	-0.01	0.02
4	0.13	0.10	0.09	0.05	0.07
5	0.10	0.10	0.07	0.06	0.07
6	0.09	0.08	0.03	-0.01	-0.01
7	0.09	0.10	0.03	0.11	0.04
8	0.08	0.09	0.03	0.02	0.01
9	0.12	0.14	0.02	0.10	0.07
10	0.16	0.16	0.09	0.08	0.07
11	0.08	0.12	0.08	0.06	0.06
12	0.10	0.11	0.06	0.05	0.04
13	0.14	0.14	0.06	0.14	0.07
14	0.10	0.09	0.04	0.05	0.06
15	0.04	-0.04	-0.07	-0.10	-0.10
Mean	0.09 ± 0.01	0.09 ± 0.01	0.04 ± 0.01	0.04 ± 0.02	0.01 ± 0.07

Post-Exercise Heart Rate for Leg-Only Exercise, Minutes 0 through 5 (bpm)

Subject	0	1	2	3	4	5
1	182	137	134	125	125	125
2	182	155	134	125	119	115
3	158	125	105	102	104	103
4	175	132	122	115	113	110
5	179	127	122	113	112	113
6	185	142	135	136	125	127
7	167	137	121	113	112	108
8	157	113	95	93	95	95
9	185	143	131	124	117	118
10	173	143	134	132	127	127
11	160	113	110	96	99	98
12	173	135	124	121	117	120
13	175	127	117	116	116	118
14	185	168	162	153	139	132
15	150	110	93	91	87	85
Mean	172.4 ± 3.0	133.8 ± 4.1	122.6 ± 4.5	117.0 ± 4.4	113.8 ± 3.5	112.9 ± 3.4

Post-Exercise Heart Rate for Leg-Only Exercise, Minutes 10 through 60 (bpm)

Subject	10-12	12-15	25-30	40-45	55-60
1	91	89	73	66	72
2	98	88	82	76	70
3	93	90	80	73	75
4	95	93	84	83	88
5	99	95	94	65	63
6	99	94	78	69	77
7	91	87	76	72	65
8	80	81	73	72	60
9	103	94	84	79	66
10	114	108	95	94	87
11	88	80	67	64	64
12	109	114	78	72	85
13	101	97	93	92	92
14	102	101	102	103	83
15	67	70	63	57	65
Mean	95.3 ± 3.4	92.1 ± 2.8	81.5 ± 2.8	75.8 ± 3.2	74.1 ± 2.7

Post-Exercise Heart Rate for Arm-and-Leg Exercise,

Minutes 0 through 5 (bpm)

Subject	0	1	2	3	4	5
1	173	131	124	119	111	112
2	185	154	140	127	123	123
3	154	117	97	99	96	94
4	175	131	113	111	100	109
5	175	135	122	119	115	111
6	184	132	125	119	120	112
7	167	122	118	112	103	104
8	145	115	91	87	85	79
9	187	145	135	124	125	117
10	174	139	126	119	113	110
11	164	119	110	113	103	100
12	182	147	132	125	123	129
13	174	138	122	118	119	117
14	189	161	147	146	144	143
15	157	114	97	98	85	76
Mean	170.3 ± 3.5	133.3 ± 3.7	119.9 ± 4.2	115.7 ± 3.6	111.0 ± 4.1	109.1 ± 4.5

Post-Exercise Heart Rate for Arm-and-Leg Exercise, Minutes 10 through 60 (bpm)

Subject	10-12	12-15	25-30	40-45	55-60
1	96	93	72	57	60
2	108	103	84	80	74
3	86	83	78	74	70
4	92	92	76	80	72
5	93	92	75	73	62
6	99	95	77	78	87
7	96	94	77	78	80
8	74	74	74	62	58
9	97	97	84	78	68
10	108	107	93	87	84
11	94	92	73	74	72
12	105	101	89	89	78
13	93	98	78	80	76
14	109	108	105	105	104
15	68	68	62	60	66
Mean	94.5 ± 3.0	93.1 ± 2.9	79.8 ± 2.6	77.0 ± 3.1	74.1 ± 3.0

Total Excess Caloric Consumption After Exercise (kcal)

Subject	Leg-Only	Arm-and-Leg
1	32.5	20.7
2	28.8	17.8
3	33.7	19.3
4	32.0	35.5
5	29.9	30.7
6	29.3	17.8
7	35.0	31.7
8	30.2	22.0
9	30.9	36.0
10	40.9	39.3
11	23.7	33.1
12	29.3	29.5
13	44.3	42.3
14	22.8	30.1
15	11.8	-2.0
Mean	30.3 ± 1.9	26.9 ± 2.9

Excess Caloric Consumption After Exercise,

Minutes 0 through 5 (kcal)

