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A comparison of oxygen consumption in light and heavy resistance weight training methods in males

Kean Gerard Richard
University of Northern Iowa

A COMPARISON OF OXYGEN CONSUMPTION IN LIGHT AND HEAVY RESISTANCE WEIGHT TRAINING METHODS IN MALES

An Abstract of a Thesis

Submitted

In Partial Fulfillment

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ABSTRACT

Heavy resistance and low resistance weight training methods are commonly used in off season conditioning programs for various sports. Research has indicated that heavy resistance training elicits muscular strength development whereas low resistance training elicits the development of muscular endurance. However, there is very little or no research which has investigated a comparison of oxygen consumption between heavy resistance and low resistance training while keeping work constant.

The purpose of this investigation was to compare the oxygen cost of performing heavy and low resistance weight training methods. Also, a second purpose of the study was to determine the contribution of the concentric phase to total O_2 cost during low resistance weight training. Twelve males moderately experienced in weight training participated in the study. Three treatments were employed in the study. Each subject performed at 80% of their one repetition maximum for six repetitions (heavy resistance training), 40% of their one repetition maximum for 12 repetitions (low resistance training) and 40% of their one repetition maximum for 12 repetitions performing only the concentric phase. The results indicated that there was a significantly higher ($p < .05$) oxygen consumption for the heavy resistance method than the low resistance method and the low resistance method using

both concentric and eccentric movements exhibited a significantly higher ($p < .05$) oxygen consumption than the concentric only low resistance method. The results also indicated that the majority of difference in O_2 cost between the heavy and low resistance methods could be accounted for during the recovery periods. Heavy resistance training was also significantly higher than the low resistance method for ventilation, respiratory exchange ratio and time to recovery, while there was no significant difference in heart rate. Therefore, it would seem that the heavy resistance training method is physiologically more demanding than low resistance training even if total work is held constant.

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Forrest Dolgener

7-12-84
Date — Chairman, Thesis Committee

Elton E. Green

7-11-84
Date — Member, Thesis Committee

Larry D. Hensley

7·11·84
Date — Member, Thesis Committee

John C. Downey

8·20·84
Date — Dean of the Graduate College

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CHAPTER 1

INTRODUCTION

Weight training has been quite popular in the last two decades as a means for conditioning athletes in various sports programs. This method of training has been traditionally noted for its contributions in the areas of strength, power and muscular endurance (Wilmore, Parr, Ward, Vodak, Barstow, Pipes, Grimditch, & Leslie, 1978). Weight training has made its way into health spas, YMCAs and even into the basements of many homes. Also, with the increased popularity of weight training a variety of training methods have been devised. The present study will investigate the two most commonly used weight training methods, low resistance and heavy resistance training. Low resistance training is commonly used to develop muscular endurance by using light weight and high repetitions (Wilmore et al., 1978). Heavy resistance training is used to develop increases in lean body mass and strength by utilizing heavy weight and low repetitions. Most of the research conducted on weight training has primarily investigated changes that occur in strength, power and body composition. Traditionally, weight training has not been used as a primary means of weight reduction. With the popularity increasing, it would be useful to quantify the effect weight training has on weight reduction. It is the purpose of the present study

to investigate the oxygen consumption ($\dot{V}O_2$) associated with light and heavy resistance weight training.

Gettman, Culter and Strathman (1980) reported that low resistance circuit training increases maximal oxygen consumption ($\dot{V}O_2$ max) and strength while decreasing percentage body fat. This and other research has been concerned with the long term training effects of low resistance circuit weight training. However, these long term studies may provide some information that can be used to quantify the acute effects on energy expenditure occurring during training. It is well known that $\dot{V}O_2$ max is comprised of two components: 1) maximal cardiac output (stroke volume x heart rate) and 2) maximal a-v O_2 difference or the working muscles ability to extract O_2 from the capillaries (McArdle, Katch, & Katch, 1981). Since the increase in ones $\dot{V}O_2$ max can be attributed to a greater O_2 delivery and increased extraction rate, then it is reasonable to assume that an increase in acute O_2 consumption must also be the result of these factors. If one is to train these two factors (O_2 delivery and extraction) he/she must do so each workout, or if put in another context, a long term increase in $\dot{V}O_2$ max results from a summation of individual workouts which overload the system repetitively. This may be better understood by comparing this concept to the overload principle in strength development. For a muscle to be strengthened it must be worked close to its force-generating capacity workout after workout before a long term gain can be manifested (McArdle et

al., 1981). Thus, measuring the O_2 consumption during one workout may give some insight into the utility for long term cardiovascular development. Also, measuring the O_2 consumption during one workout would lend additional insight as to its utility as a potential weight reducing training method.

The relationship that exists between weight training and O_2 consumption using light and heavy resistances when total work is held constant should reflect how varying degrees of workloads affect O_2 consumption. Low resistance training (LRT) will involve a higher frequency of muscular contractions with a smaller amount of muscular force (tension), while heavy resistance training (HRT) involves fewer muscular contractions and a greater amount of tension per contraction. Hickson, Rosenkoetter and Brown (1980) found no significant increases in $\dot{V}O_2$ max during 10 weeks of high resistance circuit training while other studies have shown an incremental increase in muscle O_2 consumption with increased workloads (Stainsby & Barclay, 1971).

The O_2 consumption in the working muscles seems to depend on the frequency of muscle contractions and the magnitude of muscle contractions. Stainsby et al. (1971) utilized in situ muscle from a dog when investigating the relationship between the degree of resistance and its effects on O_2 consumption. However, there has been very little or no research found comparing the acute O_2 consumption of LRT

versus HRT in humans during isotonic weight training. A study conducted by Wilmore et al. (1978) found that the O_2 consumption (expressed in Kcals) was 7.0 and 6.0 Kcal/Kg/hr for men and women respectively, when utilizing the low resistance circuit training method. This is an average gross energy expenditure of 539.7 and 367.5 Kcal/hr for the average size male and female.

The present study is also concerned with the oxygen consumption required to perform only concentric contractions (shortening of the muscle fibers) during the same magnitude of resistance as the light resistance training method. By isolating the concentric portion of the lift, one can determine its contribution of O_2 consumption for the entire lift. A considerable amount of research is available comparing concentric and eccentric contractions on O_2 consumption. The fact that the eccentric contraction requires some of the total O_2 consumed for the total work during isotonic lifting is reason enough for further investigation. Abbott, Bigland and Ritchie (1952) found that O_2 consumption during concentric contractions was significantly higher than during eccentric contractions. Since this study, Stainsby (1970) and Petersen, Knutgen and Henriksson (1972) have found similar results.

The purpose of the present study is to investigate the metabolic responses to weight training resistance and to determine the O_2 consumption of performing concentric contractions during bench press isotonic weight training.

