Comparison of Concentric and Eccentric Bench Press

by

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ABSTRACT

Eccentric muscle action (ECC) occurs when the force exerted by a working muscle is less than that of an outside resistance. This is characterized by muscle lengthening, despite actin-myosin crossbridge formation. Research has indicated that muscles acting eccentrically are capable of producing more force when compared to muscles acting concentrically. Further, research has shown ECC muscle actions may have different fatigue patterns that CON actions. The purpose of this study was to determine if a) ECC bench press yields greater strength than concentric (CON) as measured by one-repetition maximum (1RM), b) there is a difference between the number of repetitions that can be completed concentrically and eccentrically under the same relative intensities of 1RM (90%, 80%, 70%, 60%), c) a prediction model may be able to predict ECC 1RM from CON 1RM or CON repetitions to fatigue. For this study, 30 healthy males (age = 24.63 $\pm$ 5.6 years) were tested for 1RM in CON and ECC bench press, as well as the number of repetitions they were able to complete at various intensities of mode-specific 1RM. A mechanical hoist was affixed to a gantry crane and placed over a standard weightlifting bench. The hoist was connected to 45lb plates that were loaded on a standard barbell, which allowed for mechanical raising and lowering of the barbell. For CON repetitions, the weight was mechanically lowered to the chest and the participant pressed it up. For ECC repetitions, the weight was mechanically raised and the participant lowered it. Paired t-tests showed that ECC 1RM was significantly ($p < 0.05$) greater than CON 1RM (ECC =255.17 + 68.37lbs, CON = 205.83 + 58.43lbs). There was a significant difference ($p < 0.05$) between the number of repetitions completed at 90% 1RM (CON = 4.57 $\pm$ 2.21 repetitions, ECC = 7.67 $\pm$ 3.24 repetitions).

There were no differences in repetitions completed at any other intensity 1RM. CON 1RM and the number of repetitions completed with two different absolute loads (130-150lbs and 155-175lbs) concentrically and eccentrically were valid predictors of ECC 1RM. These data indicate that ECC actions yield increased force capabilities than CON actions, there is no difference in the rate of the fatigue, and ECC 1RM may be predicted from various CON tests.

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Chapter 1

INTRODUCTION

Eccentric muscle action (ECC) occurs when the force exerted by a working muscle is less than that of an outside resistance. This is characterized by muscle lengthening, despite actin-myosin crossbridge formation. Thus, the separation of myosin from actin is mechanical rather than chemical (Flitney & Hurst, 1978). This is in contrast to concentric muscle actions (CON), during which the muscle shortens as actin filaments are pulled over myosin filaments. During CON contractions, crossbridges are separated through the cleaving of an ATP molecule, hence a chemical reaction and more energy dependent process that results in less muscular damage. ECC action, when utilized during resistance training, has been shown effective in eliciting more efficient neural activation than CON (Hortobagyi, 2001; Enoka, 1996), strength adaptation (Vikne, 2006; Hortobagyi, 1996), and muscular hypertrophy (Vikne, 2006; Hather, 1991). Enoka (1996) further suggests that muscles are less prone to fatigue when acting eccentrically. Emphasizing ECC muscle actions during training has been shown to be more effective in eliciting increases in muscular strength than traditional ECC/CON actions and CON muscle actions alone (Brandenburg and Docherty, 2002). Based on the emergence of research which supports the utilization of ECC muscle actions for a variety of outcomes, programs which emphasize ECC actions through resistance training methods have become increasingly popular.

As evidence of the effectiveness of ECC training emerges, it is important to ensure that the basic scientific principles of traditional training are applied. A training program which utilizes a prescribed number of sets and repetitions with a specified

intensity remains the most effective way to maximize the benefits of resistance training and improve the likelihood that the desired adaptations will occur. This is generally carried out by measuring or predicting an individual's 1-repetition maximum (1RM) in a particular exercise and using that value to determine submaximal intensities to be used during training.