Subject	Leg-Only	Arm-and-Leg
1	10.3	9.2
2	10.2	10.2
3	10.8	10.7
4	10.0	13.5
5	11.6	10.1
6	9.4	10.3
7	10.5	11.7
8	17.1	11.0
9	14.1	13.4
10	10.8	11.7
11	10.9	11.7
12	10.0	10.5
13	14.3	12.8
14	11.2	13.4
15	7.3	10.1
Mean	11.2 ± 0.6	11.4 ± 0.4

Excess Caloric Consumption After Exercise, Minutes 5 through 60 (kcal)

Subject	Leg-Only	Arm-and-Leg
1	22.3	11.6
2	18.7	7.6
3	22.8	8.6
4	22.1	21.9
5	18.3	20.6
6	19.9	7.6
7	24.5	20.0
8	13.1	11.1
9	16.9	22.6
10	30.2	27.6
11	12.8	21.4
12	19.3	19.0
13	30.0	29.5
14	11.7	16.7
15	4.5	-12.1
Mean	19.1 ± 1.8	15.6 ± 2.7

Post-Exercise Respiratory Exchange Ratio for Leg-Only Exercise, Rest and Minutes 1 through 5

Subject	Rest	1	2	3	4	5
1	0.83	0.90	0.91	0.95	0.94	0.93
2	0.91	0.97	1.04	1.03	1.00	0.97
3	0.85	0.94	1.01	0.99	0.96	0.94
4	0.86	0.99	1.05	1.03	1.00	1.00
5	0.83	0.94	0.97	1.00	0.96	0.94
6	0.90	0.97	0.95	0.97	0.94	0.93
7	0.85	0.91	0.93	0.94	0.91	0.91
8	0.91	0.98	1.01	1.00	1.00	1.00
9	0.92	1.01	1.05	1.04	1.00	1.00
10	0.87	0.96	0.96	0.97	1.00	0.93
11	0.91	0.98	1.05	1.13	1.03	0.96
12	0.83	0.91	0.94	0.97	0.97	0.97
13	0.83	0.92	0.92	0.92	0.92	0.89
14	0.86	0.92	0.94	0.93	0.91	0.94
15	0.89	0.93	0.97	0.96	0.92	0.92
Mean	0.87 ± 0.01	0.95 ± 0.01	0.98 ± 0.01	0.99 ± 0.01	0.96 ± 0.01	0.95 ± 0.01

Post-Exercise Respiratory Exchange Ratio for Leg-Only Exercise, Minutes 10 through 60

Subject	10-12	12-15	25-30	40-45	55-60
1	0.73	0.64	0.65	0.67	0.67
2	0.69	0.68	0.70	0.68	0.72
3	0.67	0.61	0.57	0.60	0.61
4	0.90	0.90	0.73	0.75	0.80
5	0.67	0.65	0.59	0.60	0.62
6	0.67	0.67	0.63	0.65	0.68
7	0.68	0.66	0.59	0.63	0.67
8	0.68	0.67	0.64	0.67	0.70
9	0.79	0.73	0.70	.74	0.73
10	0.70	0.67	0.69	0.73	0.67
11	0.64	0.67	0.67	0.67	0.70
12	0.66	0.64	0.60	0.64	0.62
13	0.62	0.61	0.57	0.61	0.59
14	0.66	0.70	0.66	0.61	0.65
15	0.71	0.69	0.67	0.71	0.67
Mean	0.70 ± 0.02	0.68 ± 0.02	0.64 ± 0.01	0.66 ± 0.01	0.67 ± 0.01

Post-Exercise Respiratory Exchange Ratio for Arm-and-Leg Exercise, Rest and Minutes 1 through 5

Subject	Rest	1	2	3	4	5
1	0.98	0.97	1.00	1.00	0.96	0.97
2	0.90	0.93	0.96	0.97	0.95	0.94
3	0.84	0.90	0.96	0.95	0.94	0.93
4	0.84	0.96	1.00	1.00	1.00	0.96
5	0.92	0.95	0.99	1.00	0.99	0.98
6	0.91	0.92	0.95	0.95	0.94	0.93
7	0.93	0.94	0.96	0.94	0.94	0.93
8	0.91	0.95	0.97	0.97	0.97	0.94
9	0.92	0.94	0.95	1.00	0.95	0.97
10	0.89	0.91	0.95	0.95	0.94	0.91
11	0.84	0.95	0.98	1.00	1.00	0.96
12	0.94	0.93	0.96	1.00	1.00	1.00
13	0.81	0.95	0.97	0.96	0.93	0.92
14	0.81	0.94	0.95	0.96	0.92	0.91
15	0.86	0.91	0.93	0.91	0.91	0.93
Mean	0.89 ± 0.02	0.94 ± 0.01	0.97 ± 0.01	0.97 ± 0.01	0.96 ± 0.01	0.95 ± 0.01

Post-Exercise Respiratory Exchange Ratio for Arm-and-Leg Exercise, Minutes 10 through 60

