Effects of standard set weight training and circuit weight training on excess post exercise oxygen consumption
by Emmett Thomas Murphy

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education
Montana State University

Abstract:
The purpose of this study was to compare the effects of standard set weight training and circuit weight training on excess postexercise oxygen consumption. The exercises and order of exercises were the same for both programs. The weight programs differed in three respects: 1. a circuit approach as opposed to three sets of the same exercise; 2. the percent of maximum weight used was high in standard weight training (80%) and low in circuit weight training (50%); and 3. the rest periods were shorter for circuit weight training (30 seconds) than standard weight training (120 seconds). This longer rest period resulted in a longer standard program (50 minutes) than the circuit program (19 minutes) . Ten untrained, college males performed both weight training programs. Resting metabolic rate was determined prior to each weight program followed by a determination of excess postexercise oxygen consumption.

The magnitude and duration of excess postexercise oxygen consumption produced by circuit weight training were significantly (P<.01) greater than those produced by standard weight training. The excess postexercise oxygen consumption produced by circuit weight training was 2 0 minutes in duration with a net caloric cost estimated at 24.9 kilocalories while that produced by standard weight training was 15 minutes in duration with an estimated net caloric cost of 13.5 kilocalories. The intensity of circuit weight training (638 pounds per minute) was also . greater than that of standard weight training (233 pounds per minute).

The weight training programs used in this study did not produce a prolonged excess postexercise oxygen consumption. However, the intensity of the weight training program affected both the magnitude and duration of excess postexercise oxygen consumption. The magnitude and duration of excess post exercise oxygen consumption produced by weight training was similar to that found for aerobic exercise. The magnitude of excess post exercise oxygen consumption produced by weight training was found to be a substantial portion of the total energy cost. Therefore, excess post exercise oxygen consumption may be of some significance in weight control.

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Physical Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

August 1990

APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the graduate committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Robert Schwarzkopf for his ideas and support throughout the planning and completion of this study. This study would not have taken place without his help.

I would also like to thank Dr. Craig Stewart and Dr. Anne Shovic for their constructive criticism in helping to complete this thesis.

Special thanks to the reliable subjects who participated in this study.

Finally, I express my gratitude to the faculty and staff at Montana State University for creating a challenging and beneficial graduate program.

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ABSTRACT

The purpose of this study was to compare the effects of standard set weight training and circuit weight training on excess postexercise oxygen consumption. The exercises and order of exercises were the same for both programs. The weight programs differed in three respects: 1. a circuit approach as opposed to three sets of the same exercise; 2. the percent of maximum weight used was high in standard weight training (80%) and low in circuit weight training (50%); and 3. the rest periods were shorter for circuit weight training (30 seconds) than standard weight training (120 seconds). This longer rest period resulted in a longer standard program (50 minutes) than the circuit program (19 minutes). Ten untrained, college males performed both weight training programs. Resting metabolic rate was determined prior to each weight program followed by a determination of excess postexercise oxygen consumption.

The magnitude and duration of excess postexercise oxygen consumption produced by circuit weight training were significantly ($P<.01$) greater than those produced by standard weight training. The excess postexercise oxygen consumption produced by circuit weight training was 20 minutes in duration with a net caloric cost estimated at 24.9 kilocalories while that produced by standard weight training was 15 minutes in duration with an estimated net caloric cost of 13.5 kilocalories. The intensity of circuit weight training (638 pounds per minute) was also greater than that of standard weight training (233 pounds per minute).

The weight training programs used in this study did not produce a prolonged excess postexercise oxygen consumption. However, the intensity of the weight training program affected both the magnitude and duration of excess postexercise oxygen consumption. The magnitude and duration of excess post exercise oxygen consumption produced by weight training was similar to that found for aerobic exercise. The magnitude of excess post exercise oxygen consumption produced by weight training was found to be a substantial portion of the total energy cost. Therefore, excess post exercise oxygen consumption may be of some significance in weight control.

CHAPTER 1

INTRODUCTION

Excess postexercise oxygen consumption (EPOC) is the additional energy expenditure following exercise due to a metabolic rate elevated above the resting level (Gaesser and Brooks, 1984). Any physical exertion will cause an increase in EPOC upon completion of exercise (Sedlock, Fissinger, and Melby, 1989). Estimates of the duration of EPOC range from 10 minutes to 48 hours (Bahr, Ingnes, Vaage, Sejersted, and Newsholme, 1987; Freedman-Akabus, Colt, Kissileff, and Pi-Sunyer, 1985; Kaminsky, Kanter, Lesmes, and Laham-Saeger, 1987; Knuttgen, 1970; Maehlum, Grandmontagne, Newsholme, and Sejersted, 1986; Pacy, Barton, Webster, and Garrow, 1985; and Sedlock et al., 1989). The primary reason for the large range is due to the influence of different intensities and durations of exercise.

The cellular basis of EPOC has not been clearly established. Gaesser and Brooks (1984) concluded that an explanation of EPOC is directly related to the mitochondrion. They contend that EPOC may be influenced by a number of factors including: lactate levels, creatine phosphate concentrations, catecholamine levels, lipolysis, ion concentrations, and core and tissue temperature. However, the degree of influence of these factors and their relation to different types of exercise has not been expressly determined.

Some researchers have linked EPOC with the potential for weight control (Sedlock et al., 1989; and Maehlum et al., 1986). The caloric cost of EPOC is not included in energy expenditure estimates, therefore, a knowledge of the added caloric cost related to the type, intensity, and duration of exercise can be beneficially employed by overweight individuals.

Researchers who have studied EPOC have either used cycling, walking, or jogging as the mode of exercise. Many people use weight training as a recreational and fitness activity. Questions about the EPOC of weight training, and its magnitude in comparison to that found for aerobic exercise need to be answered.

Statement of the Problem

The purpose of this study was to examine and compare the effects of standard set weight training and circuit weight training on excess postexercise oxygen consumption.

Hypotheses

1. Circuit weight training and standard set weight training will not yield statistically different EPOC's.

2. The EPOC from weight training will be similar to that from aerobic exercise.

Definitions

1. Repetition: Performing a lift through the full range of motion (Kraemer and Fleck, 1988).

2. Set: Performing a lift for a specified number of repetitions (Kraemer and Fleck, 1988).

3. Absolute muscular strength: The maximum amount of weight which can be properly lifted for 1 repetition (1-RM) (Berger, 1982).

Operational Definitions

1. Standard set weight training (SWT): A series of exercises in which multiple sets of one exercise are completed before moving to another exercise.

2. Circuit weight training (CWT): A series of exercises in which one set is performed before moving to the next exercise.

Delimitations

This study was delimited to ten novice volunteer college males.

Limitations

1. Selection of subjects was based on sex, age, available time, and previous weight lifting experience.

2. Subjects were not randomly selected from a larger

population group.

3. The exercises used are a small sample of many weight training exercises.

4. Factors involved in the mechanism of EPOC, such as lactic acid levels, core temperature, hormone levels, etc., were not measured.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The primary focus of this study was to compare the effects of two different weight training programs on EPOC. EPOC serves as a repayment of the "oxygen debt" acquired during exercise. EPOC is the process by which the body returns to resting homeostasis. Several studies investigating the influence of aerobic exercise on EPOC have been completed. However, many questions remain regarding the duration of EPOC, the cellular basis of EPOC, the effects of EPOC on fit and unfit individuals, and the comparative effect of weight training to aerobic exercise on EPOC. This chapter will provide a review of the current research related to EPOC structured in the following manner:

1. Basis of EPOC
2. Duration of EPOC
3. Effects of EPOC in Fit and Unfit Individuals

Basis of EPOC

The specific cellular mechanism(s) responsible for EPOC have not been identified. Gaesser and Brooks (1984) stated that any explanation of EPOC will be associated with the mitochondrion, the site of cellular respiration. These same authors listed the direct factors which control the mitochondrion: ADP (adenosine triphosphate), ATP (adenosine diphosphate), Pi (inorganic phosphate), and CP (creatine phosphate). Indirect factors which they considered to be of importance are: catecholamines, thyroxine, glucocorticoids, fatty acids, calcium ions, and temperature. The contribution of these indirect factors remains uncertain (Sedlock et al., 1989).

