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THE EFFECTS OF VARYING LOADS AND REPETITIONS ON CALORIC EXPENDITURE DURING TRADITIONAL BACK SQUATS

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ABSTRACT

A leading topic of interest in the health-fitness and wellness industry is how to maximize caloric expenditure in the shortest amount of time through physical activity. The goal of this study is to identify a resistance training (RT) protocol that appeals to these two demands through the use of the back squat exercise. A total of 15 subjects between the ages of 18 and 40 participated in four separate exercise protocols in a randomized order. Each protocol performed the same amount of work in the same 4 minute duration using either a 5kg, 10kg, 15kg, or 20kg load at a contraction speed of 1, 2, 3, or 4 seconds respectively. The mean physical activity energy expenditure (PAEE) demonstrated a trend of decreasing as the loading increased from 5kg to 20 kg with a 29.3% difference between the 5kg and 20gk condition values. All of the mean heart rate (HR) recordings exhibited a similar trend of decreasing as loading increased from 5kg to 20kg with the exception of the mean minimum HR (MNHR) measurements in which case the largest value was associated with the 10 kg load as opposed to the 5kg load. The mean values for MNHR indicated an 8.7% difference between the 10kg condition and the 20kg condition while the 5kg condition displayed a 4.9% difference. For the average heart HR (AHR) values, there proved to be a 13.4% difference between the 5kg and 20kg conditions while the maximal HR (MXHR) values showed a 13.8% difference. In conclusion, using a work load that maximizes the total work output as a result of a high capacity for the number of repetitions performed at the fastest rate of contraction will most likely yield the highest PAEE.

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Chapter 1 -Introduction

Background

Including regular resistance training into either a currently active or previously inactive lifestyle has obtained substantial awareness over the past few decades regarding its many health benefits consisting of improved strength, bone density, body composition, anaerobic capacity, flexibility, physical function, and more. The importance of resistance training for improved health and well-being was recognized by the American College of Sports Medicine (ACSM), American Heart Association, and Surgeon General's Report on Physical Activity and Health (Robergs, 2007). Tremendous progress has been made in our attempt to understand the many benefits of resistance training and the key variables that govern the extent to which those benefits are experienced.

A few variables that have been tested already include measurements of relative muscular effort (RME), effects of load-volume, rate of contraction, work performance, and repetition cadence. RME refers to the muscle force implemented during a particular task relative to the maximum amount of force the muscle is capable of producing. Load-volume relates the magnitude of the training load to the total amount of accumulated mass lifted. The rate of contraction concerns the degree of acceleration that takes place while displacing the training load through its designated range of motion. The total amount of force generated to move a particular mass through a particular distance dictates the total amount of work performed, while the pace at which each phase of a lift is executed will determine the repetition cadence. One commonality between these variables is a direct influence on physical activity energy expenditure (PAEE).

Physical activity may be defined more broadly as all bodily actions produced by the contraction of skeletal muscle that increase energy expenditure (EE) above basal level (Butte, 2012). PAEE is the most variable portion of any individual's total energy expenditure (TEE) and can range from as little as 5% of the TEE to 45-50% depending on their physical activity level. Numerous methods for measuring PAEE have been tested and evaluated including heart rate (HR) monitors. These devices have been used to incorporate the FLEX HR technique for measuring PAEE which has proven to be a valid and reliable method on the basis of the linear relationship between HR and EE (Butte, 2012).

The back squat is a common exercise utilized in a multitude of settings ranging from clinical rehabilitation to strength and conditioning for athletic performance. This is because there are so many similar movements demonstrated in numerous activities of daily living in cultures all over the world as well as athletic movements. Additionally, it is a multi-joint exercise requiring various large muscle groups to function in an organized manner. From a performance perspective, both in terms of simple functional movements to ease activities of daily living as well as athletic performance, the back squat exercise will benefit both the joint structures themselves, by strengthening the ligaments, tendons, and bones that constitute them, as well as the physical functions such as strength, speed, power, and neuromuscular efficiency of the muscles that cross those joint structures. This is especially true for the knee, hip, and low-back joint structures which perform most of the work. A strong correlation between speed as well as relative and absolute strength has been found as a result of exploiting free weight squats in particular (Keiner, 2013). When participating in RT exercises such as the back squat, it is important to perform each repetition through a full range of motion (ROM) as recommended by the American College of Sports Medicine. By doing so, strength adaptations may occur at each angle within the ROM which may lead to enhanced injury prevention due to the strengthening of the various joint structures as previously mentioned (Cotter, 2013).

Despite all of the benefits that may be acquired from squats as part of a RT program, if the movement is not executed properly the risk for injury could substantially increase. Therefore proper execution of the exercise is essential to minimizing this risk. The back squat is often performed following two common sets of instructions regarding proper form. In one case, the knees are not allowed to pass over the toes during the lift. In the other case, the knees are allowed to pass over the toes during the lift. A study performed by List et al. (2013) found that restricting the distance traveled by the knees results in an increased range of motion for thoracic curvature leading to higher stresses in the hips and low-back. When the knees were allowed to pass over the toes during the lift, a larger ROM was demonstrated in the knees and to a much lesser degree in the thoracic curvature and other spinal segments leading to lower stresses in the back and a larger capacity for strength training of the leg muscles. This would suggest that squatting instructors should be more open to allowing anterior knee displacements slightly beyond the position of the toes (List, 2013).

An alternative mode in which the squat exercise is often manipulated concerns the technique that is used to reverse the movement once the desired depth has been established. In one case a momentary pause is demonstrated before reversing the movement in which case there is no rebound effect to alter the movement mechanics. In the second case there will be a rebound effect to introduce an element of bouncing out of the end range of depth. With the work and load being standardized between both the rebound and no rebound modes of squatting, the rebound uses less oxygen and in effect proves to be significantly more efficient in its energy cost. It is suggested that the increased efficiency is the result of an elastic recoil effect from the muscles and tendons. As the muscle-tendon unit is stretched at the bottom of the movement, elastic potential energy is stored and then reconverted into kinetic energy upon reversing the movement back towards the standing position (Villagra, 1993).

One of many factors effecting caloric expenditure during exercise is the effort displayed by muscle groups that cross all participating joint structures. For multi-joint exercises it is unknown whether all of the muscle groups involved have the same relative muscular effort (RME), which can be defined as the muscle force needed to perform a task relative to the maximum force that muscle can produce, or not (Bryanton, 2012). In the case of the back squat exercise, there are two manipulations that can be made to influence the RME of the muscles involved, more specifically the muscles responsible for the necessary joint rotations to perform the movement including the ankle plantar flexors, knee extensors, and hip extensors. These two manipulations consist of the depth to which the squat is performed and the magnitude of the load (Bryanton, 2012).

Another energetic influence along the lines of muscular effort that has drawn some attention is the rate of muscular contraction while performing a particular exercise. It had been widely accepted since the 1990’s that resistance training with an emphasis on PAEE should be performed using slow muscle contractions. One argument for this reasoning claims that slow repetition speeds increase the workout's intensity and effectiveness (Mazzetti, 2007). Exercise intensity may be defined by both the training load's percentage of the individual's 1RM and the rate of acceleration at which the training load is moved. Since neither of these factors will increase by using slower repetition speeds, the exercise intensity will not increase either. Slow contractions instead only prolong repetition durations resulting in greater muscle fatigue and apparent muscularity due to an increase in blood flow to the muscle, neither of which contributes to EE efficiency.

