11-1-1989

Energy Cost of Resistive Exercise

Jan A. Polychronis
Portland State University

AN ABSTRACT OF THE THESIS OF Jan A. Polychronis for the Master of Science in Teaching in Physical Education presented November 1, 1989.

Title: Energy Cost of Resistive Exercise

APPROVED BY THE MEMBERS OF THE THESIS COMMITTEE:

[redacted]

Gary R. Brodowicz, Chair

[redacted]

Milan D. Svoboda

[redacted]

Robert J. Brustad

[redacted]

Maxine L. Thomas

The energy cost of performing 1 and 3 sets of strength-type (6-8 RM) and endurance-type (30-35 RM) bench press exercise was estimated by indirect calorimetry in 10 male college students.

The total net energy cost of performing 3 sets of endurance-type resistive exercise (20.57 ± 1.86 kcal) was significantly ($p < .05$) greater than strength-type resistive exercise (15.24 ± 1.51 kcal) (mean ± SEM). Results were similar when energy cost was expressed relative to lean body

mass. However, when expressed relative to the amount of work performed (kcal·kgm^{-1}) the strength-type exercise (2.35 ± 0.19) resulted in a significantly ($p < .05$) greater expenditure of energy than did endurance-type exercise (1.64 ± 0.30). The energy cost relative to work performed was found to be significantly greater for 1 set of strength-type exercise than for any other condition ($p < .05$). The relationship between the energy cost of 1 set, multiplied by 3, and 3 sets was r=0.64 for endurance-type exercise and r=0.27 for strength-type exercise.

It was concluded that compared to strength-type resistive exercise, endurance-type resistive exercise requires a greater net energy expenditure. The results suggest that endurance-type exercise be performed by individuals who wish to expend the greatest amount of energy during resistive exercise. Although a poor relationship was found between the energy cost of performing 1 set (x3) and 3 sets of resistive exercise, conclusions must await further study with larger sample sizes.

Additional research is needed to define the importance of the exercise:rest ratio including the possible effects of prior exercise, potential differences in utilization of energy substrates, and the influence of training on the energy cost of resistive exercise.

ENERGY COST OF RESISTIVE EXERCISE

by

JAN A. POLYCHRONIS

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

MASTER OF SCIENCE in TEACHING
in
PHYSICAL EDUCATION

Portland State University

1989

TO THE OFFICE OF GRADUATE STUDIES:

The members of the Committee approve the thesis of Jan A. Polychronis presented November 1, 1989.

[redacted]

Gary R. Brodowicz, Chair

[redacted]

Milan D. Svoboda

[redacted]

Robert J. Brustad

[redacted]

Maxine L. Thomas

APPROVED:

[redacted]

Jack S. Schendel, Dean, School of Health and Physical Education

[redacted]

C. William Savery, Interim Vice Provost for Graduate Studies and Research

DEDICATION

To my family, for their love and support.

ACKNOWLEDGEMENTS

The author would like to thank the following people for their help, guidance and support of this study:

Gary Brodowicz, Ph.D. - GRB, for all of the red pens you used, the cold pizzas you had to endure, the availability of your time, your interesting sense of humor, and the quality of your editing and suggestions, thank you!

My thesis committee - Milan Svoboda, Ph.D., Robert Brustad, Ph.D., Maxine Thomas, Ph.D., and Loarn Robertson, Ph.D., for your valuable input and assistance.

My fellow students and friends, for caring.

My subjects, for their perserverance in meeting my demands.

The secretaries and assistants of the PSU, Health and Physical Education office for all of their help and excellent work throughout the years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Resistive exercise has proven to be one of the most effective methods of increasing muscular strength, endurance and muscle size. It is widely used by recreational lifters, athletes, bodybuilders, and patients in rehabilitation. Physical benefits include increased muscular tone, enhanced strength of connective tissue, increased speed and power, loss of body fat, improved range of movement and cardiovascular fitness. Of growing interest is the energy cost of resistive exercise. Although the energy cost of numerous activities and exercises have been determined, there is a paucity of data with respect to the energy requirements of resistive exercise.

Metabolic studies of resistive exercise have investigated a number of topics, including the cardiovascular benefits of circuit weight training (Hempel & Wells, 1985; Strathman, Gettman & Culter, 1979), the fuel substrates used during resistive exercise (Keul, Haralambie, Bruder, & Gottstein, 1978; Tesch, Colliander & Kaiser, 1986), the metabolic consequences of Olympic weight training and weight lifting (Scala, McMillan, Blessing, Rozenek, & Stone, 1987; Stone, Ward, Smith & Rush, 1979), and the energy cost of resistive exercise compared with other activities, such as treadmill running (Liverman & Groden, 1982), cycling (Kuehl, Elliot, Goldberg, & Frame, 1987) and jogging (Gettman, Ayres, Pollock, & Jackson, 1978). Other investigators have attempted to predict energy expenditure from work performed (Byrd, 1985; Byrd, Hopkins-Price, Boatwright, & Kinley, 1988; Morton, Kuehl, Frame, Elliot, & Goldberg, 1987).

These studies have failed to address possible differences in energy cost due to exercise type. In resistive exercise, type is defined by the level of intensity (load), and duration (number of repetitions performed). Strength and power-type resistive exercise is characterized by use of heavy weights with few repetitions while endurance-type exercise is typified by use of light weights with many repetitions.

Research has shown that the use of a larger muscle mass in resistive exercise requires more energy (Ballor, Becque, & Katch, 1987; Hickson, Buono, Wilmore, & Constable, 1984; McArdle & Foglia, 1969; Scala et al., 1987); however, it is not known whether there is a significant difference in energy expenditure between varied types of exercise using the same muscle groups. Only one study was found which reported changes in energy expenditure as a result of variations in exercise intensity (Hunter, Blackman, Dunnam, & Flemming, 1988).

There is reason to believe that differences in energy cost found between strength and endurance-type resistive exercise are not substantial. This belief centers around the relationship between the intensity of muscle contraction and the total exercise time. Strength-type exercise may initially create greater energy expenditure due to the intensity of the contraction. Electromyographic signals have been found to increase in amplitude and frequency proportional to the magnitude of contraction (Basmajian & De Luca, 1985), which indicates a greater recruitment of motor units, thereby increasing the fuel requirements (i.e., energy cost). Additionally, in 1975, Gaesser and Brooks (cited in Hunter et al., 1988) found that increasing force causes a shift in type of muscle fiber used to less efficient fast twitch fibers which may also increase energy requirements.

Consequently, one might conclude that the endurance-type exercise requires less initial energy because of the lighter weight lifted and therefore less intense contraction. The longer duration of the exercise period for the endurance-type workout, however, would presumably cause utilization of fuel substrates over a longer period of time, resulting in a total energy cost similar to that of a strength-type workout.

In addition to possible differences in energy expenditure between types of exercise workout, it is not known whether a relationship exists between number of sets performed and the energy cost of a specific exercise type. Although some investigators have attempted to predict the energy expenditure of resistive exercise, the relationship between the energy cost of performing varied sets of a given exercise type (e.g., 1 x 3 vs. 3) has not been explored. If a strong relationship is found to exist, it would provide a method of predicting the energy cost of multiple sets of resistive exercise. This method would be less time consuming and provide an alternative to measuring 3 sets.

In the attempt to predict energy expenditure, only one study has compared energy expended per amount of resistive exercise work performed (Hunter et al., 1988). Expressing energy cost relative to external work provides an estimate of "economy". Such an estimate may assist in the selection of resistive exercise type by individuals wishing to optimize work involved.

Although published research on energy expenditure of resistive exercise has provided useful information regarding energy cost of various types of workouts, the results have not always been applicable to the "typical" individual involved in resistive exercise training. Inadequate sample size (Scala et al., 1987), insufficient exercise duration (McArdle & Foglia, 1969), employment of specific resistive exercise devices (Hickson et al., 1984; Katch, Freedson, & Jones, 1985; Liverman & Groden, 1982), varied methodology

(Ballor et al., 1987; Gettman, 1978; Hempel & Wells, 1985; Stone et al., 1979; Strathman et al., 1979; Wilmore, Parr, Ward, Vodak, Barstow, Pipes, Grimdith, & Leslie, 1978), inappropriate sampling procedures (Hunter et al., 1988) and questionable analytical procedures (Morton et al., 1987; Byrd, 1985; Byrd et al., 1988) have all limited the external validity of published research in this area.

STATEMENT OF THE PROBLEM

At the present time it is not known whether performance of resistive exercise of varying intensities and duration result in significantly different energy expenditure. It is also not known whether a relationship exists between the number of sets performed within a given exercise type. Energy cost relative to external work also remains largely unexplored.

HYPOTHESIS

The energy cost of performing a 6-8 repetition maximum (RM) strength-type exercise is not significantly different from the energy cost of performing a 30-35 RM endurance-type exercise using bench press exercise.

PURPOSE

The purpose of this study was to estimate the energy expenditure of two types of resistive exercise (strength and endurance) to determine whether a significant difference exists. An ancillary purpose was to investigate the relationship, if any, between the number of sets of a given type of exercise and the energy expenditure required to perform the exercise. The result of expressing energy cost per unit of external work was also examined.

SIGNIFICANCE OF THE STUDY

There is little information available regarding the estimation of the energy cost of resistive exercise. The results of this study should provide estimates of the energy cost of typical resistive exercise, thus adding to existing information in energy expenditure literature. Secondly, the individual concerned with weight control may benefit from the determination of a significant difference, if any, between exercise type (strength vs. endurance). This may be helpful in choosing a workout type when attempting to create optimal resistive exercise energy expenditure. Thirdly, if a significant relationship exists between the energy cost of performing 1 set multiplied by 3, and 3 sets of one exercise type, a less time-consuming method may be provided for future researchers in estimating caloric cost of resistive exercise. Finally, the most economical exercise type will be determined from the expression of energy cost relative to external work performed.

LIMITATIONS AND ASSUMPTIONS

The following limitations and assumptions should be considered in the interpretation of this study.

Limitations

1. Subjects were not randomly selected. Individuals were selected from a group of volunteers recruited from college weight training classes.

2. Oxygen consumption was averaged from two consecutive 30-second determinations. Errors may be compounded when expressing O_2 consumption per minute.

3. Diet was not controlled during the study (except with regard to caffeine consumption before testing sessions and food intake immediately before hydrostatic weighing) and may have had a confounding effect on metabolic measurements.

4. Subjects initially performed repetitions in synchrony with an auditory metronome (40 beats per minute). Inability to maintain the desired cadence occurred at different times for each subject.

Assumptions

1. Subjects performed to their maximum ability during practice and test sessions and adhered at all times to project guidelines.

2. Open-circuit spirometry is an effective method of indirectly measuring oxygen consumption during resistive exercise.

3. Elevating the arms during rest intervals promoted circulation and assisted in recovery.

4. A 6-minute rest interval was an adequate amount of time for recovery between sets.

5. Forty-eight hours was a sufficient period of recovery between test sessions.

6. A 6-8 RM load and a 30-35 RM load represents strength and endurance-type exercise, respectively.

7. Using a caloric equivalent of 5.05 $kcal \cdot L^{-1}$ oxygen (Fox & Mathews, 1981) provides a valid estimate of calories expended during resistive exercise.

8. Hydrodensitometry and oxygen dilution are valid and reliable tests for estimating body density and residual lung volume, respectively.

9. The average of three measurements of bar movement accurately represented the actual distance moved during test sessions.

10. One familiarization session was sufficient to review proper technique of bench press exercise and adequately acquainted subjects with the testing protocol.

DEFINITION OF TERMS

<u>Resistance Exercise</u> Application of external resistance to a muscle or muscle group during exercise movement (the term "weight training" may be used interchangeably).

Muscular Strength The maximum force or tension generated by a muscle or muscle group (McArdle, Katch, & Katch, 1981).

Muscular Endurance The ability to perform repeated contractions of the muscle(s) against a submaximal resistance for an extended period of time (Luttgens & Wells, 1982).