Indirect factors may influence EPOC at different times. Margaria, Edwards, and Dill (1933) termed a faster first phase as alactacid oxygen debt, and a slower second phase as lactacid oxygen debt. These terms were based upon the belief that lactic acid played the primary role in EPOC. The majority of researchers now believe that lactic acid does not play as large a role as was once thought. The terms used today are rapid-recovery O2 phase (RRP) and slow-recovery O2 phase (SRP) (Fox, Bowers, and Foss, 1989). Fox et al. (1989) defined the RRP as the first phase which lasts about 2-3 minutes characterized by a rapid decline in oxygen consumption and the SRP as the second phase which is characterized by a slower decline in oxygen consumption to resting levels.

Creatine Phosphate and Adenosine Triphosphate

Muscular contractions use energy from the breakdown of ATP to ADP and Pi. CP is used to reform ATP from ADP and Pi. ATP and CP are rapidly restored following exercise (Fox et al., 1989). Gaesser and Brooks (1984) stated that the changes in CP concentrations may be responsible for most of the RRP and part of the SRP. Oxygen can be utilized during aerobic metabolism to oxidize carbohydrates and fats to generate the energy needed to rebuild ATP (Fox et al., 1989; and Kraemer and Fleck, 1982). The half life of ADP and Pi is approximately 20 seconds and in 3-5 minutes all of the ATP that was broken down will be restored (Kraemer and Fleck, 1982). Gaesser and Brooks (1984) estimated that the portion of EPOC needed for ADP and creatine rephosphorylation will not exceed 1.5 l of oxygen or 10% of the total EPOC volume following exercise.

Elevated Temperature (Q10 effect)

Temperature may be the most important factor contributing to EPOC (Gaesser and Brooks, 1984). Increased temperature in muscle and other tissues is a direct result of exercise. The Q10 effect expresses the increase in the rate of chemical action, therefore, the rate of O2 consumption by the mitochondrion (Brooks and Fahey, 1984; and Gaesser and Brooks,1984). Hagberg, Mullin, and Nagle (1980) estimated that the Q10 effect could account for 60-70% of the SRP of EPOC during work loads of any intensity and duration.

Calcium Ions

Calcium ions have been associated with an increase in oxygen consumption by the mitochondrion (Carafoli and Lehninger, 1971). Muscle cell contraction is triggered by calcium ion release from the sarcoplasmic recticulum. The calcium ions are transported via an active transport system, which requires energy in the form of ATP, to the muscle cell. Brooks and Fahey (1984) stated that this increase in energy is reflected in an increase in oxygen consumption for the increased energy needs required by active transport and the increased concentration of calcium ions in the mitochondria may be related to the increased regeneration of ATP which requires added oxygen consumption (Brooks and Fahey, 1984).

Hormones

Elevated levels of catecholamines and other hormones elevated during and after exercise can also cause an increase in EPOC (Barnard and Foss, 1969; Cain and Chapler, 1981; and Gladden, Stainsby, and MacIntosh, 1982). Epinephrine, thyroxine, and glucocorticoids cause an increase in Na-K pump activity which results in increased energy utilization (Gaesser and Brooks, 1984). Brooks and Fahey (1984) concluded that "because exercise affects both Na and K balance, and hormone levels, these factors probably serve to elevate oxygen consumption after exercise" (p. 201).

Fatty Acids

Gaesser and Brooks (1984) theorized that fatty acids may increase EPOC. Their explanation was that the mobilization of fatty acids during exercise may increase the need for their oxidation in mitochondria.

Lactic Acid

Hill and associates originally theorized that oxygen used in the SRP phase of EPOC was utilized for the oxidation of lactate and its conversion back to glycogen (cited in Gaesser and Brooks, 1984). Gaesser and Brooks (1984) stated that while lactic acid is often associated with anaerobic metabolism, lactate levels are influenced by factors other than oxygen deficiency. They have demonstrated that all types of exercise will result in lactate production.

The majority of lactic acid is oxidized following exercise (Gaesser and Brooks, 1984). However, Brooks and Fahey (1984) stated that this does not cause an increase in EPOC because lactate is a metabolic fuel. The authors reasoned that the oxygen used by the conversion of lactate to pyruvate would be used by the conversion of glucose to pyruvate if lactate was not present. Therefore, lactate does not cause an significant increase in EPOC. Roth, Stanley, and Brooks (1988) studied the effects of circulatory occlusion on blood lactate levels and EPOC. They found that, although blood lactate levels were significantly increased (380%), EPOC was not significantly elevated in the SRP.

In summary, the cellular basis of EPOC is clearly linked with the mitochondrion. Numerous factors could have an influence on mitochondrial respiration. However, the degree of influence of these factors remains uncertain.

Duration of EPOC

Researchers who have studied the duration of EPOC have often found conflicting results. Sedlock et al. (1989) studied the effects of (1) different intensities of exercise with equal caloric expenditures, and (2) equal intensities of exercise but different durations, on EPOC. Ten male triathletes volunteered to perform three exercise programs on a cycle ergometer: (1) 75% of VO2 max for approximately 20 minutes (high intensity- short duration, HS), (2) 50% of VO2 max for approximately 30 minutes (low intensity-short duration, LS), and (3) 50% of VO2 max for approximately 60 minutes (low intensity-long duration, LL). The subjects were instructed to fast for 12 hours and refrain from strenuous exercise for a minimum of 36 hours. Resting VO2 was measured over a period of 60 minutes while the subjects were seated. The authors found a similar duration of EPOC for the HS program (33 min) and LL program (28 min). The duration of the LS group (20 min) was significantly lower than the other two groups.

Hagberg, Mullin, and Nagle (1980) also studied the effects of exercise intensity and duration on EPOC. Eighteen male subjects completed six exercise programs on a cycle ergometer at 50, 65, and 80% of their VO2 max for 5 and 20 minutes. They did not use a resting VO2 as the baseline. Their baseline VO2 was determined by having the subjects ride at 150 rpm for five minutes. The authors found durations of EPOC which ranged from approximately 10 to 35 minutes.

Bahr et al. (1987) studied the effect of different durations of exercise on EPOC. Six male subjects exercised on a cycle ergometer at 70% of VO2 max for 80, 40, and 20 minutes. The subjects were instructed not to eat after dinner on the night prior to testing. They were also instructed not to participate in any exercise two days prior to testing and to refrain from alcohol and tobacco for 24 hours prior to testing. Resting VO2 and EPOC were determined while the subjects lay in bed. Metabolic rate was determined over a 24 hour period and the subjects were fed three meals during this time. The first meal was given two hours after exercise. Bahr et al. found the duration of EPOC to be at least 12 hours, and not more than 24 hours following all exercise durations.

Kaminsky et al. (1987) used 24 male subjects to study EPOC following aerobic exercise of different intensity and duration that required equal energy expenditure. Resting VO2 was determined after the subjects sat quietly for 20 minutes. The subjects either exercised by walking at 35% of VO2 max for 60 minutes or by running at 70% of VO2 max for 30 minutes. The authors found the duration of EPOC to be no longer than 20 minutes for both groups.

Maehlum et al. (1986) studied the duration of EPOC in four female and four male subjects. Subjects were instructed to report to the lab after an overnight fast and to refrain from exercise for two days prior to testing. Resting VO2 was determined during the last 15 minutes of a 30 minute rest period. The subjects were required to work at 70% of VO2 max for approximately 80 minutes on a cycle ergometer followed by bed rest for 24 hours. The subjects were fed three meals during this rest period. Meals were given at any time following exercise dependent on the preference of the subjects. The authors found that EPOC lasted at least 12 hours.

In summary, the duration of EPOC has been estimated to range from 10 minutes to 48 hours. However, the majority of research has not found EPOC to be prolonged. Researchers that have not found a prolonged EPOC fasted their subjects following exercise, while researchers finding a prolonged EPOC have not.

Effects of EPOC in Fit and Unfit Individuals

The effect of training on the intensity and duration of EPOC has also produced conflicting results. Freedman-Akabas et al. (1985) studied the effect of different fitness levels of subjects on EPOC. Ten men and 13 women were placed into one of three groups based upon their fitness levels. The subjects were instructed to refrain from food four hours prior to the test. Resting VO2 was measured after a 30 minute rest period. EPOC was measured while subjects worked on a treadmill at their anaerobic threshold for 20 minutes or 40 minutes. The researchers found the duration of EPOC to be no more than 40 minutes for any group at any duration. There were no significant differences in EPOC between the different fitness groups.