On the contrary there has also been evidence supporting explosive muscle contractions as having a higher PAEE rate due to the activation of the energy-inefficient fast twitch muscle cells (Ferguson, 2001; Mazzetti, 2007; He, 2000). For a muscle to generate more force it either has to increase the frequency of contractions for all active muscle cells, recruit more muscle cells through the activation of higher-recruitment threshold motor nerves (Behm 1993; Grimbly 1977), or a combination of the two. High-recruitment threshold motor nerves are known to have a higher synapse proportion with fast muscle cells further reducing the energy efficiency during force production (Mazzetti, 2007; Schiaffino, 1970).

The intense physiological and metabolic reactions to RT are the result of mechanical stimuli. These stimuli are defined by multiple criteria that ultimately result in various training methods. Such variables involved in previous studies have included loading, contraction velocity, exercise volume, repetition cadence (i.e. eccentric, concentric, and isometric contraction durations), and rest interval duration. These aspects ultimately dictate the power being generated and the work being performed while at the same time determining the PAEE (Buitrago, 2013; Villagra, 1993). A few of the physiological and metabolic reactions investigated during the different training methods so far have been the rate of EE, oxygen uptake (VO_2), lactate concentration, HR, and excess post-exercise oxygen consumption (EPOC) (Buitrago, 2012, 2013). Disparities in the metabolic and physiological reactions to different RT methods emphasizing the different mechanical stimuli may reveal a more accurate specification of their effectiveness at achieving particular training goals (Buitrago, 2013).

Purpose

Despite the awareness of all the benefits tied to participating in regular exercise, the majority of American adults still fail to engage in even the minimum exercise recommendations. There are currently two methods of how to achieve the recommended levels of exercise by ACSM, the Center for Disease Control, and the Office of the Surgeon General. The first and earliest method was based on the assumption of increasing exercise intensity (vigorous) to improve health as a result of first improving fitness levels and recommended that individuals exercise at a minimum intensity of 50% of their maximal oxygen uptake reserve 3-5 days per week. The more modern recommendation of exercising at a minimal intensity of 40% of their maximal oxygen uptake reserve 5-7 days per week is based on public health objectives and appreciates the value of physical activity levels (low to moderate) that improve health without necessarily improving personal fitness. This was accomplished by lowering the minimum intensity required while increasing the frequency of participation. In addition, the duration of exercise became more flexible by allowing for multiple bouts of shorter exercise periods to reach the recommended duration. Many of these changes were largely made under the assumption that lowering the exercise intensity will result in improved exercise adherence. Although this assumption rings true with 23% of American adults participating in low to moderate physical activity levels five or more times per week compared to the 15% who participate in vigorous physical activity three or more times per week, these numbers are still far too low (Kilpatrick, 2007).

Obesity in the United States is currently classified as an epidemic and is significantly perpetuated by these sedentary lifestyle habits among other factors such as poor dietary options. The current circumstances confirm a need to introduce this population to physical activities geared toward maximizing their impact on weight management. Despite the growing concerns, documented evidence of the increasing prevalence and efforts to emphasize physical activity and proper nutrition, obesity has continued to root itself within the American population. In 2000, no states reported a pervasiveness of obesity ≥30%, but by 2009 nine states had surpassed that number. Only one year before that, in 2008, the prevalence of obesity in the United States had reached an overall 33.8% between men and women (Menez, 2013).

The anthropometric tool of choice most commonly utilized to assess relative weight and classify it into such categories as underweight, normal, overweight, and obese is body mass index (BMI). BMI is expressed as the individual's body weight in kilograms over their height in meters squared (kg/m^2). The ranges for each category are broken down as such:

Table 1. BMI Body Weight Classifications

Classification of Body Weight	BMI Range (kg/m^2)
Underweight	< 18.5
Normal Weight	18.5 – 24.9
Overweight	25 – 29.9
Obese	≥ 30
Grade 1	30 – 34.9
Grade 2	35 – 39.9
Grade 3	≥ 40 (Severe Obesity)

Since the first expansion of the obesity subgroup (grades 1-3), the American Heart Association has proposed to once again expand it into additional subgroups of grades 4 and 5 to classify BMI values of ≥ 50 kg/m^2 and ≥ 60 kg/m^2 respectively. However, this method of classification is notorious for its inability to distinguish between lean and fat body mass especially in patients with BMI ≥ 30 kg/m^2 (Bastien, 2014).

It is primarily the acquisition of excess body fat that is more often connected to metabolic abnormalities. For this reason obesity has been linked to elevated morbidity and mortality rates. Obese individuals are more susceptible to acquiring diseases such as coronary disease, hypertension, and type 2 diabetes mellitus. The increased mortality rate of these individuals is the result of a higher susceptibility to cardiovascular disease, renal failure, obesity-related cancers, and diabetes (Menez, 2013).

With a better understanding of how to maximize PAEE from RT, individuals who are currently classified as obese, at risk for becoming obese, or simply prefer to maintain or improve their body composition, will have an easier time achieving these goals. In a fast paced world where a lot of reward for little effort is highly desirable, especially in the weight management category, efficiency is of the utmost importance in order to keep individuals motivated and on task. Knowledge of whether or not one RT method truly surpasses others in its ability to influence PAEE would be vital to a number of professionals including physicians, physician assistants, fitness trainers, physical therapists, and more. But above all, the most important population to reach with this information would be the general public to make use of it themselves before reaching a point where a health care professional feels the need to intervene.

Hypothesis

Previous studies have only examined one or possible even a few of the variables previously mentioned (RME, load-volume ratios, rate of contraction, and multiple training methods) and may or may not have focused on or even considered the contribution to PAEE (Abboud, 2013; Behm, 1993; Bryanton, 2012; Buitrago, 2012, 2013; Ferguson, 2001; Grimbly, 1977; He, 200; Schiaffino 1970). Attributes and findings from these various studies need to be incorporated into a single study with the intent of understanding how they contribute to the resulting PAEE. This would require the study to incorporate multiple training methods for comparison, consider depth and loading for each training method, and maintain a standardized work output and time constraint with a spectrum of varying contraction speeds ranging from very fast to very slow. With each training method performing the same amount of work over the same amount of time it will be much more clear as to which, if any, ratio of loading to number of repetitions, ultimately dictating the contraction speed, has a higher rate of PAEE.

We hypothesize that the training method with the lowest loading and highest number of repetitions, therefore having the fastest muscle contractions, will result in the most significant PAEE. Based on the data collected from previous studies about the magnitude of influence from quicker contraction speeds on increased energy expenditure, possibly due to the recruitment of energy inefficient motor units (Mazzetti, 2007), we believe this will supersede the influence of heavier loads with slower contraction rates. Not only will the faster contraction condition likely recruit the highest proportion of less energy efficient muscle fibers, but it will do so far more often than any of the slower conditions throughout the duration of the protocol. Following this logic, we even expect to see a trend of the highest PAEE resulting from the fastest contraction speed and then continuing to decrease as the contraction speed decreases.