Subject	10-12	12-15	25-30	40-45	55-60
1	0.75	0.80	0.80	0.81	0.80
2	0.67	0.64	0.65	0.64	0.64
3	0.66	0.66	0.60	0.61	0.62
4	0.70	0.70	0.58	0.64	0.67
5	0.71	0.70	0.65	0.66	0.67
6	0.68	0.67	0.64	0.67	0.67
7	0.83	0.74	0.67	0.81	0.84
8	0.67	0.61	0.64	0.67	0.65
9	0.66	0.71	0.64	0.73	0.70
10	0.61	0.61	0.55	0.57	0.62
11	0.67	0.68	0.68	0.68	0.68
12	0.69	0.67	0.59	0.62	0.65
13	0.63	0.61	0.57	0.58	0.55
14	0.72	0.66	0.63	0.61	0.63
15	0.67	0.69	0.62	0.70	0.60
Mean	0.69 ± 0.02	0.68 ± 0.02	0.63 ± 0.03	0.67 ± 0.03	0.67 ± 0.03

Results of Trend Analysis Comparing Post-Exercise Excess Oxygen Consumption After Leg Only Versus Arm and Leg Exercise

Comparison Across One Hour Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	0.0079	1.05	0.3233
Time	9	3.5168	385.08	0.0001*
Cond*Time	9	0.0007	0.24	0.9884

*p<0.05

Comparison Across Minutes 1-5 Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	0.0002	0.02	0.9030
Time	4	5.5764	414.50	0.0001*
Cond*Time	4	0.0040	0.04	0.9968

*p<0.05

Comparison Across Minutes 5-60 Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	0.0127	6.17	0.0260*
Time	5	0.0607	43.28	0.0001*
Cond*Time	5	0.0003	0.49	0.7825

*p<0.05

Results of Two-Way Repeated Measures ANOVA Comparing Exercise Treatments

Two-Way Repeated Measures ANOVA for Exercise Heart Rates

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Exercise (A)	1	209.09	209.089	.282	.5997
subjects w. groups	28	20772.56	741.877		
Repeated Measure (B)	5	2936.38	587.276	34.664	.0001*
AB	5	411.44	82.289	4.857	.0004*
B x subjects w. groups	140	2371.84	16.942		

*p<0.05

Two-Way Repeated Measures ANOVA for Exercise VO_2

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Exercise (A)	1	.071	.071	.261	.6133
subjects w. groups	28	7.631	.273		
Repeated Measure (B)	5	1.541	.308	19.284	.0001*
AB	5	.491	.098	6.148	.0001*
B x subjects w. groups	140	2.238	.016		

*p<0.05

Results of Paired T-Tests Comparing Exercise Treatments

Mean Achieved Workload During Leg Only Versus Arm and Leg Exercise

Mean Difference	Standard Error	T-Ratio	Prob>|T|
-7.6467	1.8664	-4.0970	0.0011*

*p<0.05

Total Caloric Cost of Work During Leg Only Versus Arm and Leg Exercise

Mean Difference	Standard Error	T-Ratio	Prob>|T|
2.4667	4.3448	1.2394	0.5792

*p<0.05

Results of Tests Analyzing Pre-Exercise Metabolic Rate

Resting Metabolic Rate Prior to Exercise Treatments

Mean Difference	Standard Error	T-Ratio	Prob>|T|
-0.003	0.008	-0.442	0.6651

*p<0.05

Repeated Measures ANOVA for Pre-Exercise Resting Metabolic Rate Measurements

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	29	.12	.004	13.051	.0001*
Within subjects	120	.038	3.180E-4		
treatments	4	.001	1.493E-4	.461	.7641
residual	116	.038	3.238E-4		
Total	149	.159			

*p<0.05

Reliability Estimates for- All treatments: 0.923 Single Treatment: 0.707

Results of Trend Analysis Comparing Post-Exercise Heart Rate After Leg Only Versus Arm and Leg Exercise

Comparison Across One Hour Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	96.33	0.88	0.3637
Time	9	25,248.59	193.54	0.0001*
Cond*Time	9	20.73	0.84	0.5764

*p<0.05

Comparison Across Minutes 1-5 Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	183.71	1.72	0.2102
Time	4	4,976.82	128.79	0.0001*
Cond*Time	4	13.56	0.92	0.4575

*p<0.05

Comparison Across Minutes 5-60 Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	21.36	0.23	0.6415
Time	5	11,575.67	104.14	0.0001*
Cond*Time	5	27.16	1.21	0.3143

*p<0.05

Results of Paired T-Tests Comparing Post-Exercise Excess Caloric Consumption After Leg Only Versus Arm and Leg Exercise

Comparison Across One Hour Post-Exercise

Mean Difference	Standard Error	T-Ratio	Prob>|T|
3.4200	2.0472	1.6706	0.1170

*p<0.05

Comparison Across Minutes 0-5 Post-Exercise

Mean Difference	Standard Error	T-Ratio	Prob>|T|
-0.1267	0.5846	-0.2167	0.8316

*p<0.05

Comparison Across Minutes 5-60 Post-Exercise

Mean Difference	Standard Error	T-Ratio	Prob>|T|
3.5467	2.0108	1.7638	0.0996

*p<0.05

Results of Trend Analysis Comparing Post-Exercise Respiratory Exchange Ratio After Leg Only Versus Arm and Leg Exercise