Brehm and Gutin (1986) studied the effects of intensity, exercise type, and fitness level on EPOC. They used a group of eight joggers and eight sedentary adults who walked and/or ran at different intensities. Each group was composed of an equal number of males and females. There were no restrictions placed on diet or activity level. Resting VO2 was determined using three minute measurements until the difference between two consecutive measurements was less than 5%. The duration of VO2 ranged from 18-48 minutes for both groups at all intensities. No significant difference was found between joggers and sedentary adults with respect to the duration of EPOC when exercising at equal intensities.

Girandola and Katch (1973) studied the effects of endurance training on EPOC. A control group of 33 male college students was compared with an experimental group, also consisting of 33 college males, who participated in a nine week training program. Both groups were pre- and post-tested at the same workloads. The researchers found that after training there was a decrease of .31 liters of oxygen for 15 minutes of recovery.

Hagberg, Hickson, Ehsani, and Holloszy (1980) also studied the effects of endurance training on EPOC. Eight male subjects were placed on an aerobic training program which increased their VO2 max by 24%. Subjects were pre- and post-tested at 50% and 70% of their VO2 max on a cycle ergometer to determine the effects of this training program on EPOC. The researchers found that the magnitude of EPOC was lower at the same absolute work load and was not significantly different at the same relative work load. The period required for oxygen consumption to return 90% of the way to the resting value ranged from 56-74 minutes. The researchers also found that the duration of EPOC was significantly less after training at both the same absolute and relative workloads.

In summary, the effect of training on EPOC is uncertain. Freedman-Akabas et al. (1985) and Brehm and Gutin (1986) found that training produced no effect on the duration of EPOC. Hagberg, Hickson, Ehsani, and Holloszy (1980) and Girandola and Katch (1973) found that both the duration and intensity of EPOC were affected by training. The researchers who found no training effect used a cross-sectional design with trained and untrained subjects, while the researchers who found a training effect used a longitudinal design pre- and post-testing the same subjects.

Conclusions

There are many unanswered questions regarding the cellular basis of EPOC, the duration of EPOC, and the effect of training on EPOC. Many factors have been associated with EPOC on a cellular level. While the degree of influence of these factors remains uncertain, the chemical action of these factors is definitely associated with the mitochondrion. The duration of EPOC has been estimated to vary from 10 minutes to several days. This discrepancy is most likely associated with the different protocols employed by researchers. Researchers who have fed subjects following exercise have found prolonged EPOC's. The effect food has on increasing oxygen consumption may explain a prolonged EPOC (Sedlock et al., 1989). The effect of training on the magnitude and duration of EPOC is also a contentious subject which directly relates to the protocol employed by researchers. Researchers who have found that training reduces the magnitude and duration of EPOC have used longitudinal type studies. Researchers who have not found a training effect on EPOC have generally used cross-sectional designs.

CHAPTER 3

METHODOLOGY

Subjects

Ten volunteer college males, ranging in age from 18-31 participated in the study. None of the subjects had used weight training as a consistent form of exercise in the past year. Informed consent was obtained from all subjects before testing began.

Table 1. Physical Characteristics of the Subjects.

Characteristics	Statistic	
	Mean	Standard Deviation
Age (years)	23.6	3.9
Height (inches)	70.6	1.95
Weight (pounds)	177.2	23.5

Study Design

Subjects performed both the circuit weight training (CWT) and the standard weight training program (SWT) in a balanced randomized crossover design with one week between tests.

Dependent Variables

Pre-exercise VO2

Subjects arrived at the laboratory where all testing was performed at approximately 3:00 P.M. on each test day. Subjects were instructed not to eat after 12:00 noon, and to refrain from caffeine, tobacco, and alcohol after 10:00 A.M. Subjects were also instructed to refrain from any vigorous physical activity on the day of testing. All subjects were familiarized with procedures before testing began.

Subjects were seated in a relaxed position for approximately 10 minutes before their baseline VO2 was measured. A five minute measurement was taken to determine their resting VO2. Ventilatory measurements were made by open circuit spirometry. A Modified Otis-McKerrow valve conducted air into a Collins Chain Compensated Tissot. Ventilatory samples were passed through a paramagnetic oxygen (Beckman E-2) analyzer and an infrared carbon dioxide (Beckman LB-2) analyzer. Both analyzers were calibrated prior to each test with gases of known concentration. Standardized methods of oxygen consumption determinations were used (Howley and Franks, 1986).

Post-exercise VO2

Subjects were seated immediately following exercise. One minute VO2 measurements were taken during the first minute of six consecutive five minute intervals.

Independent Variables

Strength and Endurance Testing

Subjects were tested for absolute muscular strength, 1-RM (repetition maximum), on five exercises: power clean, bench press, squat, biceps curl, and seated military press using standardized procedures (Berger and Hardage, 1967; and Westcott, 1983). These 1-RM tests were used to determine relative resistance for the CWT and SWT tests. Bent knee situps were tested on a flat situp bench with the hands crossed on the chest. Each subject completed as many situps as possible until exhaustion. This muscular endurance test was used to determine the number of situps performed during the SWT program. Muscular strength and endurance testing was completed over two days at least one week prior to the first scheduled program.

Circuit Weight Training

Free weights were utilized for all exercises except situps. The program consisted of six exercises in the following order: power clean, bench press, squat, biceps curl, seated military press, and bent knee situps. The sequence of exercises was designed to allow at least 45 seconds rest between exercise bouts for similar muscle groups. The weight used was approximately 50% of 1-RM for each exercise. The subjects performed three circuits with 30 seconds rest between exercises. Each exercise consisted of 12 repetitions for the first set, 10 for the second and 8 for the final set. Subjects did as many situps as possible in 30 seconds for each set. The average time required to complete the CWT program was 19 minutes with a standard deviation of 0.8 minutes.

Standard Weight Training

The SWT program used the same six exercises in the same order as the CWT program. Rest periods were 2 minutes between sets and exercises. Three sets of one exercise were performed before moving to the next exercise. The resistance for all three sets was 80% of 1-RM. As many repetitions as possible were performed for each set.

A warm up set was used for the power clean, squat, and bench press with a 90 second rest before the first work set. Each warmup set consisted of doing approximately 6 repetitions at 60% of 1-RM. Bent knee situps were done with a ten pound weight held across the chest. Subjects who had completed more than fifty situps during their endurance test performed three sets of 15 repetitions. Subjects who had completed less than fifty situps performed three sets of 10 repetitions. The average time required to complete the SWT program was 50 minutes with a standard deviation of 1.1 minutes.

Statistical Design

Group means were computed for all dependent variables. Dependent t tests were used for comparisons within groups and between groups at a level of significance of .01.

CHAPTER 4

RESULTS

The findings of this study are presented in this chapter under the following headings:

1. Excess Post Exercise Oxygen Consumption of the CWT and SWT Programs.
2. Respiratory Exchange Ratios.
3. CWT and SWT Work Load and Intensity Comparisons.

Excess Post Exercise Oxygen Consumption of the CWT and SWT Programs

The methods used were designed to measure differences in EPOC of the two different weight lifting programs for ten college males. The results are summarized in Table 2 and Figure 1. Individual results for both the CWT and SWT programs are given in Table 2.

Figure 1 provides the results of a statistical analysis within the CWT and SWT programs and between the two programs. The results from this statistical analysis ($P<.01$) indicate: 1) that there was no significant difference between the two resting VO2 measurements (RMR); 2) the CWT program produced a significant EPOC for approximately 20 minutes and the SWT program showed a significant EPOC for approximately 15