Chapter 2 –Review of Literature

Review of Heart Rate Monitor Literature

A commonly accepted claim is that activities of daily living correspond to submaximal exercises ranging from low to moderate intensities. For this reason the HR method for measuring EE does not consider the constraints of daily physical activities and is not a good predictor of EE for low activity levels (Gastinger, 2012). When compared to the EE measured from breath-by-breath gas exchange using an indirect calorimetry system, HR monitors demonstrate significant differences in measurements while standing at rest for an individual and while standing at rest or walking at 5 and 6 km/hr for a group (Gastinger, 2012). These differences are a testament to the inaccuracies of HR monitors at low to moderate activity levels. Advantages to using HR monitors include portability, ease of use, and that they are non-invasive.

Due to the overlap between active and sedentary HR, a threshold value must be established to discriminate between the two. Studies planning to utilize the HR monitor method are better off applying it to a group setting due to measures of the prediction errors for the group mean being as low as 3%, whereas for individuals the range of prediction errors were greater than 10%. More considerations to be taken into account when using these monitors is the necessity to calibrate them for use on individuals taking prescription drugs that may affect HR (Butte, 2012). HR is also subject to additional factors such as activity mode, posture, environmental conditions, and fitness levels

(Gastinger, 2012). More accurate measurements will arise from addressing more of the previously stated criteria.

Review of Physical Activity Energy Expenditure Literature

Physical activity is a construct that can be defined both qualitatively and quantitatively. Qualitatively, it can be placed into different categorizations depending on how taxing the activity is to an individual's aerobic and anaerobic energy systems. Ranging from least to most activity, such categories may include sedentary behaviors, locomotion, leisure activities, and exercise. Quantitatively, exercise can be classified based on the frequency at which the activity is participated in, the duration of the activity, and the intensity of the activity (Butte, 2012). PAEE is highly variable among individuals and depends on what the activity is, how often it is performed, for how long, and how much physiological effort is exerted in the process.

Bryanton (2012) investigated to methods, consisting of barbell loading and depth, to influence the RME while performing a barbell back squat. The results for this study showed that increasing the barbell load affected the ankle plantar flexor RME, increasing the squat depth affected knee extensor RME, while both affected hip extensor RME. More specifically, knee extensor RME was shown to be lowest between 30 and 44 degrees of knee flexion, and highest between 105 and 119 degrees of knee flexion. No significant difference in knee extensor RME was seen from 60-74 degrees and 90-104 degrees of knee flexion (Bryanton, 2012). With both elements playing a role in the resulting RME, both need to be considered when evaluating the difference in caloric expenditure for the same exercise under different conditions.

In order to take a closer look at the influence of contraction speed on PAEE Mazzetti (2007) compared three separate squat exercise protocols focused on explosive versus slow muscle contraction to a baseline measurement. Measurements taken during each protocol consisted of total oxygen consumption from expired air using a metabolic cart calibrated for each experiment as well as blood lactate accumulation from finger-prick blood samples. All familiarization and testing performed by each subject was done using a plate loaded squat machine. The first protocol (SLOW) required two seconds for both the eccentric and concentric contractions for a total of four seconds using a 60% 1RM load. This was done for four sets of 8 repetitions with 90 seconds of rest in between. The second protocol (EXPL) followed all of the same criteria for the SLOW squat with the exception of an explosive concentric contraction phase lasting about one second. The final protocol (HEAVYEXPL) used a two second eccentric phase with an explosive concentric phase to lift an 80% 1RM load for six sets of four repetitions with a 90 second rest interval.

The total amount of work performed was the same for all three protocols; however the time it took to perform the total amount of work was longer for the SLOW protocol compared to the EXPL and HEAVYEXPL protocols which were equal in duration. Mazzetti (2007) found that using a moderate load with explosive concentric contractions yields a significantly higher total oxidative energy expenditure as well as a higher total oxidative energy expenditure plus anaerobic energy expenditure than that of a slow contraction or heavy explosive protocol. Finally, the average rate of energy expenditure for the explosive contraction protocol was also significantly greater than the slow contraction and heavy explosive contraction protocols (Mazzetti, 2007). This may suggest that the use of lighter weights with quicker contraction rates may prove to be the more effective method of reaching weight management goals through RT.

Buitrago (2012) performed a study concerned with the effects of different loads and modes at which each repetition is performed and focused on how these two factors influence blood lactate concentration, oxygen uptake, HR, exercise time, number of repetitions, and accumulated lifted mass. Subjects were tested for a 1RM to define the individualized loads that would be utilized for each condition. A total of three different loads consisting of 55%-1RM (LOW), 70%-1RM (MID), and 85%-1RM (HIGH) were used to perform a single set of resistance training using a seated bench press machine. Each set was performed using one of four different exercise modes defined as 4-1-4-1 (4-s concentric, 1-s isometric, 4-s eccentric and 1-s isometric successive actions), 2-1-2-1 (2-s concentric, 1-s isometric, 2-s eccentric and 1-s isometric successive actions), 1-1-1-1 (1-s concentric, 1-s isometric, 1-s eccentric and 1-s isometric successive actions), and MAX (maximum velocity concentric, 1-s isometric, 1-s eccentric and 1-s isometric successive actions). Oxygen uptake measurements were taken using an open air spirometry system which began 10 minutes prior to exercise beginning and continued to be taken for 30 minutes post-exercise. Blood lactate was determined by an enzymatic-amperometric analyzer from blood samples taken from the ear lobe while HR was recorded using a Polar telemetric HR-system. Measurements for both blood lactate and HR were taken every two minutes post-exercise for 30 minutes. Finally, for each of the 12 possible conditions the number of repetitions completed was recorded as well as the exercise duration. The accumulated lifted mass was calculated by multiplying the number of repetitions by the mass lifted.

Both load and mode significantly affected the number of repetitions performed. As load decreased, the number of repetitions performed significantly increased. However, the number of repetitions increased with increasing mode except in the case of 1-1-1-1 and MAX where there was no significant difference. Exercise time was also effected by load and mode in which case it was significantly higher at LOW loads compared to MID and HIGH loads. MID loads also demonstrated a significantly longer exercise time compared to HIGH. In the case of exercise mode, 4-1-4-1 resulted in a significantly higher exercise time than that of the 2-1-2-1, 1-1-1-1, and MAX. There was no significant difference between 2-1-2-1, 1-1-1-1, and MAX modes. Accumulated mass lifted decreased significantly between all loads as they increased, but increased as the speed of the repetitions increased except between 1-1-1-1 and MAX in which case there was no difference. Oxygen uptake was significantly different depending on the load being used. LOW load showed the highest oxygen uptake followed by MID and then HIGH, but there was no significant difference between MID and HIGH. Mode also showed no significant difference for oxygen uptake. Blood lactate concentrations were significantly higher for LOW and MID loads compared to HIGH load, but with no significant difference between LOW and MID. Different modes showed no change in blood lactate concentrations. No significant difference was detected in HR between all of the different loads and modes (Buitrago, 2012).

In an effort to describe the relationship between EPOC and RT, Abboud (2013) investigated the effects of load-volume on EPOC after acute bouts of resistance training in resistance-trained men. Eight individuals performed two RT sessions of equal intensity but different totals of accumulated mass lifted consisting of 10,000 and 20,000 kg.