Comparison Across One Hour Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	0.0053	0.42	0.5261
Time	9	1.4333	468.60	0.0001*
Cond*Time	9	0.0003	0.32	0.9658

*p<0.05

Comparison Across Minutes 1-5 Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	0.0047	1.50	0.2404
Time	4	0.0152	17.70	0.0001*
Cond*Time	4	0.0002	0.93	0.4534

*p<0.05

Comparison Across Minutes 5-60 Post-Exercise

Source	DF	Mean Square	F-Value	Prob>F
Condition	1	0.0123	0.10	0.7604
Time	5	0.7923	288.80	0.0001*
Cond*Time	5	0.0002	0.25	0.9383

*p<0.05

APPENDIX C

REQUEST TO HUMAN SUBJECTS FORM

CERTIFICATE
OF
APPROVAL FOR RESEARCH
INVOLVING HUMAN SUBJECTS

Division of HPE

The Human Subjects Committee of the Division of Health and Physical Education has reviewed the research proposal of Stuart M.C. Lee and Dr, Reed Humphrey entitled The Elevation of Metabolic Rate after Combined Arm-and-Leg versus Leg-Only Exercise.

The members have judged the subjects' participation in the related experiment (not to be at risk) as a result of their participation.

(If a risk proposal) Procedures have been adopted to control the risks at acceptably low levels. The potential scientific benefits justify the level of risk to be imposed.

Members of the Divisional
Human Subjects Committee

________________________ Chairman	__________________ Date
________________________	__________________ Date
________________________	__________________ Date
________________________	__________________ Date

REQUEST FOR APPROVAL OF RESEARCH PROPOSAL IN THE DIVISION OF HPE

Submitted to
Dr.Charles Baffi
Chairman, Division Human Subjects Committee and/or
Chairman, Instructional Review Board

by

Stuart M.C. Lee & Dr. Reed Humphrey
Principal Investigators

TITLE: The Elevation of Metabolic Rate after Combined Arm-and-Leg versus Leg-Only Exercise

BACKGROUND/SCIENTIFIC JUSTIFICATION: There has been a significant amount of research suggesting the importance of the combination of diet and exercise over diet alone or exercise alone in weight loss programs. Although it is known that the expenditure of calories during exercise has a significant impact, it is currently unclear as to what role the elevation of metabolic rate after exercise plays in the total number of calories expended above normal daily activities. However, since previous investigations have demonstrated that there may be an elevation of metabolic rate up to 24 hours post-exercise, this phenomenon merits further elucidation.

PURPOSE(S): To determine the effect of combined arm-and-leg versus leg-only exercise on the elevation of metabolic rate and caloric expenditure during the first hour after exercise.

EXPERIMENTAL METHODS & PROCEDURES: Fifteen normal weight (<30% body fat) healthy college-age females will be recruited to participate in this study. Before testing, each subject will complete a detailed Medical History Questionnaire to determine their appropriateness for this exercise study. Selected subjects then will be given a detailed informed consent form explaining all aspects of this study for their review and agreement. After orientation to the experimental procedures, subjects will have their residual lung volume, body density, and total weight determined. Thereafter subjects will undergo a maximal exercise capacity test while being monitored for heart rate and blood pressure responses and perception of exertion. Expired gases will also be collected to assess metabolic rate. From the information obtained from the exercise test, subjects will be prescribed a moderate exercise level to be maintained during two separate 30-minute exercise sessions. One exercise session will involve riding a Monark cycle ergometer, a leg-only exercise, and the other will involve riding a Schwinn Air-Dyne, a combined arm-and-leg exercise. Order of exercise treatments will be random and be separated by at least 48 hours. During each exercise session subjects will again be monitored in the same manner as during the maximal exercise test. At the completion of the exercise sessions, subjects will remain in the laboratory for one hour while periodic monitoring continues. All testing will be conducted in the Laboratory for Exercise, Sport, and Work Physiology.

STATEMENT DESCRIBING LEVEL OF RISK TO SUBJECTS: The level of risk during this experiment is low and will be controlled through appropriate procedures.

PROCEDURES TO MINIMIZE SUBJECT RISK (IF APPLICABLE): Subjects will complete a Medical History Questionnaire to determine appropriateness for exercise testing and exercise sessions. Orientations and detailed explanations will be given to the subjects about all experimental procedures to ensure subject's comfort and safety. During all exercise sessions, subjects will be monitored for inappropriate heart rate and blood pressure responses. Their post-exercise responses will be monitored in a seated position for one hour. All testing will be handled by experienced exercise testing technicians. In addition, there are standardized emergency procedures developed for the Laboratory for Exercise, Sport, and Work Physiology which allows for prompt medical response from the Virginia Tech Rescue Squad personnel should the need arise.