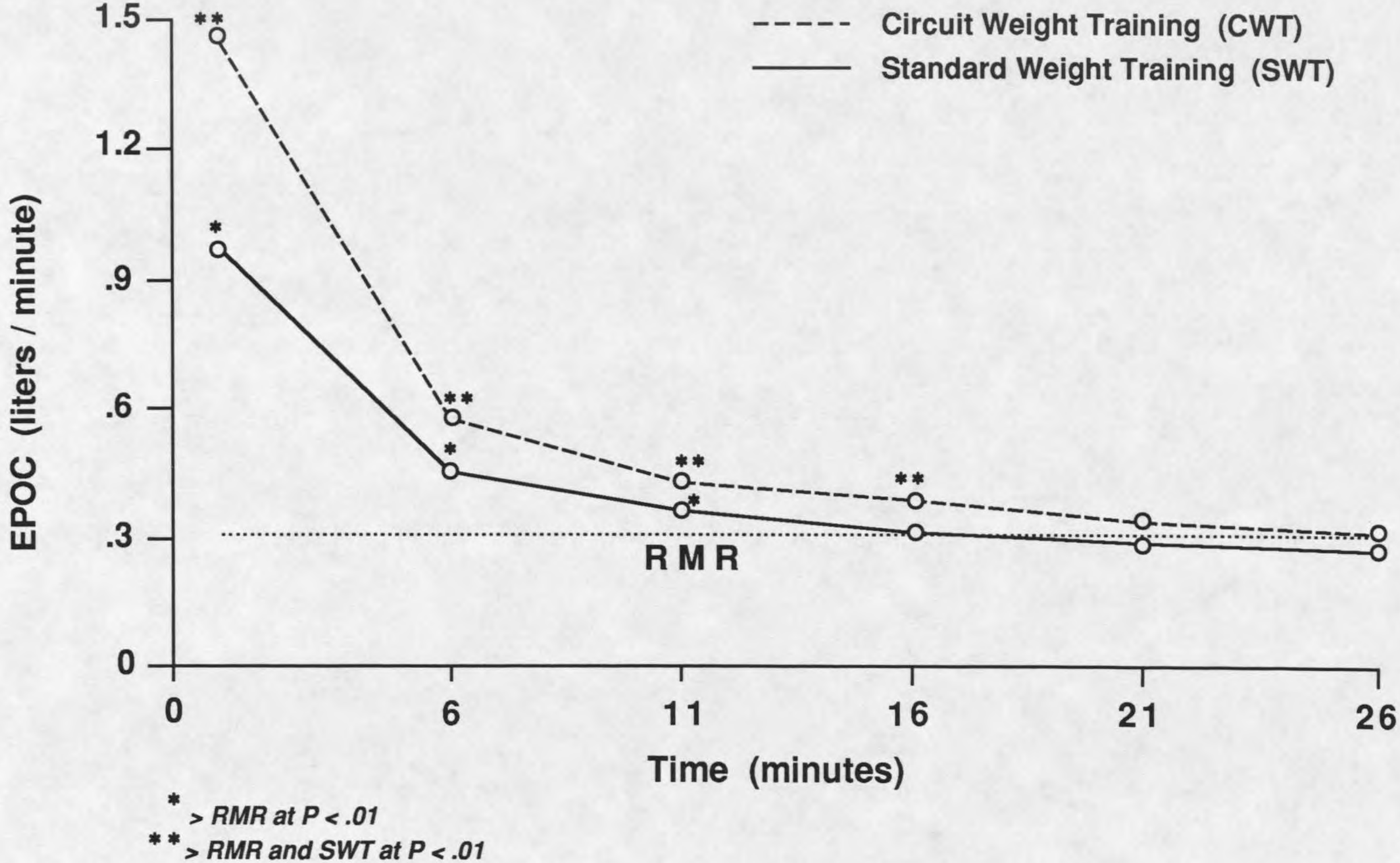

Figure 1. Excess Postexercise Oxygen Consumption (EPOC) of Circuit Weight Training (CWT) and Standard Weight Training (SWT).

minutes; and 3) the EPOC produced by the CWT program was significantly elevated above that produced by the SWT program for approximately 20 minutes.

Table 2. Individual and Group Results of the CWT and SWT Programs Related to EPOC (liters/min).

		Sampling Minutes Postexercise					
Subject	Rest	1	6	11	16	21	26
			CWT				
1	.33	1.66	.65	.44	.41	.36	.33
2	.31	1.55	.51	.40	.37	.29	.33
3	.33	1.52	.58	.50	.42	.43	.40
4	.28	1.32	.57	.40	.40	.41	.35
5	.34	1.62	.48	.35	.38	.30	.32
6	.26	1.57	.60	.49	.37	.35	.25
7	.26	1.67	.59	.40	.33	.26	.26
8	.33	1.25	.57	.42	.40	.31	.29
9	.39	1.53	.73	.56	.51	.48	.40
10	.33	.88	.51	.41	.33	.25	.21
mean	.31	1.45	.58	.43	.39	.34	.31
			SWT				
1	.34	1.00	.51	.44	.43	.42	.35
2	.29	.87	.44	.40	.36	.25	.30
3	.29	.95	.43	.32	.32	.33	.32
4	.26	.83	.45	.39	.31	.33	.32
5	.33	1.01	.46	.35	.26	.28	.26
6	.25	1.12	.43	.35	.27	.26	.23
7	.23	1.30	.42	.29	.23	.21	.23
8	.34	.80	.45	.37	.37	.31	.29
9	.36	1.02	.50	.34	.30	.31	.27
10	.29	.80	.41	.38	.24	.20	.14
mean	.30	.97	.45	.36	.31	.29	.27

Respiratory Exchange Ratios

The respiratory exchange ratios (RER) of the CWT and SWT programs are shown in Table 3. The CWT program caused an elevation in the RER immediately after exercise, followed by a return to resting levels. The SWT program caused a decrease in the RER directly after exercise followed by a increase and a decrease to below resting levels.

Table 3. Mean Values of the Respiratory Exchange Ratios.

Time(mins)	CWT	SWT
Rest	.962	.942
Recovery		
1	1.059	.939
6	1.051	.962
11	.982	.934
16	.919	.888
21	.879	.853
26	.833	.848

CWT and SWT Work Load Comparisons

The average total weight lifted (work) during the CWT program, not including situps, was 12,122 pounds which equals 808 pounds per set. A corresponding average of work completed during the SWT program, also not including situps, was 11,628 pounds which equals 775 pounds per set. The average length of the CWT program was 19 minutes, resulting in an intensity (work/time) of 638 pounds per minute and, similarly, an average of 50 minutes and intensity of 233 pounds per minute for SWT (Tables 4 and 5).

Table 4. A Comparison of Mean Weight, Repetitions, and Work Output of Selected Exercises for CWT and SWT.

	SWT			CWT		
Exercise	Wt. (lbs)	Reps	Work (lbs)	Wt. (lbs)	Reps	Work (lbs)
Clean	80	30	2400	126.5	23	2909
Bench	97	30	2910	149.5	18	2691
Squat	119.5	30	3585	189.5	16	3032
Curl	51.5	30	1545	79.5	21	1669
Military	58	29	1682	88.5	15	1327

Table 5. A Comparison of Mean Intensities of CWT and SWT.

Program	Work (lbs)	Time (min)	Intensity (lbs/min)
CWT	12,122	19	638
SWT	11,628	50	233

Summary

1. The EPOC for CWT was significantly greater than SWT in duration and magnitude.

2. The RERs of both programs demonstrated a similar pattern of decreasing over time with the exception of the initial measurement.

3. The intensity of CWT was over 2.5 times greater than SWT.

CHAPTER 5

DISCUSSION

The purpose of this study was to compare the effects of two different weight training programs on EPOC. No previous research was found which had investigated this subject. Results presented in Chapter IV will be discussed in this chapter structured in the following manner:

1. Comparison of the EPOC's From CWT and SWT
2. Comparison of the EPOC's From Weight Training and Other Modes of Exercise

Comparison of the EPOC's From CWT and SWT

A principal finding of this study was that CWT and SWT did yield statistically different EPOC's. The duration of the CWT program (20 minutes) was significantly longer ($P<.01$) than the SWT program (15 minutes). Also, the magnitude of EPOC produced by the CWT program was significantly ($P<.01$) elevated above the EPOC from the SWT program for 20 minutes. The net oxygen consumption integrated from Figure 1 was 4.95 liters for CWT and 2.70 liters for SWT. Therefore, the net caloric expenditure, converted at 5 kcal/liter, due to EPOC was greater for the CWT program (24.9 kcals) than the SWT program (13.5 kcals). It appears both the magnitude and duration of

EPOC were affected by the intensity of the weight training program.

Sedlock et al. (1989) found that exercise intensity significantly ($P<.05$) affected both the magnitude and duration of EPOC, while exercise duration affected only the duration of EPOC. Hagberg, Mullin, and Nagle (1980) found the RRP was significantly ($P<.01$) affected by the intensity of exercise but not the duration. The SRP was only affected if the intensity of exercise was greater than 65% of VO2 max and the duration was longer than five minutes. Kaminsky et al. (1987) found that exercise of differing intensity and durations but equated for total work output did not have a significant ($P<.05$) effect on either the magnitude or duration of EPOC. The duration and intensity of exercise used by Kaminsky et al. (1987) were similar to those used by Sedlock et al. (1989). This apparent discrepancy in results is difficult to explain. The results from this present study are in agreement with that of Sedlock et al. (1989), and Hagberg, Mullin, and Nagle (1980), but in disagreement with Kaminsky et al. (1987).