Resting metabolic rate (RMR) was assessed before and after exercise at multiple time intervals. Rating of perceived muscle soreness and creatine kinase levels were also measured in order to determine if differences in EPOC may have been associated with the differences in the degree of muscle damage inflicted by the exercise protocols. No significant difference in RMR as a result of EPOC was demonstrated over time or between conditions. However, the results of the study did show that the 20,000 kg session was significantly longer and expended a significantly larger amount of energy. Abboud (2013) suggests that because of the training condition of the subjects they had reached a higher level of adaptation to the stresses of exercise and were therefore less responsive to the metabolic effects of recovery from RT. These results may advocate the exclusion of EE due to EPOC while testing trained subjects for PAEE as a result of RT.

RT is highly variable and adaptable to meet the demand of the desired effect such as hypertrophy, functional capacity, energy balance, and weight management (Buitrago, 2013). For this reason there is a wide array of training methods that can be adopted to fit the individual’s needs. Buitrago (2013) tested four different training methods to highlight the advantages of each. The first method focused on strength endurance and utilized a 55% 1RM with four second concentric and eccentric contraction phases for each repetition. The second training method focused on fast force endurance which used the same loading as the strength endurance method but incorporated an explosive concentric contraction phase and reduced the eccentric contraction phase to one second. The third training method was designed for hypertrophy and used a 70% 1RM load with two second concentric and eccentric contraction phases. The final training method focused on maximum strength with an 85% 1RM load and applied an explosive concentric phase with a one second eccentric phase.

Buitrago's results showed that the total concentric power involved in each training method was significantly higher for the fast force endurance and maximum strength methods. The fast force endurance method also proved to produce a significantly higher amount of total concentric work than the other three methods. When comparing the total exercise time, the strength endurance method measured significantly higher than the others while the maximum strength method measured significantly lower. Oxygen consumption was measured to be significantly higher in the strength endurance than the hypertrophy and maximum strength methods. Maximum blood lactate concentration was significantly higher in the fast force endurance method when compared to the maximum strength method. No significant difference for EPOC was measured for any of the four training methods. By determining the generated power and the work performed, the energy demands of the exercise can also be determined. Buitrago (2013) concludes that the fast force endurance training method will consume the most energy because it measured significantly higher in the concentric work and power categories. However, this relationship discloses no information about the quantity of energy consumed or the contribution of aerobic and anaerobic metabolism to the total energy supply. Mazzetti (2007) and Buitrago (2013) have both drawn the same conclusion regarding training methods utilizing explosive contractions suggesting that this factor seems to play a significant role in maximizing PAEE.

Continuing with specificity of training mode to training results, one study compared traditional strength (TS) training programs, which include rest intervals between sets of heavier loads, to high-resistance circuit (HRC) training including relatively low loading with minimal rest between sets (Romero-Arenas, 2013). Healthy, untrained elderly men and women between the ages of 55-75 years were randomly assigned to the TS, HRC, or control group. Measurements of the isokinetic peak torque were taken in both upper and lower body extremities as well as peak VO_2 and body composition for each subject. Both training programs consisted of exercising two times per week for 12 weeks. The TS training program required subjects to complete two warm up sets of each exercise for six exercises with 1 and 2 minutes of rest in between respectively before starting the first working set of the subject's 6RM. The number of working sets performed each week varied according to a specific periodized training program. Three minutes of rest were taken between each working set and each exercise for the first three exercises (leg curl, pec deck, and seated calf raise) until a five minute rest period was given before starting the next three exercises (seated pulley row, leg extension, and preacher curls). The same warm up and working sets of 6RM were used for these three exercises as well.

The only difference between the TS and HRC training programs was the rest interval between exercises and the progression through the exercises. For both training programs the eccentric phase of each repetition was performed for three seconds while the concentric phase was performed at maximum velocity. The HRC training program was broken up into two circuits of the same six exercises, the first including the leg curl, pec deck, and seated calf raises, while the second included the seated pulley, leg extension, and preacher curls. For the HRC training program the first set of the first three exercises, including the same warm up and working sets, was performed in series with 35 seconds of rest in between each exercise. After finishing a set of the last exercise in the sequence, three minutes of rest were allotted before beginning the second series of sets and so on until the required number of working sets was completed. Five minutes of rest were allowed between the end of the first circuit and the start of the second circuit which followed the same exercise and rest intervals as the first circuit. Both the TS and HRC groups demonstrated significant increases in isokinetic strength previous to beginning the training programs and were also significantly greater than the mean of the control group.

Also, both TS and HRC groups showed significant increases in lean mass and bone mineral density, but only the HRC group showed a significant decrease in fat mass which was also significantly greater than the decrease in the control group. The walking economy of the HRC group also experienced a significant increase although there was no significant different between each group. Therefore both TS and HRC prove to be effective in increasing isokinetic strength, lean mass, and bone mineral density, but only the HRC program provokes a significant decrease in fat mass and improves cardiovascular adaptations accomplishing this through the reduction of rest intervals alone (Romero-Arenas, 2013).

Chapter 3 -Methods

Subjects

A total of fifteen subjects, six males and nine females, participated in the experiment and were between ages 18 and 40. Each had a minimum of two years of weightlifting experience and participated in weekly exercise training sessions that include squats. All of the experimental procedures and formalities were approved by the Institutional Review Board for the involvement of human participants. The procedures were disclosed to all participants both verbally and in writing. Written consent was received from each individual prior to their involvement in the experiment.

Table 2. Subject Information

Age	29.91 ± 6.72
Height (inches)	65.53 ± 4.19
Height (meters)	1.66 ± 0.11
Weight (lbs)	147.2 ± 28.33
Weight (kg)	66.91 ± 12.88

Data are means ± SD.

Equipment

Each subject was fitted with a wireless Polar Team[2] heart rate monitor prior to beginning the experiment. Additional equipment used during each trial included a Les Mills SMARTBAR™ as well as Les Mills SMARTBAR™ weight plates (2.5kg and 5kg) for each subject. Tape was placed on the floor to mark the stance width and angle of the feet for each participant. A metronome was also utilized to set and maintain the pace of each repetition for each of the different exercise protocols.

Experimental Procedure

Data collection for this experiment was administered over a single session for each subject. Prior to each subject's participation in the experiment, a 10 minute cycling warm up was administered to prepare for the physical activity involved. Following the warm up each subject was fitted with a heart rate monitor and performed a short squat routine involving the squat counts from each of the four protocols in order to give each of the subjects a chance to establish a comfortable squatting stance and familiarize themselves with the pacing of each protocol. During this time tape was placed along the medial length of each foot marking the preferred squatting stance to ensure the consistency of joint angles across all trials. Following the squat warm up the subjects were given 2-3 minutes to establish a baseline HR which played two major rolls. First, it allowed each subject to act as their own control, serving as a base for comparison of any changes that took place throughout the four protocols. Second, after the completion of each protocol, subsequent protocols could only be performed following the restoration of the baseline HR. A metronome was set to beep at the required pace for each protocol to promote consistent results by ensuring that the same number of repetitions were performed at the same pace for each subject during each protocol. At the sound of each beep from the metronome, the subject would either have reached the proper depth at the end of the eccentric portion of the lift or would have returned to the full standing position at the end of the concentric portion of the lift.