Statement of the Problem

The purpose of this study was to determine the net energy expenditure during heavy and low resistance weight training using the bench press while holding total work constant. In addition, this study was also designed to investigate how much of the total O_2 consumption during isotonic weight training is attributed to the concentric portion of the total work bout.

Hypothesis

It was hypothesized that the O_2 consumption during low resistance training will exceed high resistance training if workload is held constant. Furthermore, the O_2 consumption required for the concentric portion of the LRT lift (CLRT) will be significantly lower than the O_2 required to perform both the concentric and eccentric phases of the lift during the LRT method.

Significance of the Study

Recommendations for various training modes have been suggested to individuals interested in developing their total physical condition. With the increased sophistication of individualized conditioning programs has come the need for identifying conditioning activities that provide the most efficient means for gaining improvement in each of the various major components of performance, i.e., strength, muscular endurance, power, cardiovascular endurance, flexibility, agility, speed and weight control. Weight training has always been recognized for the development of

strength and lean body mass. Since weight training is used by many as a sole means of exercise it would be useful to know the extent to which weight training affects such parameters as cardiovascular fitness and weight reduction. The general feeling of those in the area of exercise physiology is that weight training is not a very efficient means of developing cardiovascular endurance or of losing weight. However, there is meager scientific support for either position. Also, since many training devices are totally composed of only concentric contractions, such as the isokinetic equipment, one can determine the usefulness of positive work as a means of energy expenditure. Since this study is concerned with a variety of factors which could influence a weight training program, the results could possibly be used to establish the most appropriate means of using weight training for weight control.

Assumptions of the Study

The major assumptions of this study included: 1) all subjects performed at their maximal capabilities during all tests, 2) the results obtained from the 12 subjects are representative of all subjects performing the training protocols, and 3) the Beckman metabolic measurement cart provided valid and reliable measurements of O_2 consumption during the exercise bouts.

Delimitations of the Study

The present study was delimited to the following: 1) the subjects consisted of 12 college age male volunteers moderately trained in heavy resistance isotonic weight training, 2) data was collected only on the bench press exercise involving one workout per training method using free weights, 3) the workouts were designed to utilize 40% of their one repetition maximum lift (1-RM), (the maximal amount of weight that can be lifted one time) for 12 repetitions (LRT) and 80% of their 1-RM for six repetitions (HRT), and 4) all measurements for O_2 consumption for concentric contractions were determined while the subjects performed only during the LRT method.

Limitations of the Study

The present study was limited to the following: 1) all subjects' weight training experience consisted of isotonic heavy resistance training, 2) the measurements for O_2 consumption were dependent upon the reliability of the Beckman metabolic measurement cart, 3) all subjects' 1-RM bench press were representative of their true maximal strength, and 4) the subjects may have had variation in performance, attitude and technique between the different tests.

Definition of Terms

The following terms are defined as follows:

Aerobic capacity: The level of functioning of ones

cardiovascular system to deliver oxygen to the working muscles (deVries, 1980).

One repetition maximum (1-RM): A muscle or muscle groups' ability to overcome a maximal resistance through the full range of motion one time during a standard weight lifting exercise (Fox, 1979).

Strength: The maximal pulling force of a muscle or muscle group (Fox, 1979).

Calorie: The amount of heat required to raise the temperature of one kilogram of water one degree celcius (Morehouse & Miller, 1976).

Muscular endurance: The ability of a muscle group to repetitively lift a load over an extended period of time (Fox, 1979).

Eccentric contraction: A muscular contraction in which the muscle lengthens while developing tension. Also referred to as negative work (McArdle et al., 1981).

Concentric contraction: A muscular contraction in which the muscle shortens while developing tension or overcoming resistance. Also referred to as positive work (McArdle et al., 1981).

Oxygen consumption ($\dot{V}O_2$): The intake and utilization of oxygen by the body in units per minute. More specifically, cardiac output (heart rate x stroke volume) x arteriole mixed venous oxygen difference (Fox, 1979).

Maximal oxygen consumption ($\dot{V}O_2$ max): The amount of oxygen consumed when an increased work load fails to elicit a

significant increase in O_2 consumption, the highest value obtained represents the maximal O_2 consumption. This is the point in which an individual's maximal cardiac output and arteriole mixed venous oxygen difference are reached (deVries, 1980).

Muscular work: The amount of muscular tension (resistance) x the number of repetitions (muscular contractions).

Isotonics: A weight training procedure involving free weights or a Universal machine where constant resistance is applied to the working muscles throughout the full range of motion (McArdle et al., 1981).

Post exercise O_2 consumption: The amount of oxygen consumed during recovery from exercise above the amount ordinarily consumed at rest in the same period of time (Fox, 1979).

Resting metabolic rate (RMR): This is the minimum level of energy required to sustain the body's vital functions in a waking state without fasting (McArdle et al., 1981).

Energy expenditure: This reflects the amount of energy released when a given amount of oxygen is consumed for the break down of a given amount of glycogen or fat and can be measured as the amount of heat produced or as the amount of oxygen consumed. Since one liter of oxygen is equal to approximately five Kilocalories of heat released, energy

expenditure may often be expressed as Kilocalories expended per minute (Fox, 1979).

Pulmonary ventilation: The process by which ambient air is brought into and exchanged with the air in the lungs. Ventilation is commonly expressed in liters per minute and is determined by depth of breathing x frequency of breathing (McArdle et al., 1981).

Respiratory exchange ratio (R): The ratio of the volume of carbon dioxide expired to the volume of oxygen consumed during a nonsteady state condition (Morehouse & Miller, 1976).

CHAPTER 2

REVIEW OF RELATED LITERATURE

Weight training has become a popular recreational and conditioning activity for many health conscious Americans. Since many of the myths about the effects of weight training have been experimentally found untrue, such as muscle boundness and retardation of motor skills, more individuals have become heavily involved with weight training as a part of their total physical conditioning (McArdle et al., 1981). This chapter reviews the relationship of weight training to oxygen consumption ($\dot{V}O_2$). The review is divided into two major sections. The first section will review the literature concerning the effects of isotonic low resistance circuit training and heavy resistance training methods on oxygen consumption. The second section will review the literature discussing the contributions of the isotonic eccentric and concentric phases of weight training on O_2 consumption.

Isotonic Low Resistance and Heavy Resistance Training

As mentioned in Chapter 1, training studies which concentrate on chronic physiological alterations may lend important information concerning the acute responses to these types of training methods. Therefore, a good portion of this chapter will review long term training studies and the effects that low and heavy resistance isotonic training have on $\dot{V}O_2$ max.