One explanation for the greater EPOC found during CWT is related to the greater exercise intensity of the CWT program. The intensity of the CWT program was estimated at 638 pounds per minute, and the SWT program at 233 pounds per minute (see Table 5).

Weight training can be considered a form of interval training. Fox et al. (1989) described interval training as "a series of repeated bouts of exercise alternated with periods of light relief" (p. 300). The CWT program had a work to rest ratio of 1:1 while the SWT program had a work to rest ratio of 1:5. Longer rest periods give the body a chance to return either totally or partially to resting homeostasis.

The length of the work period and the work to rest ratio will determine the extent to which energy systems are utilized and recover. The high energy phosphate system is the primary source of energy during short, near maximal weight training (Fox et al., 1986). ATP and CP stores which are used during exercise can be partially or fully replaced during the rest period by the aerobic system. Margaria, Oliva, Prampero, and Cerretelli (1969) stated that the half time of ATP and CP restoration is about 20-25 seconds. Saltin and Essen (1971) found that rest periods longer than 20 seconds gave adequate time for a significant restoration of ATP and CP stores during exercise of high intensity and short duration. The two minute rest periods used for the SWT program would allow a greater restoration of ATP and CP than the 30 second rest periods of the CWT program.

High intensity exercise of approximately 10 seconds to one minute uses the lactic acid system to supply the largest share of energy (Fox et al., 1988). Margaria et al. (1969) contended that no lactic acid production takes place, during near maximal runs, when rest periods are 30 seconds or longer. Saltin and Essen (1971) disagreed with this concept. These authors stated that muscle lactate levels increase for all interval type exercise. However, the increase in muscle lactate is less severe when shorter work periods are used. The number of repetitions per set, and hence the amount of time needed to complete a set, were less for SWT. Therefore, the increased replacement of ATP and CP as well as the dissipation of lactic acid, due to larger work-to-rest ratios during SWT, would presumably be the cause of decreased lactate. Keul, Haralambie, Bruder, and Gottstein (1978) found that SWT with rest periods of two minutes produced blood lactate levels of approximately 40 mg/dl which were barely elevated above resting levels. Gettman (1978) and Strathman, Gettman, and Culter (1979) found elevated blood lactate levels of 143-145 mg/dl associated with CWT.

Core temperature (Q10 effect) may be partially responsible for the variability in EPOC duration. Hagberg, Mullin, and Nagle (1980) found core temperature to increase with the intensity of exercise. These same authors estimated that the Q10 effect could account for 60-70% of the SRP. Therefore, circuit weight training would cause a higher core temperature than standard weight training and this would explain a greater EPOC following circuit weight training during the SRP. Other factors which have been found to alter EPOC include hormone levels and calcium ion concentrations. While hormone levels and calcium ion concentrations may be related to EPOC, their relevant contribution is not known

(Gaesser and Brooks, 1984).

In summary, the EPOC produced by CWT was found to be greater in magnitude and duration than that produced by SWT. The primary cause of this is believed to be the greater intensity of exercise inherent in the CWT program. This greater intensity results in greater lactic acid production and increased temperature (Gettman, Strathman, and Culter, 1979; and Hagberg, Mullin, and Nagle, 1980). Thus, these two factors may fundamentally be responsible for the elevated EPOC found during CWT.

Comparison of EPOC's From Weight Training and Other Modes of Exercise

The magnitude of EPOC produced by weight training was found to be similar to aerobic exercise (Figure 2). The weight training programs also produced EPOC's similar in duration to the studied intensities of aerobic exercise.

The EPOC magnitude of the CWT program was less than that of cycling at 75% of VO2 max for 20 minutes; greater than cycling at 50% of VO2 max for 30 or 60 minutes (Sedlock et al., 1989); and greater than running at 7 mph for approximately 17 minutes (Brehm and Gutin, 1986). The EPOC produced by SWT was similar in magnitude to that of cycling at 50% of VO2 max for 30 or 60 minutes (Sedlock et al., 1989) and running at 7 mph for approximately 17 minutes (Brehm and Gutin, 1986).

Wilmore, Parr, Ward, Vodak, Barstow, Pipes, Grimditch and

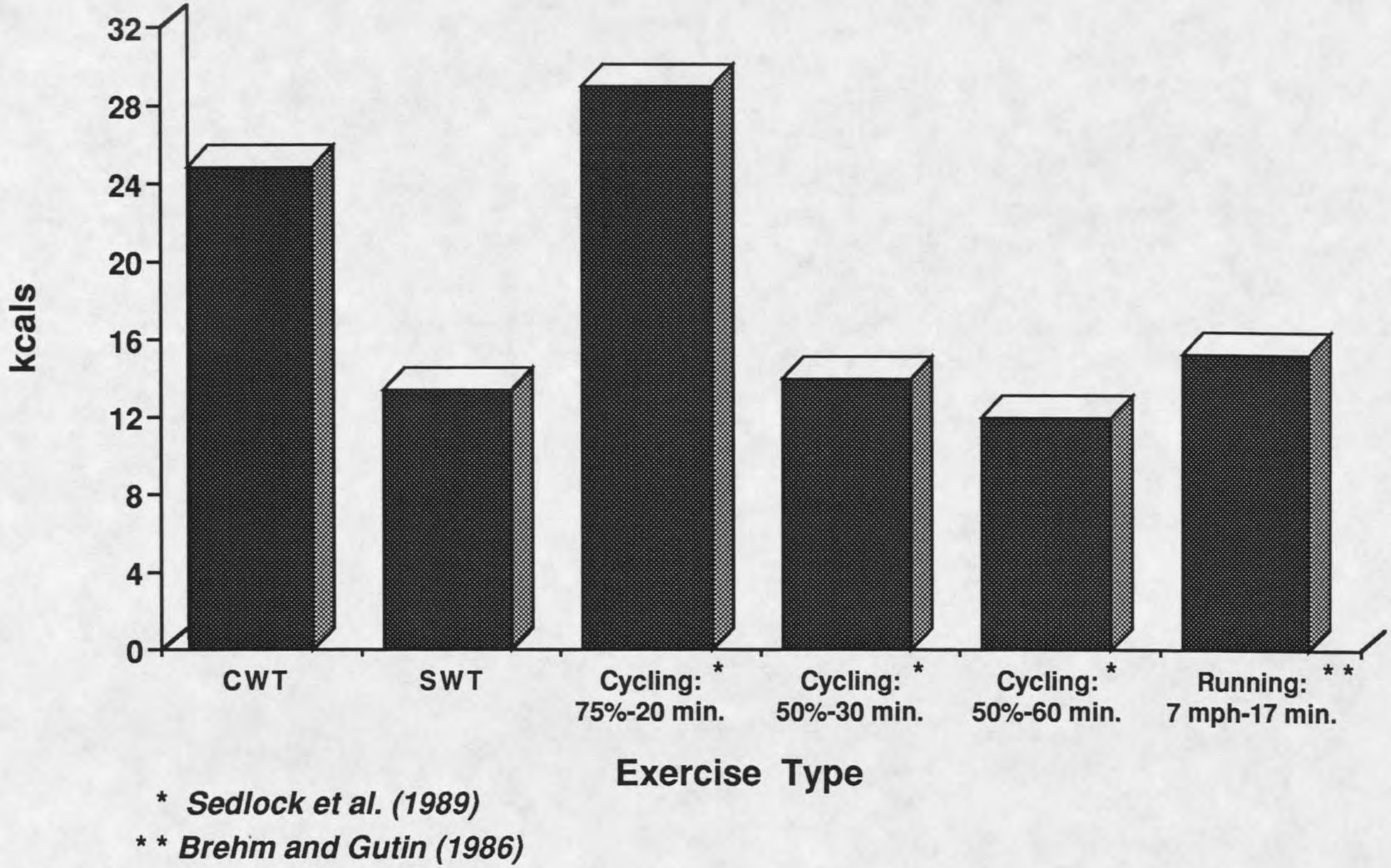

Figure 2. Comparison of Excess Postexercise Oxygen Consumption (EPOC), Circuit Weight Training (CWT), Standard Weight Training (SWT), and selected aerobic exercise.