Isotonic A type of resistance exercise meaning "equal tension" of the muscles; two examples are constant resistance and variable resistance.

Repetition Maximum The maximum resistance a muscle group can lift a given number of times before fatiguing (Luttgens & Wells, 1982).

$\dot{V}O_2$ The volume of oxygen consumed is the difference between the volume of oxygen inspired and that expired (Lamb, 1984).

CHAPTER II

REVIEW OF LITERATURE

Research studies which have measured the energy cost of resistive exercise are presented in categories by mode of resistance: constant, variable and isokinetic. Following this section is a brief summary of important findings. Finally, relevant components of determining energy cost are reviewed.

RESISTIVE EXERCISE ENERGY COST STUDIES

Constant Resistance

Early investigations of the energy expenditure of resistive exercise used an exercise mode known as "constant resistance"; more commonly referred to as "free weights". Constant resistance exercise is believed to more realistically imitate natural movement by providing an opportunity to use both major and specific muscle groups in a combination of movement planes (Weltman & Stamford, 1982) across multiple joints (Field, 1988). However, it is not known whether exercising with free weights significantly increases the energy expenditure above that required for a similar exercise performed with variable resistance equipment.

McArdle and Foglia (1969) noted the lack of objective information available and used constant resistance to determine the ventilatory, cardiovascular and metabolic responses of resistive exercise in six male college students. Oxygen consumption was measured for one set (6-8 RM), of each of four exercises. The "squat" resulted in the greatest caloric cost, followed by the "military press", "bench press" and "bicep curl" when performed isotonically. The average net energy cost for the four exercises was not reported; however, using a caloric equivalent of 5.05 kcal·L^{-1} oxygen the mean cost of the bench press exercise was calculated to be 1.42 kcal·min^{-1}. The results included exercise plus 4 minutes of recovery. The authors reported that the major portion of energy expenditure occurred during the first minute of the 4-minute post-exercise recovery. The "squat" resulted in an energy expenditure of 6.4 kcal·min^{-1} for the first minute post exercise. The immediate post-exercise recovery period coincided with small increases in ventilatory rate and larger increases in ventilatory volume. Although not without limitations, this study served as a model for future investigations attempting to determine the energy cost of isotonic resistive exercise.

Consistent with the results of McArdle and Foglia (1969), Scala et al. (1987) reported a greater net energy expenditure (11.5 kcal·min^{-1} vs. 6.8 kcal·min^{-1}) with exercises involving a larger muscle mass (e.g., "squats", "pulls"), in contrast to exercise involving a smaller muscle mass (e.g., "bench press", "sit-ups"). Data were collected on only three subjects, but a total of 12 workouts were performed during a 6-day period in an attempt to simulate the preparatory phase of strength training competition. Intensity was 62.5% of 1 RM for a variety of exercises completed in 3 sets of 10 repetitions each. The average energy expenditure was 9.4 kcal·min^{-1} and included rest intervals which averaged 2.3 minutes but did not include the 10-minute recovery period. The authors noted that recovery was incomplete during the 10-minute post-exercise time period.

In support of the findings of McArdle and Foglia (1969), Scala et al. (1987) found that the greatest energy expenditure occurred during the period immediately following the cessation of exercise. The higher overall energy cost may have been due to the combined effect of performing various exercises in rapid succession, use of a greater amount of muscle mass during exercise and performance of more than one set. The physical condition of two of the three subjects (one was a national weightlifting competitor and the other a power lifter) may also have contributed to the differences found between the two studies.

Stone et al. (1979) performed a similar study on 12 male Olympic weightlifters who performed an Olympic-type workout. Five exercises (e.g., "clean" and "snatch pulls") were performed using varying loads (50-95% of 1 RM), number of repetitions (3-8) and number of sets (3-6). Energy cost was not reported. However, if an assumed resting metabolic rate of 3.5 ml $O_2 \cdot kg^{-1}$ body weight$\cdot min^{-1}$ is subtracted from the reported average gross oxygen uptake and the result multiplied by the caloric equivalent of 5.05 $kcal \cdot liter^{-1}$ oxygen, the average net energy cost is 7.9 $kcal \cdot min^{-1}$. This calculated energy expenditure includes 1 minute rest intervals following each set but does not include the 10-minute recovery period.

Stone and associates (1979) also examined the relationship of work performed and energy expended. Work was defined as the product of weight, repetitions and distance lifted. The authors did not find a strong relationship between the two variables (values were not reported); however, some studies have found a strong relationship between work performed and energy expenditure. Byrd (1985) reported a Pearson correlation coefficient of 0.96 between oxygen consumption and work performed. Sets varied from 1 to 4, and repetitions from 5 to 30. Neither oxygen consumption nor energy cost data were reported. In 1988, Byrd et al. reported a Pearson correlation coefficient of 0.95 between energy cost and work performed. Again, sets ranged from 1 to 4, and repetitions from 5 to 30. Only total energy expenditure was reported and it was not possible to determine energy cost per minute.

Hunter et al. (1988) also explored the association between external work and energy expended. Their calculation of work required summing the vertical distance traveled by the centers of gravity of the hands, arms and barbell and multiplying the result by the total weight of each. A metronome was used to ensure that the exercise was performed at the rate of 20 repetitions$\cdot$min^{-1}. Intensity was determined as a percentage of 1 RM and amount of repetitions to be performed was predetermined. Correlations for predicting energy expenditure from work performed ranged from 0.83 to 0.99 using 7 bench press exercise protocols. The lowest correlation was found when subjects performed various combinations of sets and repetitions at 30% of 1 RM. Except for the two protocols performed at this particular intensity, the energy cost was found to increase as intensity increased. The net energy cost ranged from 1.0 to 8.6 kcal$\cdot$min^{-1} for 4 sets of 30 repetitions performed with 20% of 1 RM and 4 sets of 5 repetitions performed with 80% of 1 RM, respectively. Energy cost included 1-minute rest intervals between sets and recovery to 4.0 mL $O_2\cdot kg^{-1}\cdot min^{-1}$.

Two possible sources of error which may affect the external validity of the study by Hunter et al. (1988) include variance in number of subjects performing each protocol and the predetermined number of repetitions to be completed for each set. A total of 10 males and 7 females served as subjects; however, not all subjects performed each exercise protocol (i.e., only 6 males performed the exercise protocol at 20% of 1 RM). In addition, the pre-established number of repetitions did not require subjects to complete repetitions to muscle failure.

The actual number of repetitions subjects are able to perform varies with intensity. Westcott (1986) found that subjects differed significantly in number of repetitions performed (5-24) using 75% of 1 RM. The author suggested that both training and heredity affect the number of repetitions performed. It may be concluded, therefore, that subjects who participated in the study by Hunter et al. (1988) may not have performed resistive exercise of equal intensity due to individual differences.

Variable Resistance

Variable resistance obtains its name from the changing position of the workload in relation to the muscle group being used. During exercise using a variable resistance machine, the load does not remain at a set distance from the fulcrum of the machine or the fulcrum of the joint. Therefore, the resistance does not remain constant as with free weights but varies during performance of the exercise. Variable resistance machines allow movement only in one plane and do not allow the person exercising to alter the movement pattern (e.g., increasing the horizontal movement of a barbell in the bench press to optimize use of the tricep muscles).

Hickson et al. (1984) used a Universal Gym to reduce intersubject variability in performance of strength-type resistive exercise. Four male subjects executed 6-9 repetitions (75-80% of 1 RM) of 10 types of exercise. Net energy cost (including a 1-minute rest between sets, 2.5 minutes between exercises and 14 minutes of recovery) was 5.9 $kcal \cdot min^{-1}$ and 6.3 $kcal \cdot min^{-1}$ for small and large muscle mass activities, respectively. The average net energy expenditure was 6.1 $kcal \cdot min^{-1}$.

Variable resistance machines have also been used in a number of studies estimating the energy cost of circuit training. Circuit training studies are characterized by use of a greater number of repetitions, less weight and shorter rest periods, allowing more continuous and rhythmical movement associated with increased cardiovascular fitness.

Wilmore et al. (1978) investigated the energy expenditure of 20 males and 20 females who used a Universal Gym to perform a circuit of 10 exercises (15-18 repetitions with 40% of 1 RM). Exercise at each "station" lasted approximately 30 seconds with 15 seconds rest between each station. The average net energy expenditure was 5.9 $kcal \cdot min^{-1}$ and 4.2 $kcal \cdot min^{-1}$ for males and females, respectively. The mean for the entire sample was 5.1 $kcal \cdot min^{-1}$. Calculations did not include recovery data.

Hempel and Wells (1985) used Nautilus equipment in a circuit of 14 exercises. Eighteen subjects (10 males, 8 females) performed 8-12 repetitions for upper body movements and 8-20 repetitions for lower body movements until either the highest number was completed or the occurrence of momentary muscle failure. No rest was allowed between stations. Energy expenditure included 2 minutes of recovery but was reported in gross cost only (i.e. resting energy expenditure was not subtracted from measurements). Under the assumption that resting oxygen uptake was 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ and using a caloric equivalent of 5.05 $kcal \cdot L^{-1} O_2$, the net energy cost was calculated to be 4.1 $kcal \cdot min^{-1}$ and 5.9 $kcal \cdot min^{-1}$ for females and males, respectively. The average for the entire sample was 5.0 $kcal \cdot min^{-1}$. These values are almost identical to those reported by Wilmore et al. (1978) and are only slightly lower than the results of Hickson et al. (1984) who used higher intensity exercise more comparable to a resistive strength workout.

In two other circuit weight training studies, a special type of hydraulic exercise machine (Hydra-Fitness, Belton, TX) was used which permits only maximal concentric contractions performed at selected speeds. Katch et al. (1985) studied cardiorespiratory responses of 20 male subjects who performed 3 sets of 3 exercises with an average of 19 repetitions per set. A 20-second work:20-second rest ratio was used for each exercise. A 5-minute rest period was allowed between exercises but oxygen consumption data were obtained only for the fifth minute; no recovery period was mentioned in the published report. Again, using an assumed resting metabolic rate of 3.5 $mL\cdot kg^{-1}\cdot min^{-1}$, the net energy expenditure was calculated to be 6.8 $kcal\cdot min^{-1}$.

In another study, Ballor et al. (1987) measured the metabolic responses of 13 men who performed 7 exercises using Hydra-Fitness equipment. Several movement speeds were used and the number of repetitions performed (6.5 to 25) varied according to these speeds. Three sets of each exercise were performed with 30 seconds rest between sets and 60 seconds rest between each exercise. The net energy cost during exercise averaged 7.3 $kcal\cdot min^{-1}$.

Isokinetic Resistance

The term "isokinetic" refers to the constant speed maintained throughout a range of movement and can only be accomplished with special exercise machines. It is thought that this type of resistance provides advantages over constant and variable resistance exercise as speed of movement is controlled, maximizing the force capable of being generated by a muscle or muscle group. Disadvantages of this type of exercise include restriction of movement to one plane and use of only one type of muscle contraction during the movement (i.e., concentric).

In a study by Gettman (1978), five males were tested at slow and fast speeds of movement on seven isokinetic exercises. Twelve repetitions were performed for each exercise with 30 seconds of rest between each station.

Three circuits were completed. Total gross energy cost was significantly greater for the slow speed circuit; however, when averaged per minute the energy cost was 9.9 $kcal \cdot min^{-1}$ for the fast speed and 9.6 $kcal \cdot min^{-1}$ for the slow speed. It is not known if these figures include recovery data as the study was published in abstract form.

Summary

Energy cost research of resistive exercise has utilized a variety of methods and modes of exercise. The methodologies have normally varied with differences in subject characteristics, length of rest periods, load lifted, number of repetitions (or duration), number of sets, reason for termination of repetitions (e.g., muscle failure or attainment of prescribed number) and type of resistance. Differences also exist with regard to the way results are reported including net vs. gross energy expenditure, total vs. relative rate of energy expenditure, combining data from both sexes and failure to mention or include recovery energy expenditure.