Each of the four exercise protocols was performed over a four minute duration for each subject with rest intervals in between to reestablish baseline heart rates. The first protocol used a 20 kilogram load and performed each repetition with a four second count for both the eccentric and concentric portions of the lift for a total of 30 repetitions over the four minute period. The second exercise protocol incorporated a 15 kilogram load and performed each repetition with a three second count for both the eccentric and concentric portions of the lift for a total of 40 repetitions over the four minute duration. The third exercise protocol utilized a 10 kilogram load and performed each repetition with a two second count for both the eccentric and concentric portions of the lift for a total of 60 repetitions over the four minute duration. The final exercise protocol applied a 5 kilogram load and performed each repetition with both a one second eccentric and concentric portion of the lift for a total of 120 repetitions over the four minute duration. These particular loads and repetition rates were specifically designed to ensure that each protocol performed the same amount of work. The order of each of the four exercise protocols was randomized for each set of 3-4 subjects to ensure the results were not skewed as a result of fatigue.

Table 3. Resistance Training Protocols

Resistance Training Condition	5 kg	10 kg	15 kg	20 kg
Contraction Mode	c-e	c-e	c-e	c-e
Repetition Cadence (s)	1-1	2-2	3-3	4-4

*c = concentric phase, e = eccentric phase

The range of the loading involved was chosen to accommodate a wide range of participants and allowed them all to handle the weight with minimal to no assistance. Each subject would position the bar just under the spinous process of their C7 vertebrae. Once each set of subjects were situated and comfortable, the metronome would be set to the proper pacing for each repetition and begin to beep. The data recording began at the start of the second repetition in order to allow each subject a practice repetition to adjust to the pacing. All squats were performed in front of a mirror, allowing each subject to monitor their own consistency, and to a depth where the hips were roughly two inches above parallel with the knees. After each protocol was completed, the subjects would remove the loaded bar from their back and place it on the floor where the weights would be replaced with the proper loading for the next protocol. The data of interest recorded from each subject for each protocol was the minimum HR (MNHR), average HR (AHR), and maximum HR (MXHR) which were ultimately used to calculate the total PAEE for each condition which was also recorded.

Figure 1. Subjects performing the 10kg squat protocol

Statistical Analysis

Averages were calculated for each of the minimum, average, and maximum heart rates as well as the total caloric expenditure for each protocol. The data is represented as means ± standard deviations (SD). An ANOVA was performed to compare the means of each protocol in order to assess how statistically different they were from one another, specifically, the means of the minimum, average, and maximum HR as well as the total PAEE. Following the ANOVA, a Tukey post-hoc analysis was run between all conditions to assess how statistically different the means for each condition were from the other three conditions. Statistical significance was defined as $P \leq 0.05$ for this study.

Chapter 4 -Results

Mean PAEE demonstrated a trend of decreasing as the loading increased from 5kg to 20 kg with a 29.3% difference between the 5kg and 20gk condition values. The differences in mean HR for the minimum, average, and maximum measurements as well as the PAEE are displayed as a visual comparison in Figures 1-4 and are also listed in Table 4 represented as the means ± SD.

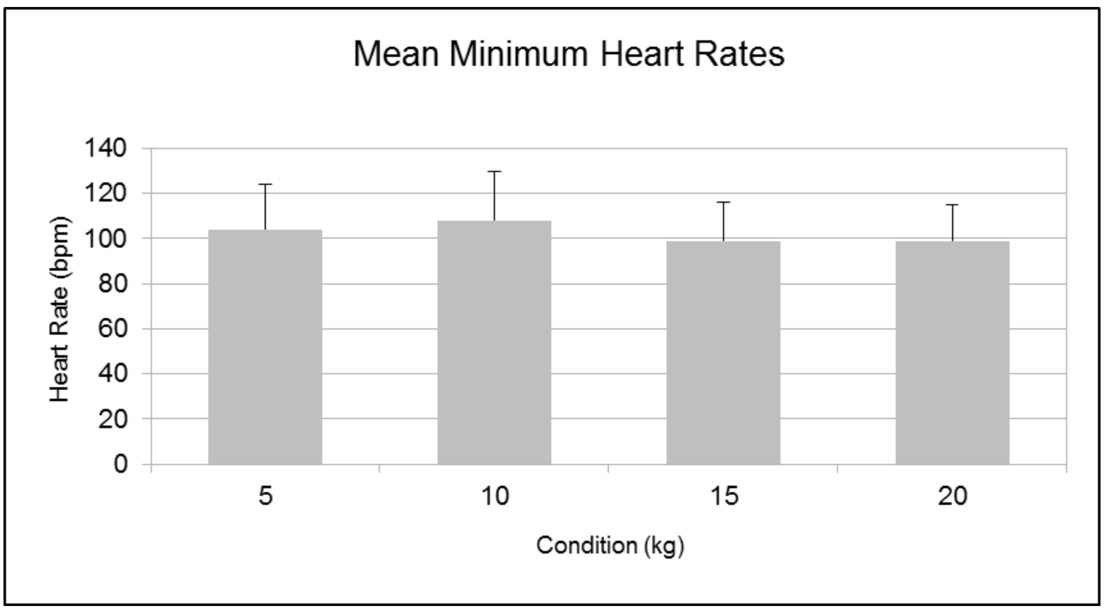

Figure 2. Mean MNHR (bpm) as a result of performing a four minute protocol for each of the four conditions ranging from low-load high-repetition fast contractions (5 kg) to high-load low-repetition slow contractions (20kg).

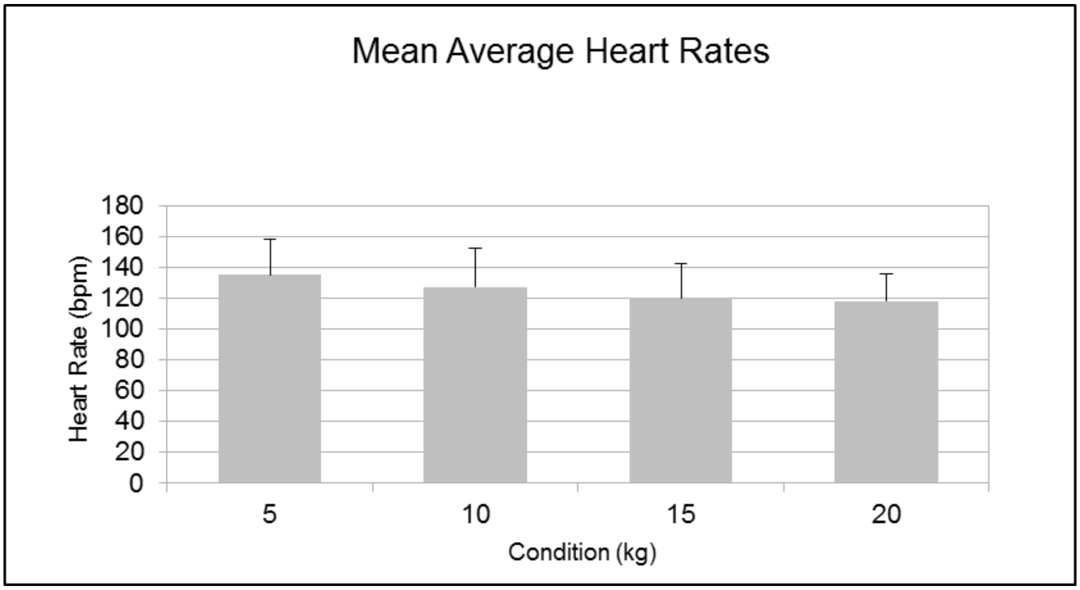

Figure 3. Mean AHR (bpm) as a result of performing a four minute protocol for each of the four conditions ranging from low-load high-repetition fast contractions (5 kg) to high-load low-repetition slow contractions (20kg).