Leslie (1978) found the net energy expenditure of males during CWT to be 5.73 kcals/min. Using Wilmore et al's. (1978) energy expenditure value, the net energy expenditure for a 19 minute CWT program would be approximately 109 kcals. The net caloric EPOC expenditure for CWT from this present study was 24.9 kcals. This value represents approximately 23% of the net energy expenditure during exercise. Sedlock et al. (1989) found the net energy expenditure during EPOC to be approximately 10% of the energy expenditure when cycling at 75% of VO2 max for 20 minutes. Results from the present study indicate that caloric expenditure during EPOC can be of significant value in an exercise program designed to maximize energy expenditure. This concept agreed with Sedlock et al. (1989).

The duration of EPOC producd by weight training was similar to that found by researchers using other modes of exercise (Figure 6). The results of these studies pertaining to the duration of EPOC, were in disagreement with those of Bahr et al. (1987) and Maehlum et al. (1986). Bahr et al. (1987) and Maehlum et al. (1987) found EPOC to last in excess of 12 hours. The consumption of three meals following exercise was the most likely cause for the prolonged EPOC from these studies. Sedlock et al. (1989) stated that dietary induced thermogenesis (DIT) may account for a prolonged EPOC. Subjects in the present study, and other studies in which a prolonged EPOC was not found, were not fed following exercise. However, not all of the difference can be attributed to DIT. Bahr et al. (1987) found an elevated EPOC for two hours before the first meal was given. This duration was longer than any of the other fasting studies reviewed. The protocol employed by Bahr et al. (1987), to find a resting metabolic rate (RMR), is similar to the process employed to determine basal metabolic rate (BMR). The subjects fasted overnight and rested in a supine position for 20, 60, and 100 minutes before their RMR was measured. The length of the resting period was dependent upon the duration of the upcoming exercise session. The mean basal level produced by this protocol is a possible reason for the 2 hour duration of EPOC.

Table 6. EPOC Duration Comparisons of Weight Training and Aerobic Exercise.

Mode	Duration (minutes)	Reference
CWT	20	Present Study
SWT	15	Present Study
Cycling	<33	Sedlock et al. (1989)
Walking and Running	<20	Kaminsky et al. (1987)
Running	<40	Freedman-Akabas et al. (1985)

In summary, the magnitude and duration of EPOC due to weight training were found to be similar to other studies using aerobic exercise. The caloric cost of EPOC associated with weight training is large enough to warrant considerable attention in weight control programs.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this investigation was to compare the effects of standard set weight training (SWT) and circuit weight training (CWT) on excess post-exercise oxygen consumption (EPOC). Ten untrained, volunteer college males participated in the study. A randomized crossover design was used in which each subject performed both the CWT and SWT programs. Following a 10 minute rest period, resting metabolic rate (RMR) was determined by a five minute measurement prior to each weight training program. EPOC was determined from one minute VO2 samples taken during the first minute of six consecutive five minute intervals. The exercises and order of exercises were the same for CWT and SWT. The programs differed in three respects: 1. a circuit approach as opposed to three sets of the same exercise; 2. the percent of 1-RM used was high in SWT (80%) and low in CWT (50%); and 3. the work to rest interval was 1:1 for CWT (30 second rest periods) and 1:5 for SWT (two minute rest periods). The two minute rest resulted in a longer program for SWT (50 minutes) than CWT (19 minutes). Dependent t tests, at a level of significance of .01, were employed for comparisons within groups and between groups.

The magnitude and duration of EPOC produced by CWT were significantly greater than that produced by SWT. The EPOC produced by CWT was 20 minutes in duration with a net caloric cost estimated at 24.9 kilocalories. SWT produced an EPOC of 15 minutes in duration and estimated caloric cost of 13.5 kilocalories. The amount of work output for the two programs was very similar. However, the intensity of CWT (638 pounds per minute) was greater than SWT (233 pounds per minute). It appears that the magnitude and duration of EPOC were affected by the intensity of exercise.

The EPOC produced by weight training was similar in magnitude and duration to that produced by aerobic exercise in most other studies. The caloric cost of EPOC produced by CWT compared with the caloric cost during CWT was estimated to be 23%.

Conclusions

Several factors could have influenced the results of this study. The number of subjects was relatively small and met selection criteria of: age, sex, and previous weight lifting experience. Within the limitations of this study, the following conclusions can be made:

1. CWT produced an EPOC which was significantly greater in magnitude and duration than that of SWT.

2. The intensity of weight training affected both the

magnitude and duration of EPOC.

3. The magnitude of EPOC produced by weight training is a substantial proportion of the energy cost of the programs.

4. The magnitude and duration of EPOC produced by weight training was similar to that found for aerobic exercise.

Recommendations

The following recommendations are made based on the results of this study:

1. A study using females and/or a mixed population should be performed to determine if the EPOC found is sex specific.

2. A study using trained and untrained subjects would be useful to compare total work done with the EPOC.

3. A study measuring VO2 during exercise would permit an accurate comparison between exercise energy cost and that from EPOC.

4. A study which measures VO2 continuously following exercise could obtain an exact measurement of the magnitude of EPOC.

5. A study using a cross-over design between CWT and an equated (caloric expenditure and duration) aerobic exercise to determine more accurately their relative influence on magnitude and duration of EPOC.

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APPENDICES

APPENDIX A:

INFORMED CONSENT FORM

SUBJECT CONSENT FORM
FOR
PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

Title of Project: Comparison of Circuit Weight Training and Standard Weight Training

Name of Researcher: Emmett Murphy

You are being asked to participate in a study of two weight training programs. This study will help to clarify whether standard weight training (SWT) produces the same benefits as circuit weight training (CWT). You must agree not to participate in weight training activities other than those specified by the study for the one week duration. You must agree not to use any ergogenic aids during this study. You will be required to undergo a pretest for muscular strength variables. You will be required to perform both the CWT program and the SWT program with a one week rest period between programs. You may experience some muscle soreness during the study. You will have the opportunity to read the proposal and ask questions at any time during the experiment. The data that you provide for this study will be anonymous and your identity will not be revealed. In the event your participation in this research directly results in injury, you will be referred to the Health Service Center. However, there is no compensation for such injury available.

I have read the above and understand the discomforts, inconvenience and risk of this study. I,____________________________________, agree to participate in the research. I understand that I may later refuse to participate or that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed____

Witness____

Investigator___________________________________

Date__________________________

APPENDIX B:

SUBJECT DATA SHEETS

Name: M.E.

Age: 18 Ht.: 70.5" Wt.: 165#

Max Tests(#)

bench: 230# squat: 280#

military: 115# curl: 100#

clean: 170# situps: >50

CWT (50%) Time: start: 3:21 finish: 3:39

	weight(#)	reps(1)	reps(2)	reps(3)
clean	85	12	10	8
bench	115	"	"	"
squat	140	"	"	"
curl	50	"	"	"
military	55	"	"	"
situps		23	24	21

SWT(80%) Time: start: 3:26 finish: 4:15

	weight(#)	reps(1)	reps(2)	reps(3)
clean	135	11	6	5
bench	185	8	5	4
squat	225	8	7	7
curl	80	11	7	5
military	90	8	6	4
situps	10	15	15	15

Name: T.F.

Age: 20   Ht.: 73.4"   Wt.: 184#

Max Tests(#)

bench: 210   squat: 280

military: 120   curl: 110

clean: 160   situps: >50

CWT (50%)   Time: start: 3:23   finish: 3.41

	weight(#)	reps(1)	reps(2)	reps(3)
clean	80	12	10	8
bench	105	"	"	"
squat	140	"	"	"
curl	55	"	"	"
military	60	"	"	"
situps		23	24	19

SWT(80%)   Time: start: 3:27   finish: 4:16

	weight(#)	reps(1)	reps(2)	reps(3)
clean	125	9	7	7
bench	165	8	7	7
squat	220	5	5	4
curl	85	8	7	5
military	90	5	5	4
situps	10	15	15	15

Name: L.L.

Age: 27 Ht.: 70.5" Wt.: 185#

Max Tests(#)

bench: 200 squat: 250

military: 120 curl: 120

clean: 160 situps: >50

CWT (50%) Time: start: 3:31 finish: 3:51

	weight(#)	reps(1)	reps(2)	reps(3)
clean	80	12	10	8
bench	100	"	"	"
squat	125	"	"	"
curl	60	"	"	"
military	60	"	"	"
situps		21	20	20

SWT(80%) Time: start: 3:35 finish: 4:25

	weight(#)	reps(1)	reps(2)	reps(3)
clean	125	12	8	7
bench	160	9	7	4
squat	200	10	7	5
curl	90	12	10	7
military	90	6	5	5
situps	10	15	15	15

Name: C.M.