Net energy costs have ranged from 1.0 to 9.4 $kcal \cdot min^{-1}$ for use of constant resistance exercise and from 4.1 to 7.3 $kcal \cdot min^{-1}$ for variable resistance exercise. Isokinetic exercise data were reported in gross values and averaged 9.6 to 9.9 $kcal \cdot min^{-1}$. The data suggest that intensity is linearly related to energy cost, but unequivocal support for this conclusion is not available.

ENERGY COST COMPONENTS

Indirect Calorimetry

Measurement of the volume of oxygen ($\dot{V}O_2$) consumed is a well-accepted method of estimating the energy cost of work and exercise. The amount of work performed by the body ultimately depends, to a large degree, on oxygen utilization; therefore, the amount of energy used may be approximated by measurement of $\dot{V}O_2$ (indirect calorimetry). The indirect method has several advantages over the direct method requiring a human calorimeter: it is simple to use, relatively inexpensive and readily available. The validity of indirect calorimetry was established early in this century by Zuntz & Schumburg as cited in a current review by Livesey & Elia (1988) who reaffirmed this finding. Recent investigators have used indirect calorimetry to estimate the energy expenditure of isotonic (Ballor et al., 1987; Byrd, 1985; Byrd et al., 1988; Hempel & Wells, 1985; Hickson et al., 1984; Hunter et al., 1988; Katch et al., 1985; Kuehl et al., 1987; Liverman & Groden, 1982; McArdle & Foglia, 1969; Morton et al., 1987; Scala et al., 1987; Stone et al., 1979; Strathman et al., 1979; Wilmore et al., 1978) and isokinetic (Gettman, 1978) resistance exercise.

In using $\dot{V}O_2$ to estimate energy expenditure in resistive exercise, it is necessary to consider the ventilatory response that occurs with this type of activity. It is not unusual for breathing rhythm to be coupled with exercise rhythm (i.e., one breathing cycle per repetition). Breath-holding may also occur (Scala et al., 1987; Veicsteinas, Feroldi, & Dotti, 1986). The breathing pattern during recovery is likely to vary from that used during the exercise period, usually with an increase in ventilation during recovery (McArdle & Foglia, 1969).

The increased rate of ventilation during recovery from resistive exercise leads to increased oxygen consumption. Consequently, it should be recognized that data from the exercise period may not reflect the total amount of energy required during the exercise. Measurement of oxygen consumption during the recovery period is likely to improve the estimate of the energy used during the exercise.

Energy Substrates

The intensity, duration and type of work performed are factors which determine the energy system used during exercise. Resistance exercise normally involves performance of short exhaustive work periods which may be as long as 2-3 minutes. Keul et al. (1978) suggested that strength exercise energy requirements appeared to be met exclusively from the high energy phosphates -- adenosine triphosphate (ATP) and creatine phosphate (CP). They noted little change in glucose or lipid substrate utilization. McArdle et al. (1981) confirmed the prominent use of phosphates during resistive exercise but noted the supplementation of glucose and glycogen through anaerobic glycolysis for the resynthesis of ATP. More recent evidence supports anaerobic glycolysis and even mobilization of lipid as supplemental sources of energy in resistive exercise (Tesch et al., 1986; Saltin and Gollnick, 1983, cited in Tesch, 1987).

Tesch et al. (1986) studied metabolic changes in muscle during intense, prolonged heavy resistance exercise. They found significant reductions in ATP and CP with significant increases in glycogenolytic intermediates which aid in the resynthesis of glycogen. Glycogen utilization, however, was found to be modest in comparison with other studies. The investigators concluded that although high-energy phosphagens provided a significant source of fuel substrate, the modest utilization of glycogen may indicate that other supplemental sources of energy are used. The differences found in use of fuel substrates between studies performed by Tesch et al. (1986) and Keul et al. (1978) may be the result of the exercise protocol used, with differences in regard to the number of repetitions per set, and the rest intervals between sets and exercises.

Recently, Tesch (1987) discussed the metabolic alterations which occur as a result of heavy resistance exercise, and indicated the possible utilization of fat in addition to other fuel substrates. He suggested that high intensity, heavy resistance exercise could mobilize all available energy systems even though oxygen consumption may reflect low energy output.

In his review of metabolic research on resistance exercise, Dudley (1988) agrees that additional energy systems appear to make significant contributions to the energy supply, especially when a greater number of repetitions per set and shorter rest periods are used. In an earlier paper, Keul (1973) mentioned the importance of duration of exercise and the length of rest interval in the use of energy substrates. Kraemer, Marchitelli, McCurry, Fleck, Dziados, Harman, Vela, and Frykman, (1986) found that manipulation of the length of rest periods is important in determining the level of blood lactate, a product of energy metabolism. Thus, the number of repetitions per set and the exercise:rest ratio may play important roles in the determination of energy substrate utilization during resistive exercise.

Caloric Equivalent

In order to estimate the exercise energy expenditure using indirect calorimetry, it is necessary to assign a caloric equivalent for a given amount of oxygen consumed. A mixed diet of protein, fat and carbohydrate produces about 5 kcal of energy for each liter of oxygen consumed (Lamb, 1984; McArdle et al., 1981).

If oxygen consumption measurements are available, a more precise method may be used to determine the caloric equivalent. The respiratory exchange ratio (R) is the ratio of the volume of CO_2 expired per minute to the volume of O_2

consumed per minute (Fox & Mathews, 1981). If R is known, then a more accurate caloric equivalent may be assigned. During resistive exercise training, however, R may be abnormally elevated. Large quantities of expired CO_2 can result from the buffering of lactic acid, a by-product of anaerobic glycolysis, and thereby elevate R (Fox & Mathews, 1981; Lamb, 1984; McArdle et al., 1981).

Fox & Mathews (1981) suggest a caloric equivalent of 5.05 $kcal \cdot L^{-1} O_2$ for short-term exhaustive exercise. In two recent studies, investigators used this value to estimate energy expenditure during resistive exercise (Hempel & Wells, 1985; Wilmore et al., 1978) unless R was less than 1.0, in which case the corresponding caloric equivalent for a given collection period was used (Hempel & Wells, 1985). Other investigators have used a caloric equivalent of 5.00 $kcal \cdot L^{-1} O_2$ consumed (Byrd 1985; Hickson et al., 1984; Hunter et al., 1988; Scala et al., 1987; Katch et al., 1985), the corresponding R (Byrd et al., 1988) or failed to report the equivalent used (Ballor et al., 1987; Kuehl et al. 1987; Gettman, 1978; McArdle & Foglia, 1969; Morton et al., 1987; Liverman & Groden, 1982; Strathman et al., 1979).

<u>Net Energy Expenditure</u>

The net energy expenditure is the amount of energy expended from performance of the exercise, calculated by subtracting the resting energy cost from the total expenditure. Accurate estimation of the resting value is necessary for correct interpretation of exercise energy cost. Resistive exercise studies, however, do not appear to be in agreement regarding the measurement of the pre-exercise resting period. Time intervals used for the measurement of resting energy expenditure have been defined as 5 minutes (Ballor et al., 1987; Wilmore et al. 1978), 10 minutes (Byrd et al., 1988), 15 minutes (Hickson et al., 1984), the final 2 minutes of a 12-minute rest period (Katch et al., 1985) and a 3-minute average after a 15-minute rest (Scala et al., 1987). Hunter et al. (1988) assumed a resting oxygen uptake of 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ for their subjects. Several investigators did not report the technique used for calculating net energy expenditure or examined total energy expenditure (Byrd, 1985; Hempel & Wells, 1985; Gettman, 1978; Kuehl et al., 1987; Morton et al., 1987; Liverman & Groden, 1982; McArdle & Foglia, 1969; Stone et al., 1978; Strathman et al., 1979; Tesch et al., 1986).

The length of the recovery measurement period reported in the recent literature also varies considerably. Recovery measurement periods of 4 minutes (McArdle & Foglia, 1969), 5 minutes (Ballor et al., 1987), 10 minutes (Scala et al. 1987; Stone et al. 1979), 12 minutes (Wilmore et al., 1978), 14 minutes (Hickson et al., 1984) and 2 hours (Kuehl et al., 1987) have been reported. Hempel & Wells (1985) obtained O_2 uptake data on 3 of their 18 subjects for 20 minutes post-exercise, while measurements during recovery for the remaining subjects were not obtained. Other investigators did not use an absolute time limit for measuring recovery periods but used a relative measure defined as attainment of the original resting value (Byrd, 1985), a value within 10% of the initial O_2 uptake (Byrd et al., 1988) or until $\dot{V}O_2$ was below 4.0 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ (Hunter et al., 1988). Many studies do not provide definitions of the recovery periods used (Gettman, 1978; Liverman & Groden, 1982; Morton et al., 1987; Katch et al., 1985; Strathman et al., 1979; Tesch et al., 1986).

CHAPTER III

METHODS

The following methods were used to estimate the energy cost of performing the bench press with free weights, specifically comparing strength and endurance-type exercise, the relationship of one to three sets, and the energy requirement relative to the amount of external work performed.

SUBJECTS

Male college students (age 19-34 years) were recruited from weight training classes at Portland State University. Prospective subjects were interviewed by the principal investigator during class or by phone. Selection for participation was based on meeting requirements discussed during the interview, including abstinence from steroid use and the subject's willingness to adhere to project guidelines.

Selection of 19-34 year old males allowed variety in age range of students enrolled in weight training classes at the university while providing a precautionary safety measure. The type of resistive exercise performed in this study required maximum physical effort from subjects.

Although recommended for maximal exercise testing for individuals 35 years or older (ACSM, 1986), medical supervision was not provided for this study as all subjects were 19-34 years of age.

Additional selection criteria included recent resistive exercise training. An attempt was made to select subjects who had not trained regularly 1) more than six months of the past 12 months, and 2) longer than three months immediately prior to the beginning of the study. These limitations reduced intersubject variability and helped provide a more "typical" group of college males (i.e., non-competitive in weight lifting or bodybuilding).

To further control the influence of external variables during testing, the following requests were made of each subject prior to each test session: 1) refrain from weight training for 48 hours, 2) avoid heavy exercise for 12 hours, 3) refrain from caffeine intake for four hours, and 4) fast from solid food four hours prior to hydrostatic weighing.

Screening

Subjects were screened for supine resting heart rate and blood pressure to detect any abnormal physiologic condition (e.g. hypertension). Informed consent was obtained from each subject in accordance with the guidelines of the Portland State University Human Subjects Research Review Committee. In addition, a data sheet was completed which included questions regarding health history and status (including use of medication), current activity level, exercise background and resistive exercise experience (Appendix A).

Characteristics

Eleven participants volunteered for the study and ten subjects completed all test sessions. One subject dropped out because of schedule conflicts in addition to illness. Physical characteristics of the subjects are presented in Table I.

TABLE I

SUBJECT CHARACTERISTICS

	$\bar{X}$	s	Range
Age (yrs)	24.50	4.86	19-34
Height (cm)	173.55	9.01	163.83-193.04
Body Weight (kg)	71.58	8.04	59.89-86.82
Body Fat (%)	12.84	5.17	6.92-21.29
Lean Body Mass (kg)	60.76	5.33	54.11-67.80

(n=10)

All subjects were actively involved in various types of exercise from 1.5 to 10.5 hours per week, including such sports as tennis, wrestling, basketball and resistive exercise. Resistive exercise performance and experience was further defined. Prior to the beginning of the project, performance of resistive exercise including the bench press ranged from 0 to 4.5 hours per week ($\bar{x}$=1.75). Total resistive exercise experience ranged from 2.5 months to 6 years ($\bar{x}$=3.1). Four of the ten subjects typically used free weights to perform the bench press with the remainder using the Universal Gym. Five subjects performed resistive exercise recreationally, four subjects trained to improve sport performance and one subject indicated both reasons. None of the subjects classified themselves as bodybuilders or competitive weight lifters.