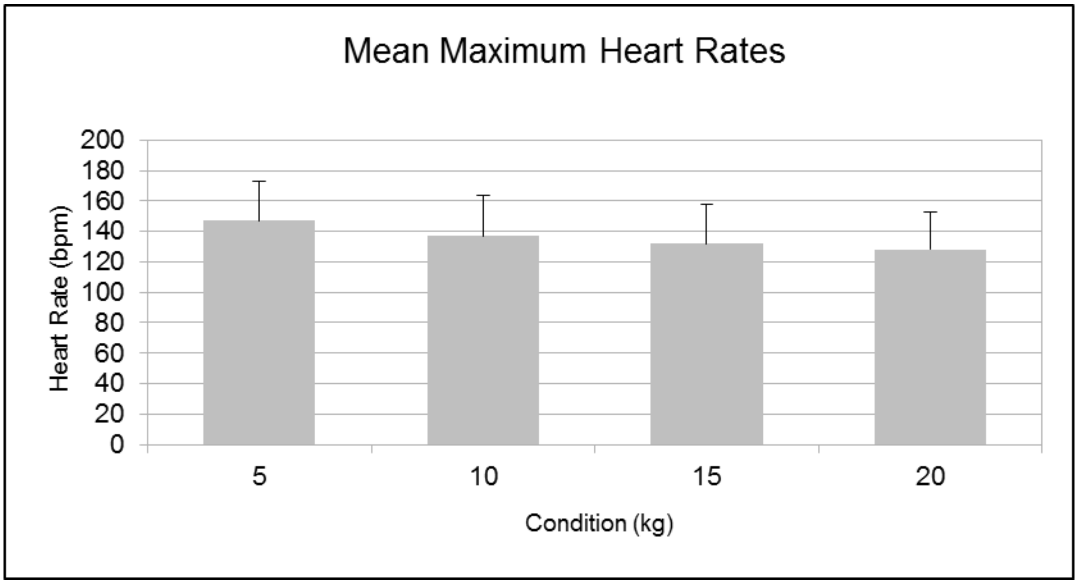

Figure 4. Mean MXHR (bpm) as a result of performing a four minute protocol for each of the four conditions ranging from low-load high-repetition fast contractions (5 kg) to high-load low-repetition slow contractions (20kg).

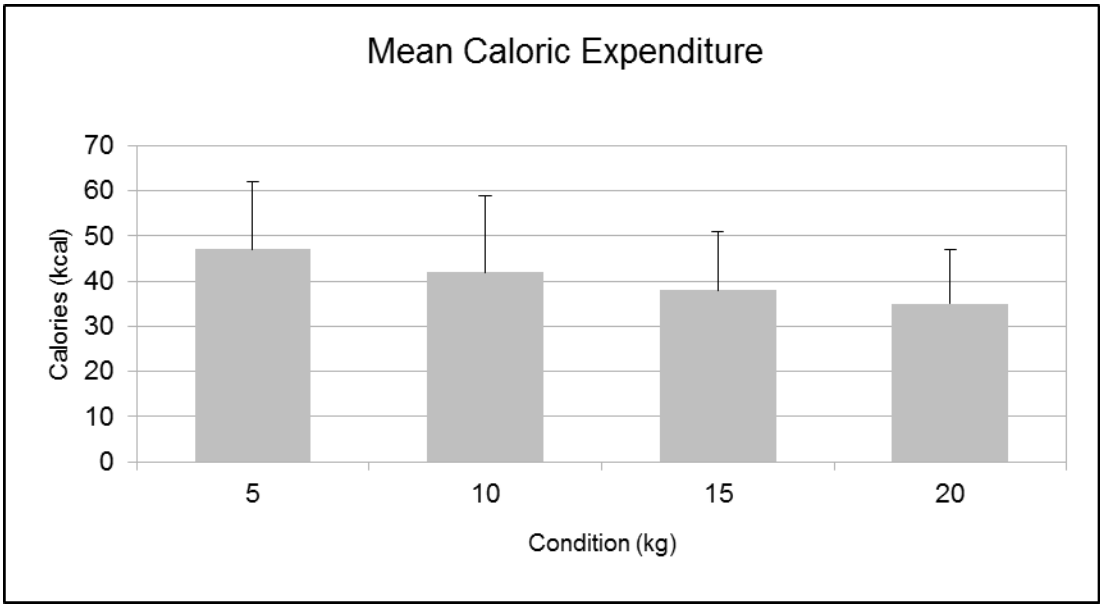

Figure 5. Mean PAEE as a result of performing a four minute protocol for each of the four conditions ranging from low-load high-repetition fast contractions (5 kg) to high-load low-repetition slow contractions (20kg).

All of the mean HR recordings exhibited a similar trend of decreasing as loading increased from 5kg to 20kg with the exception of the mean MNHR measurements in which case the largest value was associated with the 10kg load as opposed to the 5kg load. The mean values for MNHR indicated an 8.7% difference between the 10kg condition and the 20kg condition while the 5kg condition displayed a 4.9% difference. In regards to the AHR values, there proved to be a 13.4% difference between the 5kg and 20kg conditions while the MXHR values showed a 13.8% difference.

Table 4. Mean Values of HR and PAEE for all Conditions

Condition	Min HR	Ave HR	Max HR	kcal
5 kg	104 ± 20	135 ± 23	147 ± 26	47 ± 15
10 kg	108 ± 22	127 ± 25	137 ± 27	42 ± 17
15 kg	99 ± 17	120 ± 22	132 ± 26	38 ± 13
20 kg	99 ± 16	118 ± 18	128 ± 25	35 ± 12

Data are means ± SD.

The mean values in each category for each condition were compared to one another using a Tukey post-hoc analysis to determine their statistical differences ($P \leq 0.05$). The 5kg condition registered a significant difference in AHR ($P < 0.01$), MXHR ($P < 0.001$), and PAEE ($P < 0.01$) in comparison to the 10kg condition, but showed no significant difference in the MNHR category. Also, compared to the 15kg condition the 5kg condition registered a significant difference in AHR ($P < 0.01$), MXHR ($P < 0.001$), and PAEE ($P < 0.001$), but no significant difference in MNHR. Lastly, when considering the results of the 20kg condition the 5kg condition once again reported a significant differences in the AHR ($P < 0.001$), MXHR ($P < 0.001$), and PAEE ($P < 0.001$), but with no significant difference between MNHR values. The 10kg condition showed a significant difference in MNHR ($P < 0.01$), AHR ($P < 0.05$), MXHR ($P < 0.05$), and PAEE ($P < 0.05$) categories compared to that of the 15kg condition. The 10 kg condition also demonstrated a significant difference in the AHR ($P < 0.05$), MXHR ($P < 0.05$), and PAEE ($P < 0.05$) categories compared to that of the 20kg condition with no significant difference in the MNHR values. The final comparison between the 20kg condition and the 15kg condition revealed only a significant difference in the PAEE ($P < 0.05$).