In some studies, low resistance circuit training has been shown to improve cardiovascular conditioning and $\dot{V}O_2$ max, but other studies have failed to show significant increases. Gettman, Culter and Strathman (1980) used 29 male volunteers who were trained on a 20 week isotonic low resistance circuit weight training program. The duration was 20-30 minutes per workout, three days per week while lifting at 50% of their 1-RM using 12 repetitions per set for nine selected exercises. Pre and post test $\dot{V}O_2$ max performances were collected using treadmill running. A significant increase in $\dot{V}O_2$ max of seven percent was found. This increase compared favorably to a later study conducted by Gettman, Ward and Hagen (1982). This experimental design was similar to the previous study in that 41 males and 36 females underwent 10 weight training exercises completed with 12-15 repetitions at 40% of their 1-RM at each station for a 12 week training period. Both the females and males increased their $\dot{V}O_2$ max values by 12% and 15% respectively; these were significantly higher improvements compared to the control group. Wilmore et al. (1978), using a study design similar to Gettman's (1980), found that the sedentary female subjects improved their $\dot{V}O_2$ max significantly over the control group (10.7%), but no differences were noted between the males and females.

All studies have not shown that isotonic low resistance circuit weight training elicits significant improvements in $\dot{V}O_2$ max performances on a running treadmill. In 1978,

Gettman, Ayers, Pollock and Jackson found no significant changes in $\dot{V}O_2$ max following a 20 week low resistance circuit training program designed similarly to the previous studies. This study also found that the running group significantly increased their cardiovascular endurance following the same duration of training. It was concluded that the improvements may be due to the continuous nature of running compared to the intermittent circuit wieght training procedure.

Heavy resistance training consists of higher resistance with fewer repetitions as compared to the low resistance circuit training method. Allen, Byrd and Smith (1976) conducted an experiment where 66 male college freshmen participated in a high resistance, low repetition circuit weight training program using a Universal Weight Training Gym. The subjects trained for 30-minute sessions, three times/week for 12 weeks. The workloads were assigned so that the number of repetitions were limited to eight or less per set. Using O_2 consumption measurements on a running treadmill, no significant cardiovascular improvements occurred even though their working heart rates and blood pressures were comparable to those reported in running programs. Hickson et al. (1980) subjected nine healthy men ($\overline{X}$ age = 23 years) to a HRT program consisting of three days per week for a 10 week training period. The repetitions were held to five per set on selected leg exercises (the training involved all leg exercises). The post test results obtained

from O_2 consumption on a running treadmill showed that there were no significant changes in $\dot{V}O_2$ max from the pre test values.

The literature that has been reviewed seemed to support low resistance circuit training as a more effective means for producing improvements in cardiovascular endurance as compared to heavy resistance circuit training. However, in a study conducted by Nagle and Irwin (1960), a comparison was made between the cardiovascular changes due to a heavy resistance training program as compared to a low resistance program. Sixty freshmen students, 18 to 19 years of age, volunteered to serve as subjects for the experiment. They were divided into three groups, equated on the basis of body surface area and 300 yard run time which allowed for control of body size and endurance fitness. The experimental design consisted of three groups, two experimental and one control, each group involving 20 subjects training three days per week. One experimental group employed a low resistance-high repetition procedure while the other experimental group employed a high resistance-low repetition procedure. Both groups used the same series of 13 exercises. The heavy resistance group used five reps/set while the low resistance group used 12-15 reps/set. It was concluded that no significant changes occurred for any of the sources of variation for the measurement of minute volume of respiration, CO_2 production, respiratory exchange ratio, ventilatory efficiency and $\dot{V}O_2$. Thus, no differences were

observed between the control and experimental groups for cardiorespiratory endurance. The studies presented in this chapter have not carefully controlled for equal amounts of muscular work between the heavy resistance and low resistance training groups. This factor may have had some influence on the obtained results.

Aside from Nagel's (1960) study, it has generally been found by Gettman et al. (1980), Gettman et al. (1982), Gettman et al. (1978) and Wilmore et al. (1978) that low resistance circuit training can produce significant improvements in cardiovascular endurance, whereas no evidence has been found that supports the heavy resistance method as a means for developing the cardiovascular system. The differences may be accounted for by the nature of the exercises. Low resistance circuit training requires a longer duration of rhythmical and continuous muscular movements, whereas the heavy resistance method is much more intermittent. Weight training has been shown to impede muscular blood flow caused by high levels of intramuscular pressure resulting in a lessened stimulus for vascular adaptations at the local muscular level (Allen et al., 1976). Humpheries and Lind (1963) have shown that peripheral blood flow is severely restricted in the working muscles during heavy resistance contractions. Since heavy resistance training is generally near a maximum work load, it is quite possible that peripheral blood flow is impaired, venous

return reduced, and stroke volume diminished. Hemodynamic adaptations may not occur due to a lower stroke volume resulting from a high intramuscular pressure during heavy resistance training. Since blood flow may be impaired by intramuscular pressure, it may make sense to relate a higher resistance (greater muscular tension) to a greater amount of intramuscular pressure resulting in less blood flow to the active muscle mass. Therefore, low resistance circuit training should elicit less resistance to blood flow to the working muscles due to a lower amount of tension within the muscles. In addition, McArdle et al. (1981) stated that the more continuous and rhythmical the muscle mass the greater the muscles can generate a "milking" action of blood returning to the heart; this will elicit a greater venous return.

Another possible explanation for the lack of improvement in cardiovascular endurance following heavy resistance exercise may be the result of a decreased mitochondrial volume density in the conditioned muscles. This decrease has been explained by an apparent increase in contractile protein without a proportional increase in mitochondrial volume (MacDougal, Sale, Moroz, Elder, Sutton, & Howald, 1979). Since the mitochondria are the energy producing organelle at the cellular level, this decrease in its volume density may affect the a-v O_2 difference at the local muscular level.

The previously reviewed studies have been long term training studies which concentrated on the chronic changes in

cardiovascular endurance. The focus of this section will now shift to the acute responses of weight training. Very little research has been found on the acute effects of heavy and low resistance weight training in humans. However, a considerable amount of research has been conducted on animal muscle. Earlier it was stated that an acute effect during heavy resistance training may reduce blood flow in the active muscles and would seem to correlate well with a decrease in $\dot{V}O_2$ since blood is the carrying component of O_2 (deVries, 1980). Stainsby, Petersen and Barbee (1981) have found some information that may make this assumption more complicated than it seems. This study investigated the O_2 consumption of the gastrocnemius-plantaris muscle group of a dog during brief submaximal isotonic-tetanic contractions. Oxygen consumption was calculated as the product of the venous blood flow and the arteriole venous blood oxygen content difference. Shortening of the contractions were kept constant while the load was altered by adjusting the stimulus of voltage to the sciatic motor nerve. The results of this study showed $\dot{V}O_2$ to be linearly related to work. Since the distance the muscle shortened in this experiment was kept constant, $\dot{V}O_2$ was linearly related to the load to which the muscles shortened against. Oxygen consumption was also related to the stimulation voltage, which was increased as load was increased to keep shortening of the muscle constant. Stainsby et al. (1981) concluded that the only factor which

elicited the increased $\dot{V}O_2$ with an increased load and work rate was the result of recruiting additional muscle fibers in order to meet the demands of increasing work loads. The results of this experiment were similar to the work load and $\dot{V}O_2$ relationship found in a stimulated gastrocnemius-plantaris muscle group of a dog in an earlier study (Stainsby, 1970). The results of a third experiment by Stainsby and Barclay (1971) further supports this positive relationship between $\dot{V}O_2$ and work load. By stimulating an in situ semitendinosis muscle, their results showed that there was also a linear relationship as reported previously by Stainsby et al. (1981) using the gastrocnemius muscle.