RISK/BENEFIT RATIO (IF RISK PROJECT): Risk will be low and benefits will be high. Subjects will receive copies of their maximal exercise capacity tests for their medical records. Counseling for appropriate levels of exercise will be given based on their performance. In addition, they will receive accurate measurement of their current percent body fat.

APPENDIX D

INFORMED CONSENT FORM

LABORATORY FOR EXERCISE, SPORT, AND WORK PHYSIOLOGY
Division of Health and Physical Education
Virginia Polytechnic Institute and State University

Informed Consent

Title of Study: The Elevation of Metabolic Rate after Combined Arm-and-Leg versus Leg-Only Exercise

Purpose of Study: Exercise has been determined to be an important adjunct to weight loss programs. It is the purpose of this study to determine if combined arm-and-leg exercise or leg-only exercise is more beneficial to weight loss programs in terms of caloric expenditure during and after exercise.

Study Requirements:

1. Completion of a detailed medical history form including information such as family history of heart disease and hypertension (high blood pressure), any personal past or present illness, injuries, or health related problems requiring medical attention, and current exercise habits.

2. Performing a maximal aerobic exercise capacity test (ie., a progressive exercise test which requires the subject to attain the point of maximal physical exertion) on a cycle ergometer with continuous monitoring of physiologic parameters (heart rate, blood pressure, and expired gases).

3. Performing two controlled exercise sessions on two separate days in random order. Exercise sessions to consist of either combined arm-and-leg or leg-only exercise with the same physiologic parameters monitored as before. Also, a required one hour rest period after exercise for continued monitoring.

4. Abstaining from exercise, food, beverages, tobacco, and analgesics for predesignated durations prior to each experimental session.

5. Having an estimation of body composition using the techniques utilizing skinfold measurements and hydrostatic weighing. The skinfold technique involves the measurement of pinches of skin and subcutaneous fat at selected sites on the body. Hydrostatic weighing is a procedure of whole body immersion and weighing so as to determine the buoyancy of the body.

Risks Associated with Participation:

This study will be supervised by Dr. Reed Humphrey, an American College of Sports Medicine certified Preventive and Rehabilitative Exercise Specialist and Program Director, and conducted by Stuart Lee, a second-year graduate student in exercise physiology with extensive experience in exercise testing. The protocols for this investigation have been reviewed by a committee of faculty members in exercise physiology and approved by the Human Subjects Committee of the Division of Health and Physical Education and the Institutional Review Board of the university. Although all procedures will be performed by trained technicians under laboratory conditions, there is always the possibility of adverse effects due to participation in this study. Possible risks and discomforts include, but are not limited to, strains, sprains, fractures, delayed muscle soreness, infections, and even the remote possibility of death. Other types of injury may occur, but it is not possible to specifically state each and every individual risk. A standardized emergency protocol is established in the Laboratory for Exercise, Sport, and Work Physiology to notify and secure prompt medical services. However, no direct medical treatment or compensation is available if injury is incurred. It is understood that the subjects reserve the right to abstain from participation in any part of this experiment or withdraw from the experiment should she feel that the activities may be injurious to her health.

All subjects will be requested to complete a medical history form. It is the subject's responsibility to advise the researchers of any pre-existing or current medical problem that may affect her participation. Based upon the subject's responses to the medical history form, the experimenter reserves the right to terminate a subject's participation should the experimenter feel that the activities may be injurious to the subject's well-being. It is also the subject's responsibility to notify the experimenter of any discomforts, injuries, or any adverse experiences during the course of the experiment. All subjects will be debriefed by the experimenter at the completion of the study.

Benefits Associated with Participation:

Subjects may request feedback regarding their aerobic fitness level based upon their maximal exercise test. Information may also be requested regarding a target heart rate range for aerobic exercise training based upon the the information gathered during this study. Prediction of body composition and resting metabolic rate may also be available.

Confidentiality:

I understand that any data of a personal nature will be held in confidence and will be used for research purposes only. I also understand that this may only be used when not identifiable with my person.

I have read and understood the above statements and have had the opportunity to ask questions. I understand that the researchers will, at any time, answer my inquiries concerning the procedures used in this experiment.