Chapter 5 -Discussion

The results obtained from this study suggest that a resistance training program utilizing low to moderate loads with a high number of repetitions performed with more explosive rates of contraction will yield the highest PAEE. In almost every case, with the exception of the mean MNHR measurements, the values of the four data categories demonstrated a decreasing trend as the loading increased. As the load increased, the rate of contraction decreased. This relationship would suggest that the rate of contraction has greater influence over PAEE than loading. Despite the total amount of work performed being the same for each condition, which should theoretically yield the same PAEE, this was clearly not the case because the PAEE was measured to be significantly different for each condition compared to all others. We know this occurs due to the considerable number of variables that influence the PAEE during exercise.

First and foremost, if the total amount of work performed between separate training protocols is not the same, it will be the protocol that performs the most amount of work that will have the highest PAEE (Hunter, 2003; Scott, 2011). This is due to the positive correlation relationship between work and EE. Secondly, it is the muscle-endurance type exercise protocols, 40-60% 1RM, that will have significantly higher EE contributions from the different energy systems to include both anaerobic EE, and possibly even aerobic EE compared to that of muscle-strength, 70+% 1RM, oriented protocols. This is largely due to the first condition in which a muscle-endurance protocol allows for more work to be performed through the use of a lighter load at a higher volume compared to that of a heavier load at a lower volume. However, when comparing the EE contribution from the physiological recovery mechanisms that take place following both muscle-endurance and muscle-strength oriented protocols, there doesn't seem to be much of a difference at all. In other words, the amount of recovery EE following a bout of exercise appears to be very much independent of any contributions from aerobic EE, anaerobic EE, and even the total amount of work. Given these consequences, the first place to start when planning an RT program geared towards weight management would be to include muscle-endurance type exercises due to their capacity to allow for large amounts of work to be performed and result in a PAEE with larger contributions from both aerobic and anaerobic energy systems (Scott, 2011).

Beyond utilizing muscle-endurance type exercises to address weight management through maximizing PAEE, the system by which they are administered my also play an important role. The results of a study performed by Clark et al. (2010) suggests that the use of a mixed-interval endurance training protocol will elicit the greatest benefit to weight management compared to that of circuit resistance training (incorporating endurance type exercises) and traditional endurance training protocols. The circuit resistance training protocol proved to have a nearly identical rate of caloric expenditure, however the mixed-interval method allowed subjects to train within their target HR range for a longer period of time admitting a greater training effect. It should also be acknowledged that these results strictly refer to the acute physiological responses and therefore do not express any absolute claim to the outcome of chronic adherence to the specific exercise regimens (Clark, 2010).

The influence of RME on PAEE is not likely to have changed very much between each condition of this study. Squat depth most significantly affects the muscular effort of the knee extensors while the barbell load has more influence over the ankle plantar flexors. Both depth and loading play a role in the hip extensor RME. Since squat depth remained constant between conditions, the knee extensor RME would have also been relatively constant and to a slightly lesser degree the hip extensors as well (Bryanton, 2012). The only varying RME, and therefore PAEE, would come from the ankle plantar flexors and possibly a small amount from the hip extensors as the loading increased. With larger muscles expending larger quantities of energy to perform movements, the role of the hip and knee extensors on influencing PAEE is much larger than the ankle plantar flexors. Since the RME of these muscle groups remain relatively constant across conditions, the contribution to the PAEE from RME for each protocol will also remain relatively constant.

In addition to load-volume influencing the total amount of work being performed and therefore playing a role in the PAEE, repetition cadence will also require consideration for the same purpose. Without standardizing the total amount of work to be performed across all protocols, including range of motion, it will be the fasted repetition speed that will ultimately accumulate the highest total mass lifted and therefore performing the most work (Buitrago, 2012). In theory by slowing the repetition speed the time under tension for the muscles involved is prolonged therefore increasing muscular effort and possibly EE (Westcott, 2001). This would be especially true for the concentric portion of the lift because it is this portion that is the most costly. However, this has been proven not to be the case most likely for the previously mentioned factor of total work performance. On top of that, faster repetition performance is unavoidably coupled with alternative muscle fiber recruitment (Mazzettie, 2007).

The basis for the higher rates of energy expenditure from the faster contractions, despite lighter loading, is likely due to the reliance on faster muscle fiber activation (Ferguson, 2001; Mazzetti, 2007). These muscle fibers compared to smaller slower muscle fibers have been known to be extremely energy inefficient upon activation (He, 2000; Mazzetti, 2007). The faster contraction rates are likely to invoke a higher ratio of fast to slow muscle fiber activation resulting in the disproportionate energy expenditure even under the same loading compared to slow contractions. The reason these faster contraction rates recruit a larger portion of the energy inefficient fast muscle fibers is because they are capable of involving higher threshold motor units (Behm, 1993; Grimbly, 1977; Mazzetti, 2007). On top of that, the higher the threshold of activation that is required of these motor units, the more fibers they innervate further perpetuating the inefficiency of energy required to perform the movement (Mazzetti, 2007; Schiaffino, 1970).

The TEE of a RT program, even at high intensities, is easily dwarfed when compared to that of a prolonged aerobic activity combine with caloric restrictions. However, RT is known to be responsible for evoking the physiological phenomenon of EPOC which is capable of remaining above resting levels for up to 48 hours. During this time period numerous energy-requiring processes are taking place in order to restore homeostatic conditions. Examples of physiological factors being address and corrected by these energy-requiring processes include heart rate, ventilation rate, body temperature, oxygen levels in the blood and muscles, adenosine triphosphate and creatine phosphate replenishment, glycogen re-synthesis, protein synthesis, and more (Abboud, 2013).

Since the degree to which EPOC is elevated above resting levels depends on how far these physiological factors deviate from normal, trained individuals will be expected to experience less of an effect from EPOC as opposed to untrained individuals (Hackney, 2008). Considering that all of the participating subjects had a two year minimum of weightlifting experience and participated in weekly exercise routines that included squats, caloric expenditure due to EPOC was assumed to be negligible (Abboud, 2013) (Hackney, 2008). This is due to the training adaptations experienced by fitness trained individuals that result in a down-regulation of acute energetically costly responses to RT (Abboud, 2013; Webber, 1993).

Many studies have focused on exercise intensity as the determining factor of PAEE. Though, intensity can be defined and altered by several methods such as loading (Hooper, 2013; Naclerio, 2011; Westscott, 2001), number of repetitions (Hooper, 2013; Naclerio, 2011), speed of contractions (Hooper, 2013; Hunter, 2003; Mazzetti, 2007; Westcott, 2001), rest intervals (Romero-Arenas, 2013), and repetition cadence (Villagra, 1993; Westcott, 2001). More specifically, exercise intensity could be increased either by increasing the loading (%1RM) or number of repetitions, using faster contraction speeds, reducing rest intervals, increasing the eccentric and isometric contraction phase durations of each repetition while shortening the concentric contraction phase, or any combination of these.