Oxygen consumption has also been investigated in human subjects tested on bicycle ergometers. Two subjects performing on a bicycle ergometer were exposed to increasing intensities ranging from 15 to 130 Watt. Oxygen consumption and work intensities were positively related in both subjects (Knuttgen, Petersen, & Klaussen, 1971). This study compared favorably to similarly designed studies by Abbott (1952) and Knuttgen, Patton and Vogel (1982). Both studies showed an increase in $\dot{V}O_2$ with a concomitant increase in work load. In a study conducted by Clark (1960), the metabolic cost of static exercise was studied in relation to work load. The exercises consisted of the subjects holding 50, 35 and 25 pound weights with the knees partially flexed. Oxygen requirements and O_2 debts increased linearly with an increase in weight. When this data were compared with available data

on dynamic work of equivalent metabolic costs, the results indicate a significantly smaller $\dot{V}O_2$ and larger O_2 debt for the static exercise. Clark concluded that blood flow through the muscles is impaired during the maintenance of tension. The large O_2 debt during the static exercise cannot be clearly explained, however, at the time of this study it was believed that the large O_2 debt accrued due to a repayment of O_2 after the muscles relaxed. In contrast, the periodic compression and relaxation of muscle pressure against the veins during dynamic work would tend to promote local blood flow toward the heart and thereby increase the oxygen transport during exercise, thus resulting in a comparatively small O_2 debt.

Danoff and Danoff (1981) investigated the energy cost response to variable-load static (isometric) and dynamic (isotonic) leg exercise on five young females who performed five minute bouts of leg extension exercises while in a sitting position on a weight-loaded dynamometer using four loads for each type of contraction. The results showed that $\dot{V}O_2$ increased linearly with work load for both types of exercises. When the two types of exercises were compared using the same resistance, the dynamic bouts required a significantly greater net $\dot{V}O_2$. This implied two possible results of increasing resistance against active muscles: 1) increasing resistance is directly proportional to an increase in $\dot{V}O_2$ and 2) as resistance increases towards or at isometric

levels, occlusion of muscular vessels is increased. No literature has been found that investigated the trade off between tension and intramuscular occlusion for maximal acute $\dot{V}O_2$ in the active muscles.

Wilmore et al. (1978) studied the O_2 consumption of circuit weight training in 20 males and females. The subjects performed three circuits (10 stations/circuit) using a work (30-sec) and rest (15-sec) ratio of 2:1, and a total exercise time of 22.5 minutes. The resistance was equal to 40% of the subjects' 1-RM values for all 10 stations. Oxygen consumption was assessed using a Beckman Metabolic Measurement cart. The males averaged a gross energy expenditure (this included a resting exercise O_2 consumption of 12 minutes) of 9.0 Kcals/minute and the females averaged 6.1 Kcals/minute for the 22.5 minute work bout. Durin and Passmore's (1967) study found that the energy cost of weight training to be 8.2 Kcal/minute. McArdle and Folglia (1969) employed an 8-RM circuit on the bench, military, curl and leg press exercises in six male subjects and found the energy cost to be approximately 6.0 Kcals/minute. Also, the study showed a maximum average increase in heart rate of 83% above the resting level following weight training. Upon completion of the exercises, heart rate returned rapidly toward the resting level.

<u>Oxygen Consumption: Eccentric and Concentric Muscular Work</u>

It is important to review the metabolic activity of concentric and eccentric contractions since isotonic devices

employ both types of contractions. Both eccentric and concentric muscular work require oxygen consumption and energy, however, concentric work demands much more O_2 than eccentric work (Petersen, Knuttgen, & Henriksson, 1972). The purpose of this section is to review the literature pertaining to the contribution of O_2 during both concentric and eccentric muscular work.

Stainsby (1976) studied the negative work and its effects on O_2 consumption in stretching twitch contractions in situ gastrocnemius-plantaris muscle of dog. Oxygen consumption was calculated from venous outflow and arterial and venous blood oxygen contents. The contractions were controlled by stimulation of the sciatic nerve. The results showed that O_2 consumption for the shortening contractions (concentric) increased with increasing loads up to isometric levels. Eccentric O_2 demands seemed to decrease as loads increased above isometric levels. Stainsby concluded that this relationship may support the reasons why O_2 consumption is less during negative work than positive work conditions in exercising humans. This study suggested that the force-velocity curve makes it possible to generate the same force for eccentric velocity contractions with fewer motor units stimulated at a lower frequency. It has also been shown that the number of impulses delivered to a muscle in a contraction is a major determinant of oxygen consumption for the contraction (Fales, Heisly, & Zierler, 1960). Stainsby (1976)

concluded that the reduction of O_2 consumption for negative work by the muscle was primarily due to the decreased number of impulses to the fibers. Thus, eccentric contractions are very efficient in utilizing O_2 during negative muscular work.

Abbott, Bigland and Ritchie (1952) determined the amount of O_2 consumption for positive and negative work using a bicycle ergometer with the muscular contractions held constant. Expired air was collected in Douglas bags. In all the experiments less O_2 was consumed when the subjects worked eccentrically. "It was hypothesized in this study that a considerable amount of work is absorbed and does not reappear as mechanical energy or heat produced; it might have been utilized to terminate or reverse some chemical process within the muscle" (Abbott, Bigland, & Ritchie, 1952). Therefore, the reduction in O_2 consumption during negative work may be attributed to this mechanism. In another experiment conducted by Knuttgen and Klaussen (1971), a comparison of various physiological responses ($\dot{V}O_2$, heart rate and blood flow) was made while subjects worked concentrically and eccentrically. Four subjects were tested on a bicycle ergometer at durations of three and six minutes. The results showed that $\dot{V}O_2$ in concentric work exceeded that of eccentric work. Oxygen deficits were near zero values in eccentric work, but the O_2 debt was similar to that of the concentric bout. This may result from factors such as hormone production, temperature increases, sympathetic nervous activity and restoration of electrolyte balance

following the eccentric work bouts. Knuttgen, Patton and Vogel (1982) created an experimental design utilizing a bicycle ergometer capable of intensities of very low to high eccentric and concentric muscular contractions. The power in watts ranged from 100 to 1500. Oxygen consumption values were much lower during eccentric contractions than for concentric contractions at equivalent values of power. The highest peak value for concentric contraction was attained at 300 Watts with a $\dot{V}O_2$ of 3.81 liters per minute and the eccentric values were at 1.01 liters per minute or 25 to 30% of the concentric peak value. The eccentric peak value was at 600 Watts, and this value was still about 50% lower than the concentric value at 600 Watts.