Signature:______________________________ Date:__________

Witness:_______________________________ Date:__________

Project Coordinator: Stuart Lee (552-5169/231-5006)
Project Supervisor: Dr. Reed Humphrey (231-5834)
HPE Human Subjects Chairperson: Dr. Charles Baffi (231-8284)
University Human Subjects Chairperson: Dr. Ernie Stout (231-5281)

APPENDIX E

MEDICAL HISTORY FORM

HEALTH STYLE QUESTIONNAIRE

Name:____________________________
ID#:________________________

Sex:______ Age:____________ Phone #:__________

MEDICAL HISTORY

Have you ever had:	YES	NO
Heart Disease or heart problems	_____	_____
Lung disease or difficulty breathing	_____	_____
Difficulty with cold hands or feet	_____	_____
Stroke	_____	_____
Kidney disease	_____	_____
High cholesterol	_____	_____
High triglycerides	_____	_____
Diabetes	_____	_____
Raynaud's Syndrome	_____	_____
Any operations (Type/Date)	_____	_____

____
____
____

Have you ever had a blood pressure reading above normal (140/90)	_____	_____
Have you ever been diagnosed ashaving hypertension?	_____	_____

Please list any medications which you are currently taking:______________________
____

Are you allergic to any medications, drugs, or foods? If so, please list.________________
____

Has anyone in your family been diagnosed as having:	YES	NO	RELATIONSHIP	AGE AT ONSET
High blood pressure/hypertension	_____	_____	_____________	______
Heart disease or heart attack	_____	_____	_____________	______
Stroke	_____	_____	_____________	______
Diabetes	_____	_____	_____________	______
Kidney disease	_____	_____	_____________	______

HEALTH HABITS

	YES	NO	
Drink caffeinated tea, coffee, or soda	_____	_____	_____cups/days
Drink alcohol	_____	_____	_____drinks/day
Add salt to meal before tasting	_____	_____	_____
Smoke cigarettes	_____	_____	_____cigs/day
Sleep			_____hours/night

EXERCISE HABITS

During the past 3 months, have you engaged in any regular (3 times/week) physical exercise?
_____Yes _____No

If yes, please list below any activities in which you engaged in an average week over the past month (Please include competitive, recreational, or leisure time activities). Also, include frequency and duration (or number of laps, miles, sets, games, etc.) of the activity and PLEASE BE AS SPECIFIC AS POSSIBLE!!

ACTIVITY	FREQUENCY	DURATION
1.___		
2.___		
3.___		
4.___		
5.___		

Do you have any orthopedic problems which may restrict your ability to participate in exercise sessions consisting of stationary cycling or combined arm-and-leg exercise?
YES_____ NO_____

If yes, please explain:____

The testing for this study will take place any day of the week, depending on your availability and that of the investigators. We will make every effort possible to meet the needs of your schedule. Please assist us by listing below times that you are not available to be scheduled for testing.

____

____

____

____

This study requires that you refrain from food, beverages (except water), tobacco products, and analgesics (aspirin, etc.) for up to four hours prior to all exercise sessions. You will also be asked to refrain from exercise for 48 hours prior to testing. Do you feel willing and capable to abide by these requests?

Yes_____ No_____

If no, please explain:____

APPENDIX F

PRE-EXERCISE MEAL FORM

WHAT TO EAT BEFORE COMING TO EXERCISE

** EAT YOUR MEAL AT LEAST 4 HOURS BEFORE THE EXERCISE SESSION.

NO CAFFEINE!!

** USE THE EXCHANGE LIST PROVIDED TO CHOOSE THE FOODS TO COMPLETE YOUR PRE-EXERCISE MEAL.

BASIC EXCHANGE MEAL:

2 BREAD EXCHANGES	(ABOUT 140 CALORIES)
1 MEAT EXCHANGE	(ABOUT 75 CALORIES)
1 FAT EXCHANGE	(ABOUT 45 CALORIES)
1 FRUIT EXCHANGE	(ABOUT 40 CALORIES)
TOTAL	300 CALORIES

SAMPLE MEALS:

1) 2 slices whole wheat bread
   1/4 c. tuna fish
   1 tsp. mayonnaise
   1 small apple

2) 1 c. oatmeal
   1 egg
   1 tsp. margarine
   1/2 c. orange juice

3) 1 bagel
   2 tbsp. peanut butter
   1 tbsp. cream cheese
   1/2 small banana

4) 1/2 English muffin
   1 slice American cheese
   1 1/2 c. popcorn
   1 tsp. margarine
   1/3 c. apple juice

These are some example meals. Once you understand how the exchange system works, you can develop your own pre-exercise meals. Just be sure that you follow the "recipe":

2 BREAD EXCHANGES
1 MEAT EXCHANGE
1 FAT EXCHANGE
1 FRUIT EXCHANGE

PLEASE WRITE DOWN WHAT YOU ATE FOR EACH PRE-EXERCISE MEAL SO THAT I CAN INCLUDE IT WITH THE OTHER EXEPERIMENTAL DATA. THANK YOU VERY MUCH FOR YOUR PARTICIPATION AND COOPERATION!!

Foods allowed in reasonable amounts

Seasonings: Celery salt, cinnamon, garlic, garlic or onion salt, horseradish, lemon, mint, mustard, nutmeg, parsley, pepper, noncaloric sweeteners, spices, vanilla, and vinegar.

Other Foods: Coffee or tea (no sugar or cream), diet beverage without sugar, fat-free broth, bouillon, unflavored gelatin, artificially sweetened fruit-flavored gelatin, sour or dill pickles, and cranberries or rhubarb (without sugar).