EQUIPMENT

Blood pressure was measured with a standard inflatable blood pressure cuff, anaeroid sphygmomanometer and stethoscope. Heart rate was estimated with an Astropulse 99 digital pulsemeter (Lafayette Instruments, Lafayette, IN) placed on the ear lobe which was periodically calibrated by comparison with manual palpation of the radial pulse. Body temperature was measured with an oral thermometer. A bench with standards and 45 lb. (20.5 kg) barbell with Olympic plates were used for performing the bench press. All weights were validated to the nearest pound with a Continental Weight Scale (Continental Scale Co., Chicago, IL) and used throughout the entire period of data collection. The distance of bar movement through each subject's range of motion for the bench press was measured with a metal tape measure. Height and weight were determined to the nearest 0.25 inch and 0.25 pound, respectively, on the Continental scale. A laboratory timer was used to measure time intervals, and a calibrated electric metronome provided an auditory cue for pacing (40 beats·min^{-1}). Subjects used in pilot work aided in selecting rate of work.

A Jaeger Ergo-Oxyscreen Metabolic Cart (Erich Jaeger, Inc., Rockford, IL) equipped with a standard mouthpiece was used with a nose-clip for open-circuit measurement of oxygen consumption. Gas analyzers were calibrated for each test session with gases of known concentration. Gas volume was calibrated according to the manufacturer's instructions. Printed output included oxygen uptake, minute ventilation, breathing frequency, expired oxygen concentration, expired carbon dioxide concentration, respiratory exchange ratio, and metabolic equivalent. Expired air was sampled continuously and averaged every 30 seconds. The amount of oxygen consumed was measured in liters·min^{-1} under standard conditions.

PROCEDURES

Pilot work was performed on four male volunteer subjects. Data collection procedures were practiced, which assisted in identifying and correcting potential problems that might occur during the study. In addition, three male and three female volunteers aided in establishing rest period intervals, number of repetitions per set for endurance type exercise, and percentages of 1 repetition maximum (RM) load for determining 6-8 RM and 30-35 RM loads.

All testing was performed in the Exercise Physiology Laboratory of the School of Health and Physical Education (HPE) at Portland State University. The familiarization session (the first of five sessions) began with completion of the data sheet, procurement of informed consent, and measurement of height and weight. Subjects were then asked to assume a supine position for ten minutes after which resting heart rate and blood pressure were determined. A 5-minute warm-up (Appendix B) was followed by instruction on proper bench press technique with free weights (Madsen & McLaughlin, 1984; McLaughlin, 1985). The instruction was given to standardize lifting technique among subjects as well as to help prevent injuries from occurring. Each subject's 1 RM in the bench press was then determined. After adequate recovery, the 6-8 RM and 30-35 RM were also determined. Subjects then practiced the bench press under simulated test conditions with mouthpiece, nose-clip, and metronome. Every effort was made to fully inform subjects of all procedures at the beginning of each testing session. This further helped ensure standardized test conditions and reduce anxiety concerning expectations.

The three bench press test sessions consisted of performing 1) one set with the subject's 6-8 RM load and one set with the 30-35 RM load; 2) three sets with the 6-8 RM load; and 3) three sets with the 30-35 RM load. The order of test sessions was randomized to control for learning effects as well as the effect of fatigue during the test session requiring performance of both exercise types.

The test sessions began by establishing resting metabolic rate (RMR). Subjects rested supine in a quiet environment for 10 minutes followed by the measurement of heart rate, blood pressure and body temperature. The subject then breathed into the mouthpiece of the metabolic cart during an additional 5 minutes of rest. The necessity of the 5-minute pre-measurement adjustment period was confirmed during pilot testing. The total time of resting prior to measurement of RMR was approximately 15 minutes. Six 30-second $\dot{V}O_2$ measurements were then obtained. Consecutive readings were averaged to express measurements of oxygen consumption per minute.

Following measurement of RMR, subjects completed the 5-minute warm-up during which the bar movement distance was measured. Subjects then assumed a supine position for 5-7 minutes to allow the heart rate to return to the initial value. Resting oxygen consumption was measured again following the 5-minute adjustment period to aid in determination of reattainment of a resting state. Oxygen consumption measurements were then made for the scheduled protocol.

The principal investigator recorded the number of repetitions successfully completed, the time required to complete each set, the allotted rest period, and served as a "spotter". The final repetition of each set was defined as the repetition where assistance was needed to fully extend the arms at the elbow joint. Only the final repetition of each set was spotted. Subjects rested 6 minutes between sets for both strength and endurance-type protocols and 10-12 minutes following the final bout of exercise. The sets involving only one set of strength or endurance-type exercise were separated by 12 minutes of recovery. Subjects were asked to remain as quiet as possible during rest and recovery periods. Arms were elevated slightly on stools placed at both sides of the body while the subject remained resting in a supine position. Pilot work indicated that this position assisted local circulation and resulted in a more comfortable recovery for most subjects.

The fifth session involved measurement of residual lung volume (RV) and body composition. Each subject's RV was measured with the oxygen dilution method (Wilmore, Vodak, Parr, Girandola, & Billing, 1980) while body composition was estimated with hydrodensitometry (Brozek, Grande, Anderson, & Keys, 1963). The 3 heaviest underwater weights of 7-8 trials were averaged, with the resultant mean used to calculate body density. Measurements of RV were made with the subject in a seated position similar to that required for the underwater weighing procedure. The average of two measurements was used, with additional trials performed if the first 2 trials differed by more than 2%.

An attempt was made to test subjects at the same time of day to minimize possible diurnal effects on strength (Ishee & Titlow, 1986; Wright, 1959). In addition, an effort was made to minimize noise in the lab and surrounding area.

Oxygen uptake measurements for each two consecutive 30-second readings were averaged, with kilocalories expended estimated by multiplying the volume of oxygen consumed by 5.05 $kcal \cdot L^{-1}$ (Fox & Mathews, 1981). Height and weight measurements were converted from inches and pounds to centimeters and kilograms, respectively.

The 3-minute recovery period following exercise was used after it was determined that subjects were normally recovered to their prexercise resting rate at this point. In addition, the $\dot{V}O_2$ after 3 minutes post-exercise often dropped to levels below the pre-exercise resting oxygen uptake.

STATISTICAL ANALYSIS

Two-way analysis of variance (ANOVA) with repeated measures was used to determine significant differences in caloric cost for type of exercise (strength vs. endurance) and number of sets (1 vs. 3) for both $kcal \cdot min^{-1}$ and kcal·

$min^{-1} \cdot kgm^{-1}$. Analysis was performed using the BMDP2V computer program (W.J. Dixson, 1985). A Newman-Keuls Multiple Comparison Test was used as a follow-up method of analysis to locate significantly different means. The predetermined alpha level of .05 was selected for all statistical tests.

Linear regression was performed using total kilocalories to determine the relationship between 1 set multiplied by 3, and 3 sets for each exercise type. Pearson's r was used to estimate the correlation between energy expenditure of the first set of the 1-set and 3-set conditions for strength and endurance-type exercise. Both analyses were performed using "Statistics With Finesse" statistical software (James Bolding, 1985) and an Apple IIe microcomputer.

CHAPTER IV

RESULTS AND DISCUSSION

The following chapter presents the results and discussion of energy cost determined from performance of 1 and 3 sets of strength and endurance-type bench press exercise. It was hypothesized that differences in energy cost due to exercise type would not be significantly different. The relationship between the energy expenditure of one set multiplied by three and three sets was also explored. In addition, an analysis of energy expenditure data relative to work performed was undertaken.

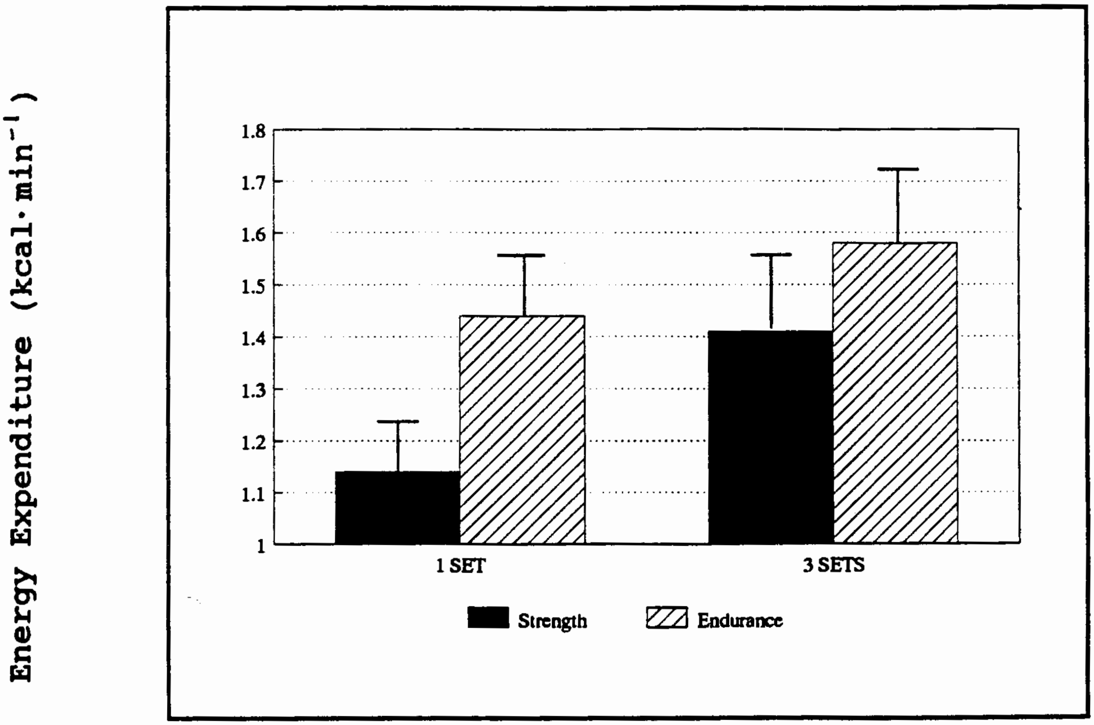
RESULTS

The net energy expenditure ($\bar{x} \pm$ SEM) for 1 set of strength and 1 set of endurance-type exercise was 1.14 ± 0.11 $kcal \cdot min^{-1}$ and 1.44 ± 0.14 $kcal \cdot min^{-1}$, respectively. For 3 sets of strength and 3 sets of endurance-type exercise, the net energy expenditure was 1.41 ± 0.15 $kcal \cdot min^{-1}$ and 1.58 ± 0.13 $kcal \cdot min^{-1}$, respectively. The total net energy expenditure ($\bar{x} \pm$ SEM) for performing 1 and 3 sets of strength-type exercise was 4.00 ± 0.40 kcal and 15.24 ± 1.51 kcal, respectively. For 1 and 3 sets of endurance-type exercise the total net energy expenditure was 6.85 ± 0.79

kcal and 20.57 ± 1.86 kcal, respectively. All values include 3 minutes of recovery between sets (if more than one set was performed) and 3 minutes following the final bout of exercise.

Net energy expenditure ($kcal \cdot min^{-1}$) data for 1 and 3 sets of strength and endurance exercise are illustrated in Figure 1. Main effects for exercise type and number of sets are present; endurance-type exercise resulted in significantly greater expenditure of energy during performance of both 1 and 3 sets ($F_{1,9}$ =7.37, p <.05). No significant interaction was found. Summary tables for the statistical analysis using ANOVA are found in Appendix C. Figure 2 shows the net energy expenditure relative to LBM and closely resembles the results depicted in Figure 1.