Age: 22 Ht.: 71" Wt.: 152#

Max Tests(#)

bench: 160 squat: 240

military: 100 curl: 90

clean: 140 situps: >50

CWT (50%)	Time: start: 3:24		finish: 3:43	
	weight(#)	reps(1)	reps(2)	reps(3)
clean	70	12	10	8
bench	80	"	"	"
squat	120	"	"	"
curl	45	"	"	"
military	50	"	6	4
situps		26	23	21

SWT(80%)	Time: start: 3:12		finish: 4:04	
	weight(#)	reps(1)	reps(2)	reps(3)
clean	110	10	10	7
bench	130	7	5	4
squat	190	5	8	7
curl	70	10	7	5
military	80	5	3	3
situps	10	15	15	15

Name: B.P.

Age: 31   Ht.: 71"   Wt.: 161

Max Tests(#)

bench: 180   squat: 240

military: 100   curl: 80

clean: 170   situps: >50

CWT (50%)	Time: start: 3:23 weight(#)	reps(1)	finish: 3:42 reps(2)	reps(3)
clean	85	12	10	8
bench	90	"	"	"
squat	120	"	"	"
curl	45	"	"	"
military	50	"	"	"
situps		23	19	18

SWT(80%)	Time: start: 3:20 weight(#)	reps(1)	finish: 4:10 reps(2)	reps(3)
clean	135	7	5	5
bench	145	8	6	4
squat	190	5	4	3
curl	65	8	6	5
military	80	5	4	4
situps	10	15	15	15

Name: D.P.

Age: 20 Ht.: 71.5" Wt.: 175

Max Tests(#)

bench: 210 squat: 230

military: 120 curl: 100

clean: 160 situps: >50

CWT (50%) Time: start: 3:35 finish: 3:55

	weight(#)	reps(1)	reps(2)	reps(3)
clean	80	12	10	8
bench	105	"	"	"
squat	115	"	"	"
curl	50	"	"	"
military	60	"	"	"
situps		25	27	25

SWT(80%) Time: start: 3:21 finish: 4:11

	weight(#)	reps(1)	reps(2)	reps(3)
clean	125	10	10	9
bench	165	10	5	5
squat	180	8	8	6
curl	80	12	8	7
military	90	10	7	7
situps	10	15	15	15

Name: E.R.

Age: 26   Ht.: 67.62"   Wt.: 195#

Max Tests(#)

bench: 150   squat: 210

military: 120   curl: 85

clean: 140   situps: <50

CWT (50%)   Time: start: 3:36   finish: 3:55

	weight(#)	reps(1)	reps(2)	reps(3)
clean	70	12	10	8
bench	75	"	"	"
squat	105	"	"	"
curl	45	"	"	"
military	60	"	"	"
situps		18	17	13

SWT(80%)   Time: start: 3:30   finish: 4:20

	weight(#)	reps(1)	reps(2)	reps(3)
clean	110	10	7	5
bench	120	7	5	5
squat	165	3	3	1
curl	70	5	6	5
military	95	3	2	1
situps	10	10	10	10

Name: J.S.

Age: 26 Ht.: 68 Wt.: 151

Max Tests(#)

bench: 140 squat: 200

military: 110 curl: 80

clean: 130 situps: <50

CWT (50%) Time: start: 3:20 finish: 3:38

	weight(#)	reps(1)	reps(2)	reps(3)
clean	105	12	10	8
bench	70	"	"	"
squat	100	"	"	"
curl	45	"	"	"
military	55	"	"	"
situps		20	21	14

SWT(80%) Time: start: 3:24 finish: 4:13

	weight(#)	reps(1)	reps(2)	reps(3)
clean	105	10	10	10
bench	110	12	5	5
squat	160	4	4	3
curl	65	11	8	5
military	85	4	3	4
situps	10	10	10	10

Name: M.V.

Age: 23 Ht.: 67.62" Wt.: 174

Max Tests(#)

bench: 210 squat: 230

military: 120 curl: 130

clean: 170 situps: >50

CWT (50%)	Time: start: 3:33		finish: 3:52	
	weight(#)	reps(1)	reps(2)	reps(3)
clean	85	12	10	8
bench	105	"	"	"
squat	115	"	"	"
curl	65	"	"	"
military	60	"	"	"
situps		26	22	18

SWT(80%)	Time: start: 3:38		finish: 4:28	
	weight(#)	reps(1)	reps(2)	reps(3)
clean	135	9	6	4
bench	165	8	6	4
squat	180	6	5	4
curl	105	8	5	3
military	90	7	6	5
situps	10	15	15	15

Name: K.W.

Age: 23 Ht.: 73 Wt.: 230

Max Tests(#)

bench: 190 squat: 230

military: 120 curl: 105

clean: 200 situps: <50

CWT (50%) Time: start: 3:21 finish: 3:41

	weight(#)	reps(1)	reps(2)	reps(3)
clean	100	12	10	8
bench	95	"	"	"
squat	115	"	"	"
curl	55	"	"	"
military	60	"	"	"
situps		16	17	12

SWT(80%) Time: start: 4:55 finish: 5:44

	weight(#)	reps(1)	reps(2)	reps(3)
clean	160	6	5	5
bench	150	5	4	6
squat	185	5	5	3
curl	85	6	5	5
military	95	6	7	3
situps	10	10	10	10

APPENDIX C:

OXYGEN CONSUMPTION FORM

Human Performance Laboratory
Montana State University
Gas Analysis Calculations

Name______________________________ Age_______ Date_______
Weight_______ Height_______

	Time Period (mins)						
	RMR	0-1	5-6	10-11	15-16	20-21	25-26
Volume							
1. T2	____	____	____	____	____	____	____
2. T1	____	____	____	____	____	____	____
3. T2 - T1							
4. (3) x 3.244							
5. BP	____	____	____	____	____	____	____
6. Temp	____	____	____	____	____	____	____
7. STPD							
8. (7) x (4)= Ve							
Oxygen Consumption							
9. E2	____	____	____	____	____	____	____
10. E2 x .021							
11. NCF x (10)							
12. 20.88 - (11)							
13. (12)/100							
14. (8) x (13)= O2 liters/min							
RER							
15. CO2	____	____	____	____	____	____	____
16. (16)/(12)= RER							

$$STPD= \frac{273}{273 + Temp} \times \frac{BP}{760} \times \frac{BP - VP}{BP}$$

$$NCF= \frac{100 - (15) + (10)}{79.03}$$

APPENDIX D:

INDIVIDUAL OXYGEN CONSUMPTION DATA

Table 7. Individual Oxygen Consumption Data.

CWT

Subject	Measure	Time Period (min) Rest	1	6	11	15	21	26
M.E.	T2	31.05	29.85	17.45	14.60	14.10	13.50	13.05
	T1	9.35	9.30	9.35	9.30	9.35	9.35	9.35
	BP	632.9	632.9	632.9	632.9	632.9	632.9	632.0
	T	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	E2	846	842	853	834	825	821	813
	CO2	2.77	3.23	2.93	2.88	2.82	2.66	2.66
T.F.	T2	20.40	25.50	15.30	14.00	12.90	12.50	11.35
	T1	9.35	9.35	9.35	9.30	9.35	9.30	9.30
	BP	641.9	641.9	641.9	641.9	641.8	641.8	641.8
	T	10.8	10.8	10.8	10.8	10.8	10.8	10.8
	E2	775	818	808.5	801	799.5	785	754
	CO2	4.15	3.96	3.93	3.79	3.64	3.64	3.72
L.L.	T2	25.75	27.40	14.55	13.00	12.95	12.10	12.10
	T1	9.35	9.30	9.35	9.35	9.35	9.40	9.30
	BP	635.4	635.4	635.4	635.7	635.7	635.7	635.7
	T	12.5	12.5	12.5	12.5	12.5	12.0	12.0
	E2	792	830	823.5	812	790.5	779.5	773
	CO2	3.71	3.76	3.78	3.75	3.80	3.80	3.79
C.M.	T2	26.56	27.00	15.30	13.70	13.20	12.30	12.70
	T1	9.35	9.35	9.35	9.30	9.30	9.30	9.40
	BP	639.8	639.8	639.8	639.8	639.8	639.8	639.8
	T	13.0	13.5	13.5	13.5	13.5	13.5	13.5
	E2	828	832	834	821	814	803	798
	CO2	3.66	3.69	3.41	3.35	3.29	3.32	3.24
B.P.	T2	19.20	27.70	15.95	13.50	12.80	11.85	11.45
	T1	9.35	9.35	9.30	9.30	9.45	9.35	9.30
	BP	628.1	628.0	628.0	628.0	628.0	628.0	628.0
	T	11.5	11.8	11.8	11.8	11.8	11.8	11.8
	E2	746	831	832	817.5	810	792	755
	CO2	4.95	4.30	3.97	3.92	3.91	3.97	4.13