List 1 milk values

Each portion supplies approximately 12 gm of carbohydrate and 8 gm of protein; the fat content and total calories vary with the type of milk. (One fat exchange equals 5 gm of fat.)

	measurement	fat exchanges	calories
Milk			
Buttermilk	1 cup	—	80
Evaporated, undiluted			
Skim	½ cup	—	80
Whole	½ cup	2	170
Nonfat dry milk mixed according to directions on box	1 cup	—	80
Nonfat dry milk powder	⅓ cup	—	80
Skim	1 cup	—	80
1% butterfat	1 cup	½	107
2% butterfat	1 cup	1	125
Whole	1 cup	2	170
Yogurt, plain, made with skim milk	1 cup	—	80

If substitution for the milk indicated in the diet plan is desired, either choose a milk product that contains the same number of fat exchanges or allow for the difference in the meal plan. For example, if the diet plan calls for 1 cup of skim milk (no fat exchange), substitute 1 cup of 2% milk by omitting one fat exchange.

List 2 vegetable exchanges

Each portion (except for vegetables marked with an *) supplies approximately 5 gm of carbohydrate and 2 gm of protein, or 25 calories. One serving equals ½ cup.

Asparagus
Beans, green or yellow
Bean sprouts
Beets
Broccoli
Brussels sprouts
Cabbage
Carrots
Cauliflower
Celery
*Chicory
*Chinese cabbage
Cucumbers
Eggplant
*Endive
*Escarole
Greens: beet, chard, collard, dandelion, kale, mustard, spinach, turnip
*Lettuce
Mushrooms
Okra
Onions
*Parsley
Peppers, green or red
*Radishes
Rutabagas
Sauerkraut
Squash, summer
Tomatoes
Tomato juice
Turnips
Vegetable juice cocktail
*Watercress
Zucchini

---

*May be used as desired.

List 3 fruit exchanges

(fresh, dried, or frozen or canned without sugar or syrup)

Each portion supplies approximately 10 gm of carbohydrate, or 40 calories.

	measurement
Apple	1 small (2" diam.)
Apple juice or cider	⅓ cup
Applesauce	½ cup
Apricots, fresh	2 med.
Apricots, dried	4 halves
Banana	½ small
Berries (boysenberries, blackberries, blueberries, raspberries)	½ cup
Cantaloupe	¼ (6" diam.)
Cherries	10 large
Dates	2
Figs, fresh	1 large
Figs, dried	1 small
Fruit cocktail	½ cup
Grapefruit	½ small
Grapefruit juice	½ cup
Grapes	12
Grape juice	¼ cup
Honeydew melon	⅛ (7" diam.)
Mandarin oranges	¾ cup
Mango	½ small
Nectarine	1 small
Orange	1 small
Orange juice	½ cup
Papaya	¾ cup
Peach	1 med.
Pear	1 small
Persimmon, native	1 med.
Pineapple	½ cup
Pineapple juice	⅓ cup
Plums	2 med.
Prunes	2 med.
Prune juice	¼ cup
Raisins	2 tbsp
Strawberries	¾ cup
Tangerine	1 large
Watermelon	1 cup

List 4 bread exchanges

Each portion supplies approximately 15 gm of carbohydrate and 2 gm of protein, or 70 calories.

	measurement
Bread, French, raisin (without icing), rye, white, whole-wheat	1 slice
Bagel	½
Biscuit, roll	1 (2" diam.)
Bread crumbs, dried	3 tbsp
Bun (for hamburger or wiener)	½
Cornbread	1" x 2" x 2"
English muffin	½
Muffin	1 (2" diam.)
Cake, angel or sponge, without icing	1½" cube (1/10 of 10"-diam. cake)
Cereal, cooked	½ cup
Dry (flakes or puffed)	¾ cup
Cornstarch	2 tbsp
Crackers, graham	2 (2½" sq)
Oyster	20 (½ cup)
Round	6
Rye wafer	3 (2" x 3½")
Saltine	6
Variety	5 small
Flour	2½ tbsp
Matzoth	1 (6" diam.)
Popcorn, popped, unbuttered, small-kernel	1½ cups
Pretzels (3-ring)	6
Rice or grits, cooked	½ cup
Spaghetti, macaroni, noodles, cooked	½ cup
Tortilla	1 (6" diam.)
Vegetables	
Beans, baked, without pork	¼ cup
Lima, navy, etc., dry, cooked	½ cup
Corn	⅓ cup
Corn on the cob	½ med. ear
Parsnips	⅔ cup
Peas, dried (split peas, etc.) or green, cooked	½ cup
Potatoes, sweet, or yams, fresh	¼ cup
White, baked or boiled	1 (2" diam.)
White, mashed	½ cup
Pumpkin	¾ cup
Squash, winter (acorn or butternut)	½ cup
Wheat germ	¼ cup