The number of repetitions to achieve muscular failure at 7 ranges of %1RM was established during a study performed by Naclerio (2011). These %1RM ranges consisted of 30-40%, >40-50%, >50-60%, >60-70%, >70-80%, >80-90%, and >90%. The corresponding number of repetitions performed for each range were 46.0 ± 7.4, 34.4 ± 5.9, 26.0 ± 4.2, 18.0 ± 4.2, 13.0 ± 2.6, 7.8 ± 2.1, and 4.7 ± 0.9 respectively. During this study subjects who had 2-5 years of recreational resistance training performed a bench press exercise applying maximal force to reach maximal velocity and power during the concentric phase of the lift (Naclerio, 2011). Given these results, one can better gauge the intensity of an exercise protocol based on how many repetitions are performed at a particular %1RM.

A study conducted by Hooper et al. had subjects perform a resistance training protocol to fatigue while sampling blood lactate and measuring ratings of perceived exertion using the CR-10 scale. All subjects involved had at least 6 months of RT experience and were familiar with the exercises involved. The protocol consisted of a back squat, bench press, and deadlift exercise performed for 10 repetitions at 75%-1RM. The number of repetition performed was reduced by 1 each set until only 1 repetition remained allowing for a potential total of 165 repetitions. The protocol elicited a mean blood lactate value of 14.21 ± 2.19 $mmol \cdot L^{-1}$ and an average rating of perceived exertion level of about a 7.5. Each repetition for the protocol was performed as fast as possible likely playing a crucial role in the results that were yielded given the relationship of contraction speed to EE in addition to the high number of repetitions and loading (Hooper, 2013).

Hunter et al. (2003) performed a study to compare the energy expenditure of two different resistance training protocols consisting of a super slow training (SST) protocol and a traditional training protocol (TT). The exercises selected to be performed in order for both protocols were leg extension, bench press, biceps curl, leg curl, french curl, bent row, reverse curl, military press, upright row, and squat. In the SST protocol one set of 8 repetitions at 25% 1RM for each exercise was performed with a 10 second concentric phase and a 5 second eccentric phase. The TT protocol required two sets of 8 repetitions for each exercise. Each set was paced to 30 seconds with 60 seconds of rest between sets. Both the concentric and eccentric portions of each repetition for each exercise were approximately 1 second in duration. The results of the study showed the TT protocol to have expended 48% more energy which can be attributed to a multitude of factors. Not only was the total amount of work higher for the TT protocol, but it utilized a heavier load being lifted at a faster rate of contraction. This suggests that any number of these differences between protocols may have some degree of influence over the intensity, and as a result the PAEE as well (Hunter, 2003).

Given the parameters of this study, the results are very much in support of high repetitions of fast contraction rates to maximize intensity relative to PAEE. They are less conclusive in terms of rest intervals due to the fact that only one set of each condition was completed and the rest between conditions was based on the heart rate recovery of each subject as opposed to a set interval. There is also little insight on the effects of repetitions cadence in the sense that the isometric portions were always only for a short pause while the eccentric and concentric portions were always equal to one another. Increasing the loading by itself will in fact increase the intensity given that it will require noticeably more effort to perform the same number of repetitions as a lighter load. In the case that the increase in loading is proportional to the decrease in the number of repetitions performed, the intensity will in fact be significantly less in terms of the total PAEE as proven by the result of this study where it was the lightest loading that resulted in the greatest PAEE.

In summary, although the results of this study reflect the findings of previous research, it arrived at this conclusion using a more direct strategy by eliminating more variables which may have ultimately pinpointed the largest contributing variable to PAEE. Aside from the same amount of work being performed for each condition, it was performed in the same amount of time, using the same workloads for each subject. Despite the workloads not being individualized through the use of 1RM percentages, the quickest contraction speeds still yielded the highest PAEE for each subject. For these reasons, the mode for maximizing PAEE through the use of a high volume of explosive repetitions has received further support and confirmation.

Practical Applications

The results of this study in light of similar previous studies suggest that the top three considerations when designing a weight management oriented RT program may be argued to be the total accumulated mass lifted, the load used to maximize that total, and the rate of contraction for each repetition. Specifically, maximizing the total accumulated mass lifted through the use of a low to moderate load with a high number of repetitions while utilizing maximal rates of contraction. Integrating these features into a mixed-interval endurance training program may possibly result in an even higher efficiency of PAEE along with the potential for additional training effects. By incorporating the most appropriate factors to reach the designated exercise goals, participants will see quicker results through higher efficiencies and be more likely to adhere to their programs.

This is critical to all professions concerning public health including physicians, physical therapists, fitness instructors and more and is the key to remedying the obesity epidemic that plagues such a considerable portion of not only the United States but the global population as well. A weight management program utilizing this information would likely prescribe a mixed interval style muscle-endurance RT program (40-60% 1RM depending on experience level) with concentric and eccentric contractions performed as fast as possible ($\leq$ 1 second). The exercise duration would be based on the individual's VO_2max and increase as exercise adaptations begin to occur. Total accumulated mass lifted will be maximized and dictated by prescribing the optimal combination of loading and exercise durations.

Limitations

In spite of the relatively clear cut results gathered from this study, it did have its share of limitations. One of which would arise from the lack of ability to strictly regulate the ROM during each repetition, depth in particular. Squat depth was monitored by simple observation thus the amount of error as a result of this is sensitive to the perspective of the subjects themselves as well as the study supervisors. Furthermore, the precision to which each subject was able to follow the rhythm of the metronome for each protocol was also subject to a certain degree of error. For this reason, the contraction speed demonstrated between each subject for each protocol is susceptible to the same degree of error.

Future Studies

Careful thought was invested into developing a study that will yield clean results with minimal complications; however, additional measures could have been taken to yield additional feedback. First, albeit contraction speed appears to have proven time and time again to be the primary contributor to PAEE during RT, including this study, however it may be supplemented by utilizing an optimal percentage of the individual’s 1RM. Supplemental study to find this optimal percentage or range of percentages of 1RM may yield even greater potential for PAEE. Other measurements that could be added to the procedure would be that of oxygen consumption and blood lactate concentrations for a better understanding of how both the aerobic and anaerobic energy systems contribute to the total PAEE.

Additionally, even though the fastest contraction condition may have yielded the highest PAEE, its potential impact during practical application is limited by individual adherence to exercise programs. For this reason, it would be beneficial to take note of the subjects' rating of perceived exertion both during and after each exercise condition. The results of previous studies have shown that exercise intensities above an individual's ventilatory threshold demonstrated less positive responses (Kilpatrick, 2007). Muscle activity levels have also been known to be influenced by their force generation capabilities. For this reason the addition of EMG recording for the primary muscle groups involved may provide further insight from the results (Fujita, 2011). Since force generation can be altered by the load, the contraction rate, or both, the EMG recordings should provide both quantitative and qualitative information about which of the two factors, or combination of them, provokes the most muscle activity.

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