A number of tables have appeared in the literature (Baechle and Earle, 2000; Chapman, 1998; Landers, 1985; Epley, 1985) which may be useful for estimating 1RM based on the number of repetitions an individual is able to complete with a given weight or for estimating the number of repetitions an individual should be able to achieve given his/her 1RM and the percentage of that 1RM he/she is lifting. These tables are designed via prediction equations which extrapolate norms from data which have been collected in a research study or a series of studies. Tables which suggest weights and repetitions per different percentages of 1RM provide information useful in program design, minimization of injury potential, and creating a time-efficient reference tool for use in the manipulation of training variables such as volume and intensity. In this context volume may be defined as the total amount of weight lifted during a given exercise which is a function of the weight of the load and the number of times the load is lifted. Intensity may be defined as the percentage of 1RM.

To date, each of these tables which predict repetition and weight values for a general population is designed for use with traditional muscle actions which consists of an ECC action immediately followed by a CON action. In these ECC/CON movements, the limiting factor in whether the repetition is successful or not is nearly always the CON portion. This is attributed to the fact that ECC force capabilities are 120%-150% of CON

force capabilities. No known literature exists which describes a prediction equation for ECC-only muscle actions, and as previous research suggests, muscle performing ECC actions may respond differently than muscles acting concentrically (Brandenburg and Docherty, 2002; Hortobagyi, 2001; Enoka, 1996). Because of logistical difficulties, ECC 1RM testing is not a common practice. Further, because resistance training programs traditionally do not emphasize or overload the ECC portion of movements, this is a novel training principle for most. Therefore, ECC 1RM testing may prove logistically difficult and lead to greater injury potential in normal gym settings. Devising a method for predicting ECC 1RM would be important and useful for the strength and conditioning or personal training practitioner.

As literature emerges demonstrating the effectiveness of training programs employing ECC-emphasized exercise, it is important to have tools which may be utilized in simplifying the implementation of such programs. It remains to be explored whether CON and ECC muscle actions react similarly in terms of repetitions to fatigue at the same relative intensity. A comparison of repetitions completed at each intensity between CON and ECC actions and a prediction equation to determine ECC 1RM will provide useful tools for quickly estimating the intensity of an exercise, estimating 1RM from submaximal lifts, and for manipulating the volume of a training routine.

Objectives

The primary aim of the current study is to determine whether there is a correlation between CON 1RM values and ECC 1RM values. The secondary aim of the study is to examine whether there are differences in the number of repetitions completed at each percentage of 1RM between CON and ECC bench press. The tertiary aim of the study is

to develop a prediction equation for estimating ECC 1RM from CON 1RM values. The study aims were explored through testing 1RM as well as number of repetitions completed at a series of percentages of mode-specific 1RM (60, 70, 80, 90%) for CON and ECC actions in the traditional bench press exercise.

Hypotheses

Previous literature has suggested that eccentric strength is up to 120% greater than concentric strength (Hortobagyi and Katch, 1990). Currently, no known studies have been published to assess how the repetitions to fatigue at various relative intensities (%1RM) differ between ECC and CON lifts. Based on aforementioned evidence, the following was hypothesized for this study:

H1:

The 1RM values for the ECC bench press will be statistically greater than those attained in the CON bench press.

H2:

There will be no significant differences in the number of repetitions completed at each percentage of 1RM between the different muscle actions.

H3:

There will be a significant correlation between CON 1RM and ECC 1RM, therefore a prediction equation will sufficiently predict ECC 1RM from CON values.

Operational Definitions

For the purposes of this study:

- Concentric (CON) repetition is defined as pressing the barbell from the chest (or very near the chest) to complete extension of the elbows from the supine position.
- Eccentric (ECC) repetition is defined as constant steady lowering of the barbell to the chest over a three-second duration from the supine position.
- 1repetition maximum (1RM) is defined as the maximum amount of weight with which a participant is able to successfully complete one repetition.