List 5 meat exchanges

Each portion supplies approximately 7 gm of protein and 5 gm of fat, or 73 calories.

	measurement
Cheese, cheddar, American, Swiss	1-oz slice (3½" sq, ⅛" thick)
Cottage	¼ cup
Egg	1
Fish and seafood	
Halibut, perch, sole, etc.	1-oz slice (4" x 2" x ¼")
Oysters, clams, shrimp, scallops	5 small
Salmon, tuna, crab	¼ cup
Sardines	3 med.
Meat and poultry	
Beef, lamb, pork, veal, ham, liver, chicken, etc. (med. fat)	1-oz slice (4" x 2" x ¼")
Cold cuts	1½-oz slice (4½" sq, ⅛" thick)
Vienna sausages	2
†Wiener	1 (10 per lb)
Peanut butter (omit two additional fat exchanges)	2 tbsp

---

†Limit wieners to one exchange per day.

List 6 fat exchanges

Each portion supplies approximately 5 gm of fat, or 45 calories.

	measurement
Avocado	⅛ (4" diam.)
Bacon, crisp	1 slice
Butter or margarine	1 tsp
Cream, half-and-half	3 tbsp
Heavy, 40%	1 tbsp
Light, 20%	2 tbsp
Sour	2 tbsp
Cream cheese	1 tbsp
Dressing, French	1 tbsp
Italian	1 tbsp
Mayonnaise	1 tsp
Mayonnaise-type	2 tsp
Roquefort	2 tsp
Nuts	6 small
Oil or cooking fat	1 tsp
Olives	5 small

Miscellaneous foods

The following foods may be used if you wish, but they must be figured into the daily diet plan, with the food exchanges allowed as indicated.

	measurement	exchanges
Fish sticks, frozen	3 sticks	1 bread, 2 meat
Fruit-flavored gelatin	¼ cup	1 bread
Ginger ale	7 oz	1 bread
Ice cream, vanilla, chocolate, strawberry	½ cup	1 bread, 2 fat
Low-calorie dressing, French or Italian	1 tbsp	—‡
Potato or corn chips	10 large or 15 small	1 bread, 2 fat
Sherbet	½ cup	2 bread
Vanilla wafers	6	1 bread
Waffle, frozen	1 (5½")	1 bread, 1 fat

---

‡The fat and calorie content do not have to be counted if the amount is limited to 1 tablespoonful.

See back of sheet for Daily Menu Guide.

VITA

Stuart Matthew Clark Lee was born on November 30, 1965, in Northampton, Massachusetts, the fourth of four children born to Dr. John Arthur Noel Lee and Dorothy Joy (Clark) Lee. Stuart lived with his family in Amherst, Massachusetts while his father taught at the University of Massachusetts in the Computer Science Department. They remained there, except for one year in Denver, Colorado, until 1974 when they moved to Blacksburg, Virginia so that Dr. Lee could accept a professorship at Virginia Polytechnic Institute and State University (Virginia Tech). Stuart attended school in Blacksburg, except for another year's trip with his family to San Jose, California, until he graduated from Blacksburg High School in 1983. Stuart was accepted for membership in the National Honor Society for his academic achievements, and was fourth in his class of 250.

During this time Stuart became involved in several extracurricular activities. Stuart performed in the marching, symphonic and jazz bands at his school and was selected three times to the All-Regional Bands. Also, he was very active in the Boy Scouts of America, and received the organization's two top awards, Eagle Scout and God and Life Awards. Stuart tried some scholastic sports teams, including cross country, tennis, and football, but found satisfaction only in the sport of kayaking, which his father had taught each of the children of the family. Stuart won numerous kayak races in the junior divisions, including the State and Southeastern Regional Championships.

After graduating from high school, Stuart accepted a full scholarship from Old Dominion University. He attended ODU in the pre-Physical Therapy division for one year until returning to Blacksburg in 1984 to attend Virginia Tech. At Tech, he completed a Bachelor's degree in the field of Exercise Science with a minor in Biology. For his undergraduate work he received membership in Phi Kappa Phi, Golden Key, and Gamma Beta Phi National Honor Societies and a Senior Scholarship Award from the College of Education.

After graduating, Stuart remained in Blacksburg to work at The Fitness Connection, a hospital-owned wellness center, as Assistant Director for two years until returning to Virginia Tech for his graduate studies. He completed a Master's degree in Exercise Physiology with a concentration in Cardiac Rehabilitation in January, 1992. During the two years that he was at Tech, Stuart received the Outstanding First Year Graduate Student Award, and was certified by the American College of Sports Medicine as a Clinical Exercise Specialist.

Currently, Stuart lives in Clear Lake City, TX, and works for Krug Life Sciences, a biomedical contractor for NASA at the Johnson Space Center. His present research encompasses zero gravity-induced cardiovascular and muscular deconditioning and appropriate countermeasures. His future plans include returning to graduate school to pursue a PhD., and teaching Exercise Physiology at the college-level.