Figure 3 illustrates the mean net energy expenditure relative to work performed ($kcal \cdot min^{-1} \cdot kgm^{-1}$). A significant interaction was found ($F_{1,9}$ =6.19, p <.05). A Newman-Keuls Post Hoc test revealed that one set of strength-type exercise was significant greater in energy cost than all other conditions. Main effects for exercise type and number of sets are also present with strength-type exercise creating a significantly greater energy cost when amount of work performed was considered ($F_{1,9}$ =14.49, p <.05). Table II presents data describing work performed, including repetitions, weight lifted, distance of bar movement, and averaged exercise time.



<u>Figure 1</u>.- Net energy expenditure for strength and endurance-type bench press exercise. ($\bar{x}$ ± SEM)

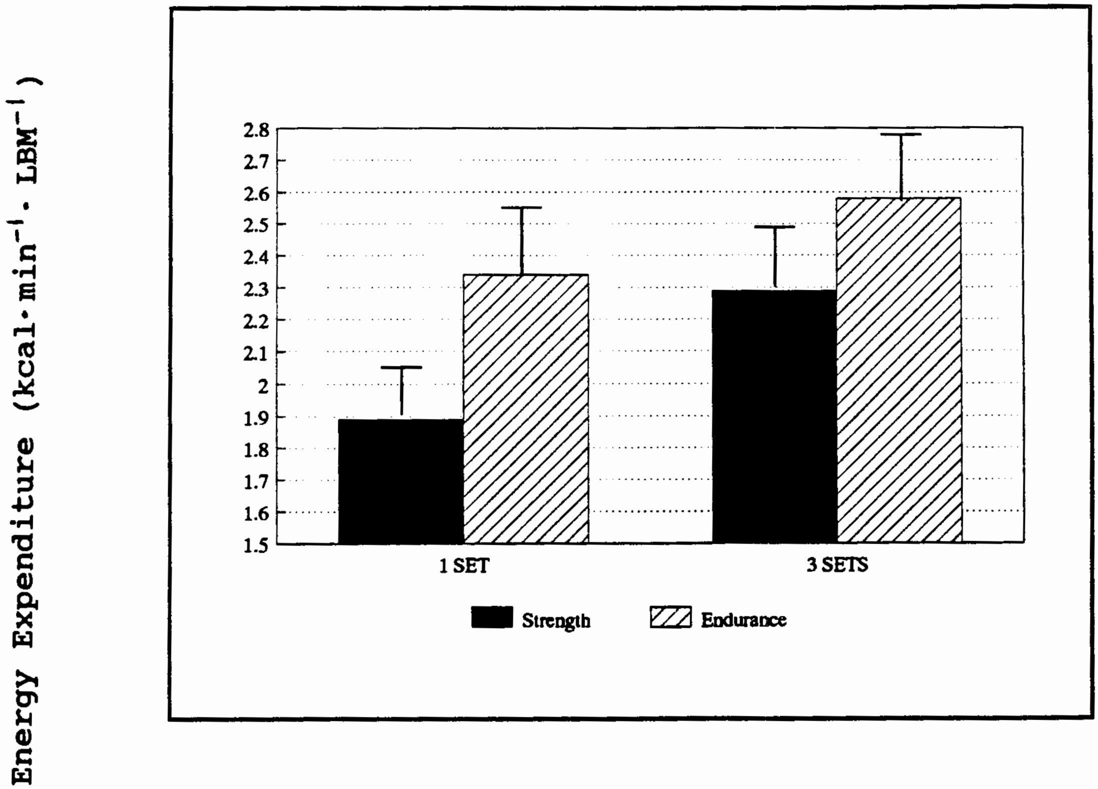
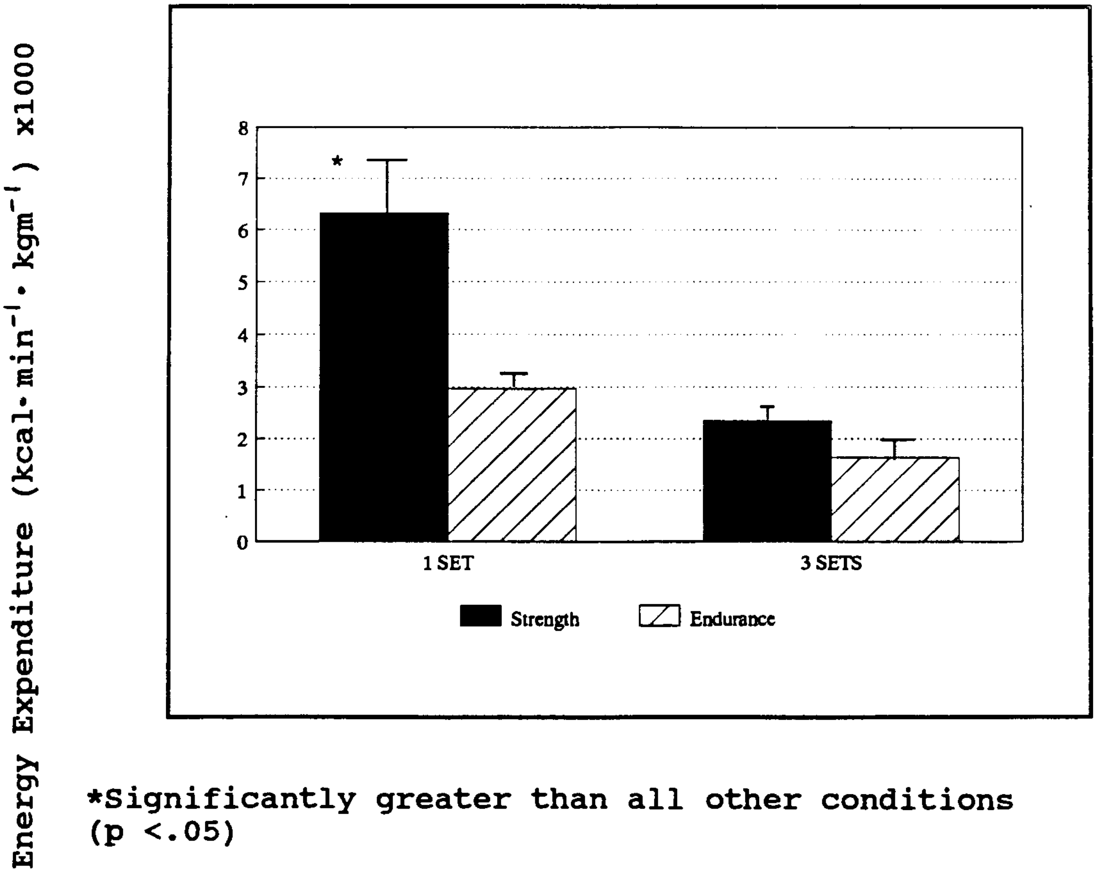


Figure 2. Net energy expenditure relative to lean body mass for strength and endurance-type bench press exercise.
($\bar{x}$ ± SEM)



*Significantly greater than all other conditions ($p < .05$)

Figure 3. Net energy expenditure relative to work performed for strength and endurance-type bench press exercise.
($\bar{x} \pm$ SEM)

TABLE II

WORK PERFORMED DURING BENCH PRESS EXERCISE

Type*	Sets	Reps	Exercise Time (min:sec)	Weight Lifted (kg)	Work (kgm)
S	1	8.5 ±2.5	0:34.6 ± 5.7	58.6 ±16.3	196.58 ± 44.56
E	1	33.0 ±6.4	1:44.7 ±20.2	36.6 ± 9.7	487.66 ±112.64
S	1	9.9 ±2.7	0:39.5 ±10.6	58.6 ±16.3	
	2	8.7 ±2.0	0:34.5 ± 6.7	58.6 ±16.3	597.73 ± 88.26
	3	7.3 ±1.8	0:33.6 ± 5.6	58.6 ±16.3	
E	1	32.4 ±4.6	1:40.1 ±18.1	36.6 ± 9.7	
	2	24.0 ±3.1	1:13.3 ±11.2	36.6 ± 9.7	1131.76 ±239.48
	3	19.7 ±2.8	1:08.3 ±12.0	36.6 ± 9.7	

*S = Strength; E = Endurance
Distance of bar movement = 0.415 m ± 0.041 m
Values are Mean ± SD; n=10

The mean values for gross energy expenditure ($kcal \cdot min^{-1}$) are presented in Table III. This table indicates a consistent pattern of increased energy expenditure during the first minute of recovery. It should be noted that there was some variation in actual exercise time among subjects as well as between exercise types. Exercise energy expenditure values presented in Table III are not indicative of total cost, but represent an average rate of oxygen consumption (per minute) for the purpose of comparing differences between exercise and recovery.

The mean resting O_2 consumption ($\pm$ SD) for all 10 subjects was determined to be 0.38 $\pm$ 0.08 $L \cdot min^{-1}$ before the exercise involving 1 set of strength and endurance, 0.36 $\pm$ 0.13 $L \cdot min^{-1}$ before the exercise involving 3 sets of strength and 0.39 $\pm$ 0.08 $L \cdot min^{-1}$ before the exercise involving 3 sets of endurance-type exercise.

For purposes of determining reliability, correlations between energy expenditure data collected during the 1-set protocol and the first set of the 3-set protocol were $r=0.81$ ($p < .05$) for endurance-type exercise and $r=0.10$ for strength-type exercise.

Appendix D graphically illustrates the relationship between total net energy expenditure resulting from the performance of 1 set multiplied by 3, and 3 sets of bench press exercise. Correlation coefficients were $r=0.27$ ($p > .22$) for strength-type exercise and $r=0.64$ ($p > .01$) for

TABLE III

ENERGY COST OF BENCH PRESS EXERCISE

Type*	Sets	Exercise	Recovery (min) 0-1	1-2	2-3
S	1	3.84 ± .89	3.28 ± .45	3.12 ± .43	2.34 ±.37
E	1	3.90 ± .66	3.94 ± .78	3.00 ± .27	2.18 ±.26
S	1	3.73 ±1.52	3.61 ±1.16	3.26 ± .89	2.30 ±.78
	2	3.40 ±1.17	3.59 ± .90	3.35 ± .85	2.47 ±.71
	3	3.49 ±1.33	3.77 ±1.13	3.52 ± .93	2.67 ±.78
E	1	3.92 ± .69	4.08 ± .74	3.17 ± .36	2.35 ±.26
	2	3.69 ± .66	4.52 ± .86	3.46 ± .71	2.56 ±.37
	3	3.99 ± .91	4.29 ± .69	3.41 ± .45	2.63 ±.47

* S = Strength; E = Endurance
Values are Mean ± SD for gross $kcal \cdot min^{-1}$;n=10

endurance-type exercise. All individual subject data is presented in Appendix E.

DISCUSSION

Exercise Type

When the energy cost of strength and endurance-type resistive exercise were compared, endurance-type exercise was found to create a greater expenditure of energy. It was initially believed that differences in intensity of muscle contraction and duration of exercise would counterbalance energy cost between the two exercise types resulting in similar total energy expenditure. Although the duration of exercise varied between exercise types, the intensity of muscle contraction did not appear to produce the hypothesized effect on oxygen consumption.

The results of this study are not in agreement with those of Hunter et al. (1988) who described a pattern of increasing caloric cost as intensity of bench press exercise increased. In the present study, a higher mean energy cost was found during low intensity endurance-type exercise rather than for high intensity strength-type exercise.

One reason for this lack of agreement between studies may be differences in methodology, particularly in regard to duration of rest intervals and criteria for exercise termination. The importance of the work:rest ratio in influencing the metabolic response to exercise was previously addressed. Hunter et al. (1988) used a 1-minute interval between sets in contrast to the 6-minute rest interval used in this study. A shorter rest period may have had an effect on the oxygen consumption of subsequent sets. However, since the energy expenditure of individual sets was not reported, the cumulative effect of repeated exercise remains speculative.