The literature has supported that in all cases concentric contractions require more O_2 than does eccentric contractions. However, the literature also indicated that eccentric contractions contribute a significant portion (20 to 30% of the total O_2 consumption during dynamic muscular contractions.

CHAPTER 3

METHODS AND PROCEDURES

The purpose of this study was to determine the net energy expenditure during heavy and low resistance isotonic weight training using the bench press and holding total work constant. In addition, this study was also designed to investigate how much of the total O_2 consumption during isotonic weight training is attributed to the concentric portion of the total work bout.

Subjects

Twelve college age male volunteers participated in the study. All subjects were moderately trained and experienced in free weight isotonic heavy resistance training. Since all the subjects were experienced weight lifters, they were aware of the proper techniques practiced in weight training. All subjects had some athletic experience, but it primarily consisted of anerobic training methods. The subjects were all healthy with no history of ventilatory resistance or obstruction, no injuries and no joint or musculature problems.

Experimental Procedure and Design

Prior to any testing or measurements, all subjects were required to complete an informed consent. The subjects were weighed and assessed for percentage body fat using skin folds and an equation developed for athletic college males (Yuhasz, 1962). The subjects also performed a one repetition maximum

(1-RM) bench press while using correct technique which eliminated any bouncing of the bar off the chest or arching of the back. This was performed on the same day as the administration of all the testing sessions. The subjects were instructed to fast for three hours and abstain from any exercise prior to the testing sessions. All three methods of training (HRT, LRT and CLRT) were demonstrated and explained carefully. All training methods involved identical techniques similar to that of their 1-RM technique.

All subjects' RMR was initially determined while in a supine rested state for five minutes prior to lifting. Oxygen consumption was determined by collecting expired air during the work bout. In order to determine recovery O_2, collections were continued until the subjects had two consecutive oxygen consumption values within $\pm$ .1 ml.kg.min. of their original resting metabolic rate value in order to determine recovery O_2. Also, collections for recovery O_2 were taken for two minutes between each set for all training methods. Heart rates were also determined by a 15 second radial pulse during RMR, immediately following all three sets and at the end of the two minute recovery periods between each set. The Beckman Metabolic Measurement cart (Beckman, Chicago, IL) was used to determine $\dot{V}O_2$, RMR, ventilation, respiratory exchange ratio and recovery O_2 for all three training protocols. The Beckman metabolic cart was calibrated for volume, room temperature, and barametric

pressure. The carbon dioxide (CO_2) and oxygen (O_2) analyzers were calibrated prior to each testing session with a known concentration of gas.

All three training methods were randomly administered to each subject in order to eliminate any order effect. Below is a detailed description of each of the three training methods.

Low resistance training (LRT): All subjects lifted 40% of their 1-RM for each exercise for 12 repetitions and three sets. The subjects performed each lift through the full range of motion and in a rhythmical manner.

Heavy resistance training (HRT): The subjects lifted 80% of their 1-RM performed at half the repetitions as the low resistance training method (since it involved twice the resistance) in order to equate the total work performed by both training methods. For example, if a subject had a 1-RM of 200 pounds, then 40% of that weight would equal 80 pounds. Eighty pounds x 12 repetitions equals 960 foot pounds of work. This calculation represents the amount of work performed during the LRT procedure. Once the subject had attained his original RMR value he proceeded in performing the HRT method. During the HRT method the subjects lifted 80% rather than 40% of their 1-RM. To equalize the work load for both training sessions the number of repetitions during the HRT method were adjusted since the new work load was 160 pounds (960 lbs./160 lbs. = 6 repetitions per set). Since the total number of repetitions for the LRT method was 36 (12

reps x 3 sets) then the HRT method must incorporate 18 total repetitions (6 reps x 3 sets). The rest intervals for both the LRT and HRT methods were two minutes in duration and the exercising time was 30 secs and 24 secs, respectively. The techniques involved for both training methods were similar in that they included a one to two second decent of negative work (eccentric portion), a pause at the chest and no arching of the back.

Concentric low resistance training (CLRT): The subjects lifted 40% of their 1-RM at 12 reps/set (same as the LRT method). The subjects lifted the weight concentrically while two spotters controlled the eccentric portion of the lift so that a minimal amount of eccentric work would occur. All other procedures, techniques and intervals were the same as the LRT method.

Data Description

The following variables were investigated in this study: 1) RMR, 2) total O_2 consumption for all three protocols, 3) recovery O_2 between sets and until the original RMR values were reached following the third set and 4) heart rates during the final minute of preexercise and immediately following each set and recovery period between sets during all training methods.

Oxygen consumption was obtained and recorded in terms of milliliters of oxygen per kilogram of body weight per minute, liters of oxygen per minute ventilation in liters per minute

and respiratory exchange ratio. Energy expenditure was recorded in total Kcals for the entire work bouts including the time of recovery following exercise. The conversion for O_2 consumed to Kcals expended was determined by setting one liter of oxygen equal to 5 Kcals (McArdle et al., 1981). Heart rates were determined by the palpation of the radial artery and recorded in beats per minute.

Data Analysis

A within groups correlated t-test was utilized to determine differences in oxygen consumption, ventilation, respiratory exchange ratio, time to recovery and heart rates during HRT, LRT, and CLRT methods. Also, a condescriptive analysis was run using the SPSS system. The .05 level of significance was used for all tests.

CHAPTER 4

RESULTS

It was hypothesized that the O_2 consumption during low resistance training (LRT) would exceed high resistance training (HRT) if work load is held constant. In addition, the O_2 consumption required for the concentric low resistance training (CLRT) would be significantly lower than the LRT method. All data were analyzed using a within groups t-test with the variables being $\dot{V}O_2$ in milliliters, time to recovery, $\dot{V}O_2$ in ml/kg, ventilation in liters/minute, respiratory exchange ratio (R) and heart rate in beats/minute. The .05 level of significance was used for all statistical analyses.