Table 7. (Continued)

CWT

Subject	Measure	Time Period (min)						
		Rest	1	6	11	16	21	26
D.P.	T2	30.00	27.30	17.15	15.90	14.35	14.40	14.20
	T1	9.35	9.30	9.35	9.30	9.30	9.30	9.35
	BP	630.9	630.9	630.9	630.9	630.9	630.9	630.9
	T	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	E2	846	835	855	849	832.5	829	830
	CO2	2.95	3.37	3.09	2.85	2.76	2.74	2.69
E.R.	T2	21.35	21.65	15.85	14.15	13.60	12.50	12.15
	T1	9.35	9.35	9.35	9.35	9.35	9.35	9.35
	BP	641.0	641.0	641.0	641.0	641.0	641.0	641.0
	T	13.0	13.0	13.0	13.0	13.0	13.0	13.0
	E2	758	805	835	831	817	804	794
	CO2	4.17	4.01	3.72	3.56	3.47	3.40	3.38
J.S.	T2	28.05	23.45	16.75	14.75	13.65	12.55	11.75
	T1	9.35	9.45	9.35	9.35	9.35	9.35	9.35
	BP	641.9	641.9	641.9	641.9	641.9	641.9	641.9
	T	13.2	13.5	13.5	13.5	13.5	13.5	13.5
	E2	831	875	869	853	850	847	827
	CO2	3.72	2.35	2.88	2.91	2.79	2.78	2.87
M.V.	T2	31.10	26.95	17.20	14.40	14.30	14.40	13.50
	T1	9.35	9.35	9.35	9.35	9.35	9.35	9.35
	BP	640.5	640.5	640.5	640.5	640.5	640.5	640.5
	T	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	E2	875	856	862	846	840	839	832
	CO2	2.65	3.08	2.95	2.98	2.93	2.89	2.90
K.W.	T2	29.00	24.95	17.00	15.25	14.25	14.00	12.95
	T1	9.35	9.35	9.35	9.35	9.35	9.35	9.35
	BP	632.9	632.9	632.9	632.9	632.9	632.9	632.9
	T	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	E2	807	819	923	812	798	793	781
	CO2	3.75	4.33	4.06	4.04	3.77	3.72	3.72

Table 7. (Continued)

Subject	Measure	SWT Time Period (min) Rest	1	6	11	16	21	26
M.E.	T2	31.35	20.75	15.85	15.10	14.10	14.15	12.95
	T1	9.35	9.35	9.35	9.35	9.35	9.35	9.40
	BP	643.1	643.1	643.1	643.1	643.1	643.1	643.1
	T	12.8	12.8	12.8	12.8	12.8	12.8	12.8
	E2	848	826	845	845	813.5	820	800
	CO2	2.94	3.04	2.73	2.61	2.65	2.61	2.72
T.F.	T2	20.40	19.10	13.30	12.45	11.75	11.60	11.25
	T1	9.30	9.30	9.40	9.35	9.40	9.35	9.35
	BP	632.1	632.1	632.1	632.1	632.1	632.1	632.1
	T	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	E2	780	776	782	778	772	765	752
	CO2	3.85	4.27	4.15	4.02	4.00	3.99	4.00
L.L.	T2	22.30	19.25	13.60	12.50	11.60	11.60	11.35
	T1	9.35	9.35	9.35	9.35	9.30	9.35	9.30
	BP	637.0	636.8	636.8	636.8	636.8	636.8	636.8
	T	11.0	11.2	11.2	11.2	11.2	11.2	11.2
	E2	752	784	789	783	770	748	744
	CO2	4.42	4.05	3.87	3.85	3.87	4.03	4.04
C.M.	T2	27.00	18.40	14.10	12.45	13.15	12.00	12.65
	T1	9.35	9.35	9.35	9.35	9.35	9.35	9.35
	BP	635.0	635.0	635.0	635.0	635.0	635.0	635.0
	T	12.8	13.0	13.0	13.0	13.0	13.0	13.0
	E2	840	811	818	816	809	809	817
	CO2	3.40	3.63	3.51	3.43	3.39	3.12	3.09
B.P.	T2	19.00	21.20	13.50	12.10	11.45	11.30	11.20
	T1	9.45	9.70	9.60	9.40	9.35	9.45	9.40
	BP	632.7	632.7	632.7	632.7	632.1	632.1	632.1
	T	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	E2	764	778	789	786.5	783.5	768	740
	CO2	4.54	4.21	3.93	3.84	3.81	3.81	3.94

Table 7. (Continued)

SWT

Subject	Measure	Time Period Rest	1	6	11	16	21	26
D.P.	T2	27.20	21.05	15.65	13.95	13.70	13.25	12.95
	T1	9.35	9.35	9.40	9.40	9.40	9.40	9.40
	BP	642.1	642.0	642.0	642.0	642.0	642.0	642.0
	T	13.0	13.0	13.0	13.0	13.0	13.0	13.0
	E2	839	840	864	861	849	823.5	818
	CO2	3.09	3.05	2.65	2.49	2.60	2.72	2.91
E.R.	T2	22.85	15.75	13.25	12.50	12.45	11.85	11.65
	T1	9.35	9.35	9.35	9.35	9.35	9.35	9.35
	BP	648.1	648.1	648.1	648.1	648.1	648.1	648.1
	T	12.0	12.5	12.5	12.5	12.5	12.5	12.5
	E2	752	757	775	772	769	763	753
	CO2	4.03	4.26	4.10	4.02	4.00	4.01	4.07
J.S.	T2	30.60	19.25	14.45	14.10	12.20	11.65	11.05
	T1	9.35	9.35	9.35	9.45	9.35	9.35	9.35
	BP	630.9	931.1	631.1	631.1	631.1	631.1	631.1
	T	14.0	13.2	13.2	13.2	13.2	13.2	13.2
	E2	862	838	844	837	827	820	834
	CO2	2.78	3.06	3.14	3.06	6.03	3.04	3.03
M.V.	T2	36.60	18.95	15.60	15.40	13.90	13.85	13.90
	T1	9.35	9.35	9.35	9.35	9.35	9.40	9.30
	BP	634.1	634.1	633.8	633.8	633.8	633.8	633.8
	T	11.8	11.8	11.5	11.5	11.5	11.5	11.5
	E2	906	831.5	863	878.5	865	856	865
	CO2	2.14	3.26	3.08	2.87	2.79	2.81	2.79
K.W.	T2	25.00	17.85	13.75	12.35	12.00	12.00	11.60
	T1	9.35	9.35	9.35	9.35	9.35	9.35	9.35
	BP	631.1	632.6	632.6	632.6	632.6	632.6	632.6
	T	13.2	13.0	13.0	13.0	13.0	13.0	13.0
	E2	767	762	776	774	771	768	759
	CO	3.83	4.22	4.34	4.20	4.16	4.11	4.09

APPENDIX E:

STATISTICAL ANALYSES

Table 8. Statistical Analyses of EPOC Means

Time (min)	Volume (liters/min)	t-ratio
	CWT: Rest	
1	1.45: .31	14.28*
6	.58: .31	11.55*
11	.43: .31	6.44*
16	.39: .31	6.37*
21	.34: .31	1.28
26	.31: .31	0.09
	SWT: Rest	
1	.97: .30	11.83*
6	.45: .30	16.11*
11	.36: .30	4.18*
16	.31: .30	0.69
21	.29: .30	0.45
26	.27: .30	1.39
	CWT: SWT	
1	1.45: .97	5.96*
6	.58: .45	6.07*
11	.43: .36	3.24*
16	.39: .31	3.51*
21	.34: .29	1.62
26	.31: .27	2.34

* A t-ratio of > or = 2.82 is required for significance at P = .01