The study conducted by Hunter et al. (1988) required subjects to perform a predetermined number of repetitions at a given intensity. Hunter's subjects performed 5 repetitions at 80% of 1 RM compared with the subjects of the present study who performed an average of 7-10 repetitions per set (see Table II) to muscle failure at a mean intensity of 81% of 1 RM. Pilot work performed for this study determined that subjects required 4-6 minutes of rest to sufficiently recover from a 6-8 RM exercise bout in order to complete a similar number of repetitions in subsequent sets without assistance. Hunter et al. (1988) may have been able to use shorter rest periods because their subjects were not required to perform repetitions to muscle failure.

Another difference in methodology between the present study and that performed by Hunter et al. (1988) is in work rate. Hunter et al. (1988) used a metronome-guided rate of 20 beats$\cdot$min^{-1} in contrast to 40 beats$\cdot$min^{-1} used in the present study. A difference in exercise rate may have influenced oxygen consumption since greater muscle forces are produced at slower speeds (Basmajian & De Luca, 1985). Differences in muscle forces between the two lifting rates are not known.

In an attempt to elucidate the mechanism(s) responsible for higher oxygen consumption during endurance-type exercise in the present study, the mean $\dot{V}O_2$ for the first 30 seconds of exercise of each set of the 3 set protocol were compared between the two exercise types. Oxygen uptake for strength-type exercise was only slightly higher than endurance-type exercise in the first 2 sets, (0.76 vs. 0.75 $L \cdot min^{-1}$ for the first set; 0.66 vs. 0.63 $L \cdot min^{-1}$ for the second set). In the third set $\dot{V}O_2$ was higher for endurance than for strength-type exercise (0.72 vs. 0.69 $L \cdot min^{-1}$).

These results show similar initial energy costs. Recovery periods, however, were not able to be included in the comparisons because of differences in duration of exercise. Therefore, these comparisons may not be reflective of total energy costs used; original hypothesized oxygen requirements derived from intensity of muscle contraction remain speculative.

An explanation for the results found between exercise type addresses the method of measuring energy cost. High intensity strength-type exercise may be completed in too short of a time period to sufficiently disturb oxygen consumption above resting measurements. Endurance-type exercise, however, requires a longer exercise duration. Perhaps $\dot{V}O_2$ is not a good method of measuring energy requirements for high intensity, short duration resistive exercise.

The type of energy substrate utilized may also have affected energy cost results of strength and endurance-type exercise. Lower intensity resistive exercise may utilize energy sources during initial work that increase oxygen consumption (e.g., lipid). Hunter et al. (1988) found an anomaly in energy cost at the 30 percent intensities where kilocalories increased in a non-linear manner. Hunter and associates (1988), however, suggested that the relationship was obscured at the 30 percent intensities due to the type of subjects who performed the protocol; the subjects studied were stronger and therefore lifted heavier weights which increased energy cost.

A final explanation of the results found in comparing exercise type involves the trained state of participants. No effort was made to select or control training background of subjects with regard to exercise type. Subjects reported that they trained primarily for strength gains through high intensity workouts. It is not known if adaptations resulting from resistive or other types of training, or lack of such adaptations, (e.g., availability of substrates and capacity for their use) influenced oxygen consumption.

As part of their study, Hunter et al. (1988) trained subjects at an intensity of 70% of 1 RM, 3 times per week for 8 weeks to investigate differences in metabolism. Small increases in energy cost from training were noted from 4.0 to 4.3 $kcal \cdot min^{-1}$. Work performed also increased and economy of exercise remained similar. Though changes in substrate utilization and possible effects on oxygen consumption were not explored, it may be concluded from this study that training did not result in a more effective use of oxygen. No other similar resistive exercise training studies could be found.

Though the mechanism(s) responsible for a greater expenditure of energy during performance of endurance-type exercise are unknown, it is known that as work progressed during the low intensity exercise $\dot{V}O_2$ increased and produced a greater mean than the strength-type exercise. Localized muscle fatigue may have contributed to these increases in $\dot{V}O_2$ (deVries, 1986). In addition, rest periods for endurance-type exercise may not have been of sufficient duration as number of repetitions performed in succeeding sets decreased in the 3-set protocol at a greater rate than for strength-type exercise (see Table II). This may have had an effect of increasing energy requirements of subsequent sets.

<u>Energy Cost Relative to Work Performed</u>

Economy of resistive exercise was estimated by expressing energy cost relative to the amount of external work performed. This expression presumably can assist in the determination of the type of exercise which provides the greatest energy expenditure for the least amount of external work performed. Hunter et al. (1988) termed this occurrence "decreased economy". External work has been estimated in other resistive exercise studies (Byrd, 1985; Byrd et al., 1988; Morton et al., 1987) but only Hunter et al. (1988) reported data on the economy of exercise.

The results from the present study show that strength-type exercise results in decreased economy. Conversely, endurance-type exercise requires a lower energy cost per unit of work (Figure 3) and results in increased economy. The work performed for the endurance-type exercise was nearly twice that performed during strength-type exercise. Endurance exercise is characterized by a high number of repetitions which significantly affects the total work. These findings are similar to those of Hunter and associates (1988) who found a decrease in economy as intensity increased.

The negative connotation of the term "decreased economy" is misleading. According to the results from both studies, an individual who wished to expend the greatest amount of calories in resistive exercise (i.e, weight control) with the least amount of work would choose the exercise of low economy.

The follow-up analysis performed on energy cost relative to work indicated that one set of strength-type exercise resulted in significantly greater energy expenditure relative to work performed than all other conditions. One explanation for this finding could be that a greater effort was made during the one set protocol because subjects knew that subsequent sets would not immediately follow. This seems unlikely, however, since the number of repetitions performed for one set of strength-type exercise was similar to the number of repetitions for the three set condition of strength type exercise. Additionally, if a greater effort was indeed made during the one set condition, it would seem that endurance-type exercise should have resulted in a similar increase in oxygen consumption in the one set vs. the three set protocol.

Another possible explanation for the increased energy expenditure during 1 set of strength-type exercise involves the considerable variability noted in energy expenditure during this type of exercise. This may be due to the number of subjects studied. Additionally, if shorter rest periods were used for 3 sets of strength, a greater energy cost may have been found which would affect the current statistical analysis.

Relationship of 1 to 3 Sets

Low correlation coefficients were found when comparing total kilocalories expended in performing 1 set (x3) vs. 3 sets of both exercise types. The correlations for both exercise types were low, and it would seem that energy expenditure during 1 set should have provided a better estimate of energy expended during 3 sets. The exclusion of subject 1's data resulted in a considerable increase in the strength-type exercise correlation; from $r=0.27$ to 0.84 ($p < .05$). Therefore, a larger sample size may have improved the power of the analysis.

Validity of Results

In comparing energy cost, results of this study are in closest agreement with those of McArdle and Foglia (1969) whose methodology is also similar. The only part of the methodology which they did not define was in the method of obtaining the pre-exercise resting metabolic rate. A difference in the determination of this rate would influence the calculation of net costs. Net caloric cost per minute for one set of strength-type exercise was determined to be 1.14 $kcal \cdot min^{-1}$ in the present study vs. 1.42 $kcal \cdot min^{-1}$ in the study of McArdle and Foglia (1969). The results from studies other than McArdle and Foglia (1969) are difficult to compare because of differences in methods used. Use of a larger muscle mass during exercise, combining various exercises, using subjects with a large lean body mass, and circuit weight training have all created greater net energy expenditure than results of the present study.

In the present study, expression of energy expended relative to lean body mass was very similar to results of absolute energy cost. This confirms previous findings that energy expenditure during resistive exercise is a function of the amount of lean body mass (Wilmore et al., 1978).

With regard to the drop in $\dot{V}O_2$ below resting measurements during recovery, there did not seem to be a pattern of occurrence (e.g., always after the second and third set) except after about 3 minutes of recovery. The reason for the drop in oxygen uptake values is unknown but may be influenced by the large intake of oxygen following exercise or perhaps the type of substrate utilized.

The strength of the correlation of energy expenditure between the 1-set protocol and the first set of the 3-set protocol for strength-type exercise increased when subject number 1 was excluded from the analysis, from $r=0.10$ to $r=0.79$ ($p < .05$). The same correlation performed with the endurance sets was not affected by exclusion of subject number 1 and remained fair in strength of relationship. It is suggested that use of a larger sample size would increase reliability of the values measured.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

Ten male college students participated in this study to determine the effects of exercise type on energy expenditure during bench press exercise. Subjects performed 1 and 3 sets of both strength-type (6-8 RM) and endurance-type (30-35 RM) resistance exercise. The relationship between performing 1 and 3 sets, and economy of exercise (determined by expression of energy cost relative to external work) were also examined. Energy expenditure was estimated from oxygen consumption. Two-way ANOVA, linear regression and correlational analyses were used.

A significantly greater energy expenditure was found to occur with endurance-type exercise. Possible mechanisms of influence were the exercise:rest ratio (including the effect of subsequent sets), energy substrate(s) utilized and training state of participants. It was originally hypothesized that strength-type exercise of higher intensity would require initially greater consumption of oxygen than endurance-type exercise, and that the longer duration would counterbalance the effect of lower oxygen consumption during endurance-type exercise. Unexpectedly, the higher intensity exercise did not result in a greater oxygen cost for the first 30 seconds of exercise when compared with lower intensity exercise.

When considering the amount of work performed during resistive exercise, strength-type exercise was found to cause a greater energy expenditure. One set of strength-type exercise resulted in greater energy cost per unit of work than all other conditions. The reason for this occurrence is unclear; however, motivation, sample size, and energy metabolism of subsequent sets may have influenced results.

The relationship of the energy cost of 1 set multiplied by 3, to 3 sets of bench press exercise for both exercise types was low. It was suggested that the small sample size and the variability of performance within this small group influenced the results.

CONCLUSIONS

The following conclusions can be made from the results of this study: 1) endurance-type exercise of 30-35 RM results in greater energy cost than strength-type exercise of 6-8 RM; 2) strength-type exercise creates requires the expenditure of significantly greater energy when the amount of external work performed is considered; and 3) the energy expenditure required during 1 set of bench press exercise is not a good predictor of that required for 3 sets.

RECOMMENDATIONS

Differences in the energy cost between types of resistance exercise requires further investigation. Comparisons of energy cost between exercise protocols similar in intensity but varied in exercise:rest ratio would clarify the influence that previous exercise has on the energy metabolism of subsequent sets. Studies measuring differences in muscle force resulting from rate of exercise and subsequent effects on energy cost would determine the significance of speed of exercise. Resistive exercise studies measuring changes in substrate utilization and the effect on oxygen consumption from training would further elucidate a possible area of influence on energy cost. Determination of whether energy substrate utilization changes with intensity of resistive exercise and the resulting effects on energy cost are needed. Use of a greater number of subjects would likely improve the quantification of any relationship between the energy cost of performing 1 and 3 sets of exercise.

For an individual interested in expending the greatest amount of energy relative to external work performed as well as optimizing the amount of time spent exercising, it is recommended that 6-8 RM strength-type exercise be performed.

If exercise duration and amount of work are not a concern, then endurance-type exercise of 30-35 RM would presumably cause the expenditure of a greater amount of energy.

REFERENCES

American College of Sports Medicine. (1986). Guidelines for exercise testing and prescription. Philadelphia: Lea & Febiger.

Ballor, D.L., Becque, M.D., & Katch, V.L. (1987). Metabolic responses during hydraulic resistive exercise. Med. Sci. Sports Exerc., 19, 363-367.

Basmajian, J.V., & De Luca, C.J. (1985). Muscles Alive: Their functions revealed by electromyography. Baltimore: Williams & Wilkins.

Brozek, J., Grande, F., Anderson, J.T., & Keys, A. (1963). Densitometric analysis of body composition: Revision of some quantitative assumptions. Ann. NY Acad. Sci., 110, 113-140.

Byrd, R.J. (1985). Metabolic cost of the bench press. NSCA Journal, 7, 68.

Byrd, R., Hopkins-Price, P., Boatwright, J.D., & Kinley, K.A. (1988). Prediction of the caloric cost of the bench press. J. Appl. Sport Sci. Res., 2, 7-8.

deVries, H. (1986). Physiology of exercise for physical education & athletics. Iowa: Wm. C. Brown.