The subjects participating in the study had a mean height, weight and body composition of 72.33 inches (SD = 1.88), 189 pounds (SD = 10.30) and 11.23% fat (SD = 2.54), respectively. Also, the subjects' mean 1-RM was 224.17 pounds (SD = 26.53) and the mean resistance values for the HRT and LRT methods were 179.17 pounds (SD = 21.62) and 89.58 pounds (SD = 70.76), respectively. The CLRT method used the same resistance as the LRT method. Resting metabolic rate was 333.3 ml/min and 3.89 ml/kg.min-1. Resting ventilation, respiratory exchange ratio and heart rate were 9.96 liters/min, 0.93 and 73.17 beats/min, respectively. The mean total $\dot{V}O_2$ during HRT, LRT and CLRT methods were 3473.17 ml (40.35

ml/kg), 2566.67 ml (29.78 ml/kg) and 2053.33 ml (23.91 ml/kg), respectfully.

The results of the between groups t-tests on the variables are in Tables 1-10. The following variables were significantly higher during HRT than the LRT: $\dot{V}O_2$ in milliliters for recovery periods 1 and 3, average $\dot{V}O_2$ from set 1 through recovery 3, remaining $\dot{V}O_2$ post recovery 3, time to recovery and total $\dot{V}O_2$ (Table 1). The following variables were significantly higher during HRT: $\dot{V}O_2$ ml/kg.min-1 for Sets 2 and 3, recovery periods 1-3, average $\dot{V}O_2$ ml/kg.min-1 from set 1 through recovery 3 and total $\dot{V}O_2$ (Table 2). The following variables were significantly higher during HRT for ventilation in liters/minute: Sets 2 and 3, recovery periods 1-3 and average ventilation from set 1 through recovery 3 (Table 3). The following variables were significantly higher during HRT: respiratory exchange ratio (R) for sets 2 and 3, recovery periods 1-3 and average (R) from set 1 through recovery 3 (Table 4). Finally, heart rate was significantly higher during the HRT method (Table 5).

Tables 6-10 compare variables during LRT and CLRT methods using a within groups t-test. From Table 6 it can be seen that the following variables for $\dot{V}O_2$ in milliliters were significantly higher during the LRT: set 1, average $\dot{V}O_2$ from set 1 through recovery 3, remaining $\dot{V}O_2$ post recovery 3 (the amount of O_2 consumed following the third recovery until returning to original RMR values), time to recovery and total $\dot{V}O_2$. Table 7 presents set 1 for $\dot{V}O_2$ ml/kg.min-1 and total

TABLE 1

t-tests between HRT and LRT methods for $\dot{V}O_2$ in milliliters.

	HRT		LRT		
	$\bar{x}$	SD	$\bar{x}$	SD	t-value
$\dot{V}O_2$ 1st set	151.33	115.49	195.83	126.20	-1.11
$\dot{V}O_2$ 1st Recovery	755.00	300.44	578.33	137.63	2.33*
$\dot{V}O_2$ 2nd set	175.00	133.57	134.58	119.40	1.86
$\dot{V}O_2$ 2nd Recovery	901.67	255.12	646.67	146.80	4.66**
$\dot{V}O_2$ 3rd set	175.00	86.50	169.58	98.29	0.20
$\dot{V}O_2$ 3rd Recovery	946.67	305.90	572.92	171.02	5.83**
Average $\dot{V}O_2$ from 1st set through 3rd Recovery	507.33	165.75	392.00	171.19	3.01*
Remaining $\dot{V}O_2$ Post 3rd Recovery	375.42	257.13	158.33	155.55	3.21**
Time to Recovery in Minutes	8.83	3.51	5.75	1.89	3.50**
Total $\dot{V}O_2$ in Milliliters	3473.17	1087.72	2566.67	551.43	3.87**

* $p < .05$
** $p < .01$

TABLE 2

t-tests between HRT and LRT methods for $\dot{V}O_2$ in ml.kg.min-1.

	HRT		LRT		
	$\bar{x}$	SD	$\bar{x}$	SD	t-value
1st set	8.06	3.65	8.39	2.94	-0.29
1st Recovery	8.28	1.58	7.24	0.65	2.43*
2nd set	8.97	3.81	7.02	2.78	3.05*
2nd Recovery	9.15	1.48	7.66	0.83	4.70**
3rd set	9.16	1.48	7.66	0.83	4.70**
3rd Recovery	12.17	3.77	8.53	1.47	3.51**
Average from 1st set through 3rd Recovery	9.30	1.84	7.85	1.20	2.70*
Total $\dot{V}O_2$ in ml./kg	40.35	12.16	29.78	5.55	3.82*

* $p < .05$
** $p < .01$

$\dot{V}O_2$ ml/kg as variables that were significantly higher during LRT. The following ventilation values were significantly higher during LRT: set 1, recovery periods 1-3 and average ventilation from set 1 through recovery 3 (Table 8). Table 9 presents the following variables that were significantly higher during LRT for respiratory exchange ratio: sets 2 and 3, recovery periods 2 and 3 and average respiratory exchange ratio from set 1 through recovery 3. There were no significant differences

TABLE 3

t-tests between HRT and LRT methods for ventilation in liters/minute.

	HRT		LRT		
	$\bar{x}$	SD	$\bar{x}$	SD	t-value
1st set	20.16	10.15	21.20	7.83	-0.33
1st Recovery	20.24	2.49	16.88	1.40	5.37**
2nd set	29.42	11.53	20.47	8.65	4.63**
2nd Recovery	24.40	3.55	18.66	2.22	7.20**
3rd set	32.72	9.53	23.88	8.26	4.35**
3rd Recovery	28.37	7.16	22.23	3.66	3.35**
Average ventilation from 1st set through 3rd Recovery	25.91	5.69	20.57	4.29	4.46**

 * $p < .05$
** $p < .01$

between the LRT and CLRT methods for heart rate (Table 10).

The total $\dot{V}O_2$ in milliliters and ml/kg during HRT was significantly higher than LRT. Therefore, my hypothesis, that the LRT method would significantly exceed the HRT method for $\dot{V}O_2$, is rejected. Also the total $\dot{V}O^2$ in milliliters and ml/kg was significantly higher during LRT than CLRT. My hypothesis, that the LRT method would be significantly higher in $\dot{V}O_2$ than the CLRT method, is not rejected.

TABLE 4

t-tests between HRT and LRT methods for respiratory exchange ratio (R).

	HRT		LRT		
	$\bar{x}$	SD	$\bar{x}$	SD	t-value
1st set	0.88	0.11	0.85	0.10	1.14
1st Recovery	1.11	0.14	0.92	0.05	3.88**
2nd set	1.28	0.16	1.07	0.07	4.37**
2nd Recovery	1.19	0.13	1.01	0.04	5.14**
3rd set	1.34	0.16	1.14	0.06	4.81**
3rd Recovery	1.08	0.10	0.98	0.05	2.92*
Average (R) from 1st set through 3rd Recovery	1.15	0.11	1.00	0.05	4.52**

* $p < .05$
** $p < .01$

TABLE 5

t-tests between HRT and LRT methods for heart rate (HR) per minute.