Dudley, G.A. (1988). Metabolic consequences of resistive-type exercise. Med. Sci. Sports Exerc., 20, 158-161.

Field, R.W. (1988). Rationale for the use of free weights for periodization. NSCA Journal, 10, 38-39.

Fox, E. & Mathews, D. (1981). The physiological basis of physical education and athletics. Pennsylvania: Saunders.

Gettman, L.R. (1978). The aerobic cost of isokinetic slow and fast speed circuit strength training programs, AAHPER Res. Papers, (p.31).

Gettman, L.R., Ayres, J.J., Pollock, M.L., & Jackson, A. (1978). The effect of circuit weight training on strength, cardiorespiratory function and body composition of adult men. Med. Sci. Sports, 10, 171-176.

Hempel, L.S., & Wells, C.L. (1985). Cardiorespiratory cost of the nautilus express circuit. Phys. Sports Med., 13, 82-86, 91-97.

Hickson, J.F., Buono, M.J., Wilmore, J.H., & Constable, S.H. (1984). Energy cost of weight training exercise. NSCA Journal, 6, 22-23, 66.

Hunter, G., Blackman, L., Dunnam, L., & Flemming, G. (1988). Bench press metabolic rate as a function of exericse intensity. J. Appl. Sport Sci. Res., 2(1), 1-6.

Katch, F.I., Freedson, P.S., & Jones, C.A. (1985). Evaluation of acute cardiorespiratory response to hydraulic resistance exercise. Med. Sci. Sports Exerc., 17, 168-173.

Keul, J. (1973). The relationship between circulation and metabolism during exercise. Med. Sci. Sports, 5, 209-219.

Keul, J., Haralambie, G., Bruder, M., & Gottstein, H.J. (1978). The effect of weight lifting exercise on heart rate and metabolism in experienced weight lifters. Med. Sci. Sports, 10, 13-15.

Kramer, W.J., Marchitelli, L.J., McCurry, D., Fleck, S.J., Dziados, J.E., Harman, E., Vela, A.L., & Frykman, P. (1986). Lactate response to different resistance exercise protocols: Impact of different variables. NSCA Journal, 8, 72.

Kuehl, K., Elliot, D., Goldberg, L., & Frame, D. (1988). Training mode affects post-exercise thermogenesis. Med. Sci. Sports, 20, 84.

Lamb, D. (1984). Physiology of exercise. New York: MacMillan.

Liverman, R.D., & Groden, C. (1982). Metabolic analysis of high intensity weight training. Med. Sci. Sports, 14, 169.

Livesey, G., & Elia, M. (1988). Estimation of energy expenditure, net carbohydrate utilization and net fat oxidation and synthesis by indirect calorimetry: Evaluation of errors with specific reference to the detailed composition of fuels. Am. J. of Clin. Nutr., 47, 608-628.

Luttgens, K., & Wells, K. (1982). Kinesiology: Scientific basis of human motion. New York: Saunders.

McArdle, W.D., & Foglia, G.F. (1969). Energy cost and cardiorespiratory stress of isometric and weight training exercises. J. of Sports Med., 9, 23-30.

McArdle, W.., Katch, F., & Katch, V. (1981). Exercise physiology: energy, nutrition and human performance. Philadelphia: Lea & Febiger.

McLaughlin, T. 1985. Biomechanics of the Bench Press. Muscular development, April, p. 22-23, 60-62.

Madsen, N., & McLaughlin, T. (1984). Kinematic factors influencing performance and injury risk in the bench press exercise. Med. Sci. Sports Exerc., 16, 376-381.

Morton, L., Kuehl, K., Frame, D., Elliot, D., & Goldberg, L. (1987). Predicting caloric use during weight lifting. [Unpublished Abstract]. Oregon Health Sciences University, Portland, Oregon.

Scala, D., McMillan, J., Blessing, D., Rozenek, R., & Stone, M. (1987). Metabolic cost of a preparatory phase of training in weight lifting: A practical observation. J. of Appl. Sport Sci. Res., 1, 48-52.

Stone, M.H., Ward, T., Smith, D.P., & Rush, M. (1979). Olympic weightlifting: Metabolic consequence of a workout. International symposium of science in weightlifting (pp. 55-67). Del Mar, California: Academic Publishers.

Strathman, T., Gettman, L., & Culter, L. (1979). The oxygen cost of an isotonic circuit strength program, AAHPER Res. Papers (p. 70).

Tesch, P.A. (1987). Acute and long-term metabolic changes consequent to heavy-resistance exercise. Med. Sci. Sports Exerc., 26, 67-89.

Tesch, P.A., Colliander, E.B., & Kaiser, P. (1986). Muscle metabolism during intense, heavy-resistance exercise. Eur. J. of Appl. Physiol., 55, 362-366.

Veicsteinas, A., Feroldi, P., & Dotti, A. (1986). Ventilatory response during incremental exercise tests in weight lifters and endurance cyclists. Eur. J. of Appl. Physiol., 53, 322-329.

Weltman, A., & Stamford, B. (1982). Strength training: Free weights vs. machines. Phys. Sports Med., 10(11), 197.

Westcott, W.L. (1986). How many reps per set? Scholastic Coach, 56, 72-73.

Wilmore, J.H., Parr, R.B., Ward, P., Vodak, P.A., Barstow, T.J., Pipes, T.V., Grimditch, G., & Leslie, P. (1978). Energy cost of circuit weight training. Med. Sci. Sports, 10, 75-78.

Wilmore, J.H., Vodak, P.A., Parr, R.B., Girandola, R.N., & Billing, J.E. (1980). Further simplification of a method for determining residual lung volume. Med. Sci. Sports Exerc., 12, 216-218.

Wright, V. (1959). Factors influencing diurnal variation of strength of grip. The Res. Quart., 30, 110-116.

APPENDIX A

HEALTH AND FITNESS EVALUATION

-Medical History

Do you have a history of any of the following? (please check areas which relate to you)

Heart Attack	___	Lightheadedness	___
Chest Discomfort	___	Asthma/Emphysema	___
High Blood Pressure	___	High Cholesterol	___
Abnormal Heart Beats	___	Diabetes	___
Heart Murmurs	___	Stroke	___
Rheumatoid Fever	___	Orthopedic Problems	___
Vascular Disease	___	Edema	___
Phlebitis	___	Muscle/Tendon/ Ligament Injuries	___
Shortness of Breath	___		

Comments on areas checked above (i.e. surgery on right shoulder, 1984 etc.):____________________________

____

____

____

-Family History

Is there a history of any of the following illnesses in your family?

		Relation	Age
Coronary Disease	___	________________	____
High Blood Pressure	___	________________	____
High Cholesterol	___	________________	____
Congenital Heart Disease	___	________________	____

-Current Health

Are you currently on any medication? ________________

Have you been ill recently? ________________

Please rate your current health: ________________

-Health Habits

Do you smoke? _____ If so, frequency is ______________/day
Are you currently dieting? __________
Have you drunk a caffeinated liquid within the last 4 hours?
_____ If so, type and amount _______________________

-Activity Level (note: weight training experience is separate)

Do you exercise regularly? _______ If so, please answer the following information:

Activity	1	2	3	4
Type:				
Frequency:				
Duration:				
Intensity:				

-Exercise History

Please state your past history of activities; this would include recreation, sports (team & individual) and leisure (please list total time spent performing, i.e. 3 years of recreational tennis).

____
____
____
____

-Weight Training Background

Length of experience ______________________________________

Current training ____
Number of mos. lifted\trained in last year ________________
Type of weights used: free weights ______ pulleys ______
machines ______
Do you used free weights or a Universal Gym to perform the bench press (predominantly)? _____________other ___________
Do you lift weights for: bodybuilding _____ sports ______
recreation ____ competition ____

APPENDIX B

WARM-UP PROTOCOL

Exercise	Quantity
Rotations:	
Large arm circles	10 forward 10 backward
Backstroke	10
Front crawl	10
Elbow circles	10 each direction
Wrist circles	10 each direction
Neck rotation	10
Chin tuck	5
Hip circles	5 each direction
Knee circles	5 each direction
Stretches:	
Overhead stretch	3 each side
Tricep/lat stretch	3 each side
Deltoid/lat stretch	3 each side
Pec stretch	3
Push Ups:	5
Actual bench press:	
Barbell alone	3
According to test session:	
Strength (50% of 6-8 RM)	3
(100% of 6-8 RM)	1
Endurance (100% of 30-35 RM)	5

APPENDIX C

ANOVA SUMMARY TABLES

ANOVA Summary Table for Energy Expenditure (kcal·min^{-1})

Source	SS	df	MS	F	P
Ex Type	.54	1	.54	7.37	.02
Error	.66	9	.07		
Sets	.40	1	.40	3.36	.10
Error	1.06	9	.12		
E x S	.05	1	.05	.69	.43
Error	.61	9	.07		

ANOVA Summary Table for Energy Expenditure (kcal·min^{-1}·LBM^{-1})

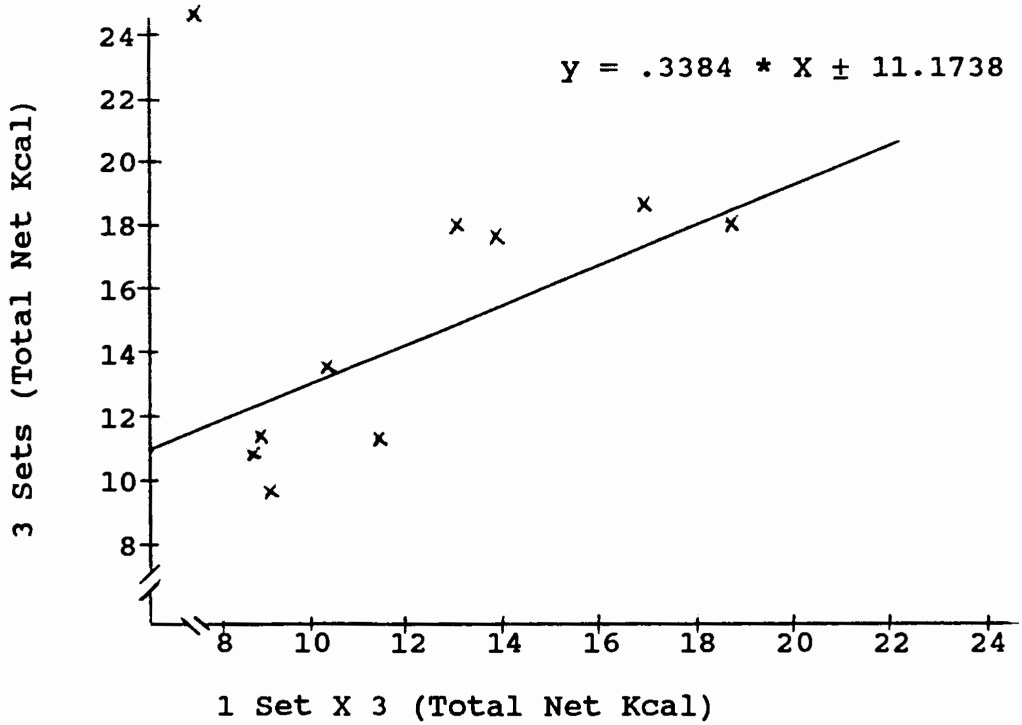
Source	SS	df	MS	F	P
Ex Type	1.37	1	1.37	7.60	.02
Error	1.62	9	.18		
Sets	1.02	1	1.02	3.32	.10
Error	2.78	9	.31		
E x S	.06	1	.06	.41	.54
Error	1.42	9	.16		