	HRT $\bar{x}$	HRT SD	LRT $\bar{x}$	LRT SD	t-value
1st set	101.25	21.43	94.67	13.31	1.05
1st Recovery	80.42	9.20	82.00	13.73	-0.36
2nd set	114.50	21.86	99.33	10.81	2.26*
2nd Recovery	84.42	12.31	80.25	11.06	0.86
3rd set	119.50	23.42	103.00	12.53	2.04
3rd Recovery	86.58	14.11	82.83	9.68	0.77
Average HR/min. from 1st set through 3rd Recovery	97.17	15.53	90.33	10.79	1.35

* $p < .05$
** $p < .01$

TABLE 6

t-tests between LRT and CLRT methods for $\dot{V}O_2$ in milliliters.

	LRT $\bar{x}$	LRT SD	CLRT $\bar{x}$	CLRT SD	t-value
$\dot{V}O_2$ 1st set	195.83	126.20	103.75	74.20	2.61*
$\dot{V}O_2$ 1st Recovery	578.33	137.63	551.67	129.18	0.54
$\dot{V}O_2$ 2nd set	134.58	119.40	122.92	79.04	0.31
$\dot{V}O_2$ 2nd Recovery	646.67	146.80	576.67	174.74	1.26
$\dot{V}O_2$ 3rd set	169.58	98.29	132.08	77.74	1.22
$\dot{V}O_2$ 3rd Recovery	572.92	171.02	511.25	143.51	1.37
Average $\dot{V}O_2$ from 1st set through 3rd Recovery	392.00	171.19	327.75	90.44	2.54
Remaining $\dot{V}O_2$ Post 3rd Recovery	158.33	155.55	88.33	97.22	2.27*
Time to Recovery in minutes	5.75	1.89	4.75	1.71	2.45*
Total $\dot{V}O_2$ in milliliters	2566.67	551.43	2053.33	560.97	2.60*

* $p < .05$
** $p < .01$

TABLE 7

t-tests between LRT and CLRT methods for $\dot{V}O_2$ in ml.kg.min-1.

	LRT $\bar{x}$	LRT SD	CLRT $\bar{x}$	CLRT SD	t-value
1st set	8.39	2.94	6.16	1.83	2.54*
1st Recovery	7.24	0.65	7.11	0.68	0.47
2nd set	7.02	2.78	6.39	2.37	0.64
2nd Recovery	7.66	0.83	7.27	0.90	1.23
3rd set	7.58	2.20	6.64	2.26	1.03
3rd Recovery	8.53	1.47	8.23	2.11	0.54
Average from 1st set through 3rd Recovery	7.85	1.20	6.96	1.18	1.78
Total $\dot{V}O_2$ in ml.kg	29.78	5.55	23.91	6.31	2.58*

* $p < .05$
** $p < .01$

TABLE 8

t-tests between LRT and CLRT methods for ventilation in liters/minute.

	LRT		CLRT		
	$\bar{x}$	SD	$\bar{x}$	SD	t-value
1st set	21.20	7.83	14.19	3.45	3.91**
1st Recovery	16.88	1.40	15.68	2.23	2.86*
2nd set	20.47	8.65	16.51	7.36	1.78
2nd Recovery	18.66	2.22	17.15	2.58	2.49*
3rd set	23.88	8.26	18.77	6.58	1.95
3rd Recovery	22.23	3.66	19.01	2.52	3.58**
Average ventilation from 1st set through 3rd Recovery	20.57	4.29	16.90	3.42	3.70**

* $p < .05$
** $p < .01$

TABLE 9

t-tests between LRT and CLRT methods for respiratory exchange ratio (R).

	LRT		CLRT		
	$\bar{x}$	SD	$\bar{x}$	SD	t-value
1st set	0.85	0.10	0.87	0.08	-0.67
1st Recovery	0.92	0.05	0.90	0.09	0.95
2nd set	1.07	0.07	1.02	0.11	1.73*
2nd Recovery	1.01	0.04	0.96	0.07	2.45*
3rd set	1.14	0.06	1.05	0.10	4.14**
3rd Recovery	0.98	0.05	0.92	0.07	3.08*
Average (R) from 1st set through 3rd Recovery	1.00	0.05	0.95	0.07	3.04*

* $p < .05$
** $p < .01$

TABLE 10

t-tests between LRT and CLRT methods for heart rate (HR) per minute.

	LRT		CLRT		
	$\bar{x}$	SD	$\bar{x}$	SD	t-value
1st set	94.67	13.31	92.58	6.24	0.47
1st Recovery	82.00	13.73	76.25	11.76	0.92
2nd set	99.33	10.81	95.42	10.98	0.78
2nd Recovery	80.25	11.06	76.92	10.10	0.72
3rd set	103.00	12.53	99.58	8.73	0.64
3rd Recovery	82.83	9.68	78.00	10.83	0.95
Average HR/min from 1st set through 3rd Recovery	90.33	10.79	86.42	7.91	0.88

* $p < .05$
** $p < .01$

CHAPTER V

DISCUSSION AND CONCLUSIONS

The purpose of this study was to determine the effect of altering resistance during weight training while holding work constant on O_2 consumption ($\dot{V}O_2$). In addition, the present study also investigated the O_2 cost of the concentric phase of weight training. The three weight training methods utilized were heavy resistance training (HRT) which incorporated 80% of the subjects' 1-RM for six repetitions x three sets, low resistance training (LRT) which utilized 40% of the subjects' 1-RM for 12 repetitions x three sets and the concentric low resistance training (CLRT) method which involved only concentric contractions at 40% of the subjects' 1-RM for 12 repetitions x three sets. It was hypothesized that the LRT method would require significantly higher $\dot{V}O_2$ than the HRT method. It was also hypothesized that the LRT method would require significantly more $\dot{V}O_2$ than the CLRT method.

The results of the present study show that $\dot{V}O_2$ during HRT is significantly higher than during the LRT method (Table 1). Also, the results show that the $\dot{V}O_2$ during LRT is significantly higher than during the CLRT method (Table 2). Wilmore et al. (1978) found the energy expenditure for weight training to be 9.0 Kcals/minute. Also, Durin et al. (1967) and McArdle et al. (1969) found the energy expenditure for weight training to be 8.2 Kcals/minute and 6.0 Kcals/minute, respectively. The present study only showed an energy