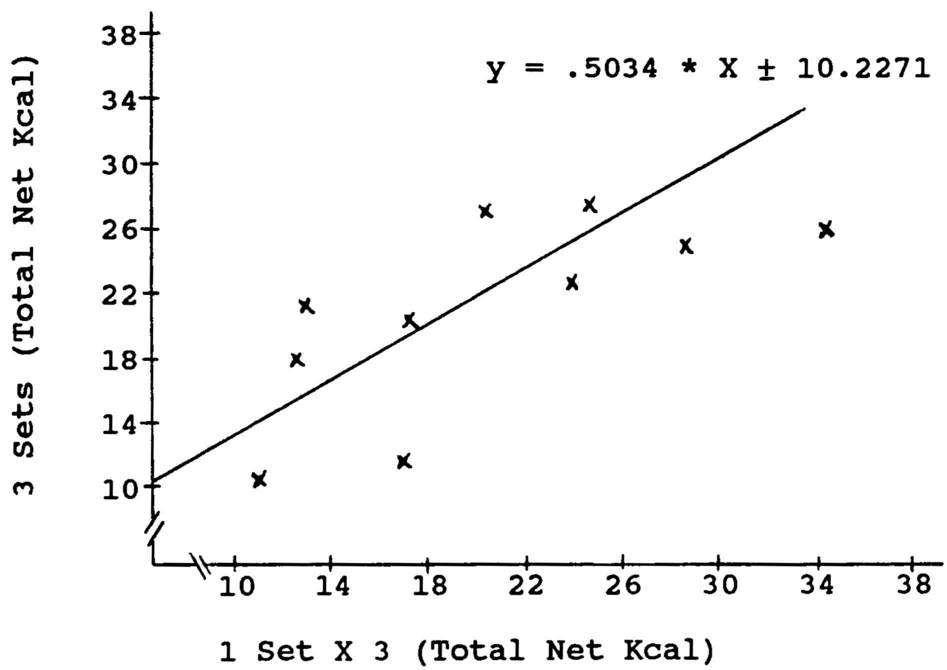
ANOVA Summary Table for Energy Expenditure (kcal·min^{-1}·kgm^{-1})

Source	SS	df	MS	F	P
Ex Type	43.01	1	43.01	14.49	.004
Error	26.71	9	2.97		
Sets	67.57	1	67.57	20.22	.002
Error	30.08	9	3.34		
E x S	16.16	1	16.16	6.19	.04
Error	23.49	9	2.61		

APPENDIX D

GRAPHS ILLUSTRATING THE RELATIONSHIP BETWEEN THE ENERGY COST OF 1 SET (X3) AND 3 SETS OF BENCH PRESS EXERCISE





Type: Upper = Strength; Lower = Endurance

APPENDIX E

INDIVIDUAL SUBJECT DATA

Subject #1

		S1	S3	E1	E3
Reps (#)		11	14	32	35
			9		26
			10		24
Wt. Lifted (kg)		45.5		31.8	
Time (min:sec)		0:34	0:56	2:00	2:15
			0:30		1:30
			0:40		1:10
Gross $\dot{V}O_2$ ($L \cdot min^{-1}$)					
	Min				
Rest		.47	.66	.47	.33
Exercise	1	*1.06	1.35	.93	.96
(Set 1)	2			.95	.70
Recovery	1	.56	1.25	.92	.68
	2	.60	1.13	.69	.56
	3	.48	.88	.52	.50
Exercise	1		*1.06		.90
(Set 2)	2				*1.01
Recovery	1		1.12		.93
	2		1.08		.59
	3		.86		.50
Exercise	1		1.08		.92
(Set 3)	2				*.84
Recovery	1		1.30		.78
	2		1.18		.65
	3		.94		.50
Total Net kcal		2.60	24.86	8.28	27.45

*30 seconds of exercise

Subject #2

	Min	S1	S3	E1	E3
Reps (#)		8	8 8 7	32	35 27 24
Wt. Lifted (kg)		81.8		45.5	
Time (min:sec)		0:30	0:32 0:27 0:30	1:31	1:32 1:25 1:10
Gross $\dot{V}O_2$ $(L \cdot min^{-1})$					
Rest		.36	.28	.36	.25
Exercise (Set 1)	1	*.89	*.72	.71	.64
	2			.94	*.85
Recovery	1	.75	.56	.82	.68
	2	.60	.56	.56	.60
	3	.39	.45	.44	.40
Exercise (Set 2)	1		*.83		.65
	2				*.79
Recovery	1		.63		.90
	2		.66		.59
	3		.49		.43
Exercise (Set 3)	1		*.86		.80
Recovery	1		.72		.92
	2		.66		.67
	3		.54		.48
Total Net kcal		4.65	17.63	6.92	26.77

*30 seconds of exercise

Subject #3

	Min	S1	S3	E1	E3
Reps (#)		8	8 8 5	32	29 25 21
Wt. Lifted (kg)		56.8		29.5	
Time (min:sec)		0:32	0:40 0:39 0:25	1:37	1:37 1:15 1:05
Gross $\dot{V}O_2$ ($L \cdot min^{-1}$)					
Rest		.21	.31	.21	.46
Exercise (Set 1)	1 2	*.70	*.82	.81 *.74	.89 *.91
Recovery	1 2 3	.70 .48 .35	.81 .56 .42	.77 .59 .34	1.10 .70 .53
Exercise (Set 2)	1 2		*.65		.69 .96
Recovery	1 2 3		.88 .77 .48		1.17 .80 .59
Exercise (Set 3)	1		*.58		.92
Recovery	1 2 3		.84 .78 .55		1.15 .74 .55
Total Net kcal		5.76	18.43	9.72	24.04

*30 seconds of exercise

Subject #4

		S1	S3	E1	E3
Reps (#)		13	15 14 10	42	40 28 22
Wt. Lifted (kg)		36.4		22.7	
Time (min:sec)		0:38	0:50 0:47 0:31	2:05	1:05 1:15 1:00
Gross $\dot{V}O_2$ $(L \cdot min^{-1})$					
	Min				
Rest		.40	.33	.40	.44
Exercise (Set 1)	1 2	*.91	.54	.57 .81	.75 *.71
Recovery	1 2 3	.53 .54 .49	.53 .51 .40	.74 .56 .48	.69 .64 .56
Exercise (Set 2)	1 2		.52		.58 *.86
Recovery	1 2 3		.58 .48 .43		.63 .63 .51
Exercise (Set 3)	1		*.48		.60
Recovery	1 2 3		.53 .56 .43		.70 .65 .58
Total Net kcal		3.06	9.67	5.78	11.39

*30 seconds of exercise

Subject #5

	Min	S1	S3	E1	E3
Reps (#)		9	11 8 9	40	36 27 18
Wt. Lifted (kg)		59.1		36.4	
Time (min:sec)		0:39	0:39 0:32 0:38	1:35	1:45 1:20 1:12
Gross $\dot{V}O_2$ ($L \cdot min^{-1}$)					
Rest		.38	.44	.38	.48
Exercise (Set 1)	1	*.80	*.80	.90	.80
	2			*.96	1.03
Recovery	1	.66	.81	.93	.86
	2	.58	.59	.57	.57
	3	.46	.41	.43	.49
Exercise (Set 2)	1		*.72		.79
Recovery	1		.69		1.07
	2		.60		.90
	3		.55		.63
Exercise (Set 3)	1		*.76		.95
Recovery	1		.83		.98
	2		.73		.77
	3		.51		.68
Total Net kcal		3.84	11.19	8.06	21.89

*30 seconds of exercise

Subject #6

	Min	S1	S3	E1	E3
Reps (#)		4	10 9 7	43	36 22 18
Wt. Lifted (kg)		50		34.1	
Time (min:sec)		0:38	0:55 0:45 0:45	2:29	2:02 1:18 1:40
Gross $\dot{V}O_2$ (L·min^{-1})					
Rest		.31	.35	.31	.31
Exercise (Set 1)	1 2 3	*.67	.65	.47 1.09 *1.01	.52 .91
Recovery	1 2 3	.60 .58 .45	.89 .66 .49	.95 .53 .43	1.03 .62 .42
Exercise (Set 2)	1		.64		.57
Recovery	1 2 3		.83 .66 .50		.97 .55 .40
Exercise (Set 3)	1 2		.55		.53 *.88
Recovery	1 2 3		.79 .61 .51		.82 .54 .38
Total Net kcal		4.42	17.93	11.36	24.06

*30 seconds of exercise

Subject #7

		S1	S3	E1	E3
Reps (#)		9	9 9 7	26	27 19 16
Wt. Lifted (kg)		45.5		29.5	
Time (min:sec)		0:42	0:34 0:37 0:30	1:35	1:28 1:10 1:00
Gross $\dot{V}O_2$ ($L \cdot min^{-1}$)					
	Min				
Rest		.46	.28	.46	.42
Exercise (Set 1)	1 2	*.48	*.32	.68 *.70	.55 *.56
Recovery	1 2 3	.82 .67 .48	.62 .55 .40	.81 .54 .41	.74 .61 .41
Exercise (Set 2)	1		*.30		.52
Recovery	1 2 3		.60 .59 .40		.73 .60 .46
Exercise (Set 3)	1		*.36		.49
Recovery	1 2 3		.63 .53 .39		.76 .58 .43
Total Net kcal		3.03	11.26	3.61	10.15

*30 seconds of exercise

Subject #8

	Min	S1	S3	E1	E3
Reps (#)		9	9 8 6	28	30 24 18
Wt. Lifted (kg)		59.1		36.4	
Time (min:sec)		0:28	0:29 0:30 0:37	1:30	1:15 0:54 1:00
Gross $\dot{V}O_2$ $(L \cdot min^{-1})$					
Rest		.40	.25	.40	.35
Exercise (Set 1)	1	*.59	*.51	.50	.66
	2			*.58	*.66
Recovery	1	.57	.51	.83	.79
	2	.68	.61	.66	.58
	3	.55	.39	.45	.43
Exercise (Set 2)	1		*.47		.63
Recovery	1		.58		1.03
	2		.55		.87
	3		.38		.53
Exercise (Set 3)	1		*.52		.70
Recovery	1		.55		.83
	2		.60		.76
	3		.43		.55
Total Net kcal		3.46	13.61	4.50	21.54

*30 seconds of exercise

Subject #9

	Min	S1	S3	E1	E3
Reps (#)		6	8 7 6	28	30 21 18
Wt. Lifted (kg)		88.6		56.8	
Time (min:sec)		0:27	0:28 0:30 0:32	1:25	1:28 0:58 1:03
Gross $\dot{V}O_2$ ($L \cdot min^{-1}$)					
Rest		.34	.25	.34	.34
Exercise (Set 1)	1 2	*.87	*.57	.67 *.71	.76 *.69
Recovery	1 2 3	.67 .75 .59	.66 .63 .34	.62 .61 .46	.78 .62 .46
Exercise (Set 2)	1		*.57		.71
Recovery	1 2 3		.63 .71 .42		.82 .64 .47
Exercise (Set 3)	1		*.58		.83
Recovery	1 2 3		.67 .67 .45		.86 .59 .44
Total Net kcal		6.31	17.04	5.90	20.38

*30 seconds of exercise

Subject #10

	Min	S1	S3	E1	E3
Reps (#)		8	7	27	26
			7		21
			6		18
Wt. Lifted (kg)		63.6		43.2	
Time (min:sec)		0:40	0:32	1:40	1:29
			0:30		1:08
			0:30		1:03
Gross $\dot{V}O_2$ ($L \cdot min^{-1}$)					
Rest		.43	.43	.43	.50
Exercise (Set 1)	1	*.64	*1.11	1.00	.97
	2			*.71	*1.00
Recovery	1	.65	.54	.44	.77
	2	.72	.67	.64	.79
	3	.40	.40	.37	.47
Exercise (Set 2)	1		*.97		.93
Recovery	1		.60		.72
	2		.57		.89
	3		.40		.57
Exercise (Set 3)	1		*1.15		1.08
Recovery	1		.63		.72
	2		.68		.81
	3		.55		.63
Total Net kcal		2.90	10.76	4.29	18.00

*30 seconds of exercise