expenditure of 2.11 Kcals/minute (HRT), 1.57 Kcals/minute (LRT) and 1.31 Kcals/minute (CLRT). These values are substantially lower than the previously mentioned studies. In fact, the present study's HRT method is about 77% lower than Wilmore et al. (1978) and 65% lower than McArdle et al. (1969). However, the present study's protocol was much different from the previously mentioned studies. The present study only utilized 80% of the subjects' 1-RM at six repetitions x three total sets (HRT) and 40% of the subjects' 1-RM for 12 repetitions x three total sets. Wilmore et al. (1978) utilized a procedure where the subjects performed at 40% of their 1-RM for 15-18 repetitions x 30 sets. It is obvious that the amount of work performed by the present study was about four times lower than Wilmore's study. Also, the work-recovery ratio was 30-sec exercise to 15-sec rest (2:1) in Wilmore's study while the present study utilized a 24-30 sec exercise to 2 minute recovery ratio (4:1). For example, if an individual used 100 lbs as a resistance representative of 40% of his 1-RM, performing 15 repetitions for 30 sets for a total duration of 22.5 minutes (30-sec exercise and 15-sec rest), the total work performed would be 2000 foot pounds per minute ((15 reps x 100 lbs x 30 sets) / 22.5 minutes). In the present study, using the same weight for 12 repetitions x 3 sets for a total duration of 7.5 minutes (30-sec exercise and two-minute rest), the total work performed would be 460 foot pounds per minute ((12 reps x 100

lbs x 3 sets) / 7.5 minutes). The fact that Wilmore's study incorporated a substantially greater amount of work at shorter time intervals could account for the large difference in caloric expenditure when expressed in Kcals/min over the total time period of the work bout and recovery periods between the two studies. Durin et al. (1967) utilized a very similar procedure to Wilmore's with the exception that the subjects performed 12-15 repetitions per set and therefore one could expect similar results with the Wilmore study. The study most comparable to the present study's protocol was McArdle et al. (1969) in which the subjects performed at an 8-RM resistance for one set on the bench press. The energy expenditure during the bench press was reported at 3.79 Kcals/minute during the eight repetitions and a 2 minute recovery period. The additional two repetitions performed in McArdle and Foglia's (1969) study may account for some of the difference during the HRT method in the present study (2.11 Kcals/minute). Since McArdle and Foglia employed an 8-RM resistance as opposed to an 80% of the subjects' 1-RM (employed by the present study), it is difficult to make an accurate comparison in work.

Also, in McArdle and Foglia's (1969) study, measurements for respiratory exchange ratios (R), heart rates and ventilation were 1.02, 122 and 17.74, respectively during exercise, while during recovery the measurements were 1.42, 75 and 24.50, respectively. Values for R from the present study ranged from 0.88 to 1.34 during the exercise sets and

1.08 to 1.19 during recovery. Heart rates were 101 to 120 during exercise and 80 to 87 during recovery. Minute ventilation was 20.16 to 28.37 during exercise and 22.24 to 32.72 during recovery.

The primary purpose of this study was not to investigate the amount of O_2 consumed in relation to other studies, but to investigate the effects of training resistance with total work held constant on $\dot{V}O_2$. The results of the present study seem to support Stainsby et al. (1981, 1976, 1971, 1970) findings that show increasing muscular tension to be positively related to $\dot{V}O_2$. In fact, the present study found the HRT method to require 26.1% more O_2 than the LRT method even though total work performed was equal. It was interesting to note that all the significantly higher values for HRT as compared to LRT were obtained during the recovery periods. McArdle and Foglia (1969) suggest that this difference is accounted for because the subjects tend not to breathe at higher resistances during contraction. This will decrease the ventilatory volume resulting in a lower amount of O_2 to be transported to the working muscles. However, contrary to this idea, the present study indicates that the ventilatory volume for sets 2 and 3 were significantly higher during the HRT method as compared to the LRT method. This suggests that the subjects were breathing at a greater rate during the HRT method. Another possible explanation for the insignificant differences during the exercising sets may be

due to the fact that high resistance training involves greater intramuscular pressure resulting in occlusion of the muscular vessels (Danoff & Danoff, 1981). This may temporarily impede blood flow during the exercise sets. This condition may put the working muscles into a state of anaerobic metabolism (no O_2 utilization), thus creating an oxygen deficit that is repaid during recovery when the muscles are relaxed. However, the existing deficit does not explain the significant difference in total $\dot{V}O_2$ between the LRT and HRT methods. Even though the HRT method was significantly higher than the LRT method, the relationship was not linear as shown by Stainsby et al. (1981), Stainsby (1970), Abbott (1952), Knuttgen et al. (1982), Clark (1960) and Danoff and Danoff (1981).

The present study also found a significantly higher $\dot{V}O_2$ for the LRT method compared to the CLRT method. However, it must be assumed that the eccentric phase of the lift does contribute a small but substantial portion of O_2 during weight training, in fact, about 20% of the total work can be attributed to the eccentric phase. Similar findings by Knuttgen and Klaussen (1971) and Knuttgen et al. (1982) using bicycle ergometers capable of allowing for negative and positive work support the present study's findings.

In conclusion, it appears from the present study that an increase in resistance while keeping work constant will elicit a significant increase in oxygen consumption. Also, the present study has shown that eliminating the eccentric

phase of weight training can significantly decrease the O_2 cost of the exercise.

Conclusions

Earlier it was mentioned that weight training could be utilized as a means of weight reduction. According to the present study and the related literature, weight training is a poor activity for expending calories. In fact, running an eight minute mile pace would result in a caloric expenditure of 17.1 Kcals/minute for a 190 pound individual (McArdle et al., 1981). This is substantially higher than the 2.11 Kcals/minute obtained by the present study or Wilmore et al. (1978) 9.0 Kcals/minute obtained during vigorous circuit training. However, the present study has indicated that a significantly greater caloric expenditure can be achieved if one utilizes a heavy resistance training procedures as compared to a low resistance procedure at the same level of total work.

Recommendations

Based upon the findings of this study, the following recommendations for future investigation are made:

1. A similar investigation using twice the number of repetitions at the same resistance.

2. Compare isotonic weight training to the modern isokinetic devices for $\dot{V}O_2$.

3. Compare various resistances on the isokinetic devices while keeping work performed constant.

4. Further investigations relating high and low resistance training protocols on $\dot{V}O_2$ for different weight training exercises.

5. Investigate the contributions of the concentric phase during a high resistance training protocl for $\dot{V}O_2$.

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APPENDIX A

Informed Consent

I, ______________________________________, hereby consent to voluntarily engage in three oxygen consumption tests to determine the metabolic responses to three weight training protocols. The exercise tests will be performed on a bench press using free weights at 40% and 80% of my one repetition maximum lift. The investigator may stop any of the tests at any time, or I may stop when I wish because of feelings of fatigue or discomfort. During the tests, my heart rate and oxygen consumption will be monitored.

The information obtained will be treated as privileged and confidential and will not be released to any person without my expressed written consent. The information obtained however, may be used for statistical or scientific purposes with my right to privacy retained.

I have read the above and I understand it and my questions have been answered to my satisfaction. The administrator of the testing is Kean G. Richard and may be contacted for any further information at the below address and phone number:

G-2009-7 University Drive
Cedar Falls, Iowa 50614
Phone: 268-1143

Date_______________

Signed_____________________________________

Witness____________________________________