Delimitations

This study is delimited to male participants between the ages of 18-30 that have at least one year of resistance training experience and are otherwise metabolically healthy. There are no weight requirements for this study. Participants will be excluded from this study if they have no previous experience with resistance training or have musculoskeletal injury that limits or prevents them participating in all study activities. Current dietary intake will not be considered for participant selection but will be required to remain consistent throughout the entirety of the study. Once enrolled in the study participants will not be permitted to participate in any form of upper body resistance training outside of the protocol required for the study.

Assumptions

It is assumed that the participants will comply with the testing protocol outside of the lab. Following proper calibration protocols, the safety, proper use, and accuracy of all testing instruments is assumed. Honesty is assumed on the part of the participant to uphold the integrity of the study instructions to:

- Abstain from exercise greater than what is needed for performing activities of daily living (ADL) during the period of testing.
- Refrain from making any alterations to their normal diet during the testing period including nutritional or ergogenic supplements.

Limitations

The number of subjects in our study will be small but sufficient to reach statistical power for the primary measures of CON and ECC strength. All participants will be healthy college-age males, and it is not known whether the present testing protocol will give similar results in other populations such as women or subjects with chronic disease or conditions.

Chapter 2

REVIEW OF LITERATURE

Resistance training, as defined as movement against an external load that results in physiological adaptation, has been demonstrated to have a number of health related benefits in human beings. While the majority of adaptations reported in the literature resulting from resistance training pertain to the musculoskeletal system, there has been an emergence of literature focusing on additional benefits such as all-cause mortality (Metter, Talbot, Schrager, Conwit, 2002), metabolic disease (Jurca, Lamonte, Barlow, Kampert, Church, Blair, 2005; Ibanez et al., 2005; Marcus et al., 2008), bone health (Cussler et al., 2003; Morris, 1997), mobility (Janssen, Heymsfield, and Ross, 2002; Fiatarone et al, 1994), and quality of life (Levinger, 2007). Further, resistance training may provide a modality of exercise for individuals for whom more common cardiovascular-emphasized programs such as walking/jogging, cycling, or swimming may be difficult or contraindicated. Based on these findings, resistance training has emerged as a viable, if not imperative, component of a regular exercise regimen.

Though there are numerous methods and modalities for providing resistance, traditional resistance training exercises involve moving a load in opposing directions (ie: raise/lower), where the muscle shortens and subsequently lengthens or vice-versa. The phase of the exercise in which the muscle shortens is referred to as the concentric (CON) phase, and the phase in which the muscle lengthens is the eccentric (ECC) phase. Proske and Morgan (2001) describes (CON) contractions as the actions that initiate movement, whereas ECC actions slow or stop movement. Though force is produced through both

types of muscle action, there are very distinct characteristics which make CON and ECC muscle actions unique and worthy of studying independently.

ECC muscle action occurs when the force exerted by a working muscle is less than that of an outside resistance. This is characterized by muscle lengthening, despite actin-myosin crossbridge formation (Figure 1). Thus, the separation of actin from myosin is mechanical rather than chemical as shown in Figure 2 (Flitney and Hirst, 1978; Enoka, 1996). ECC action, when utilized during resistance training, has been shown effective in eliciting more efficient neural activation than CON contractions (Hortobagyi, Devita, Money, Barrier, 2001; Enoka, 1996), greater strength adaptation (Vikne, Refsnes, Ekmark, Medbo, Gundersen, Gundersen, 2006; Hortobagyi, Hill, Houmard, Fraser, Lambert, Israel, 1996), and greater muscular hypertrophy (Vikne et al, 2006; Hather, 1991). Other research (Enoka, 1996; Binder-Macleod and Lee, 1996; Tesch, Dudley, Duvoisin, Hather, Harris, 1990) suggests that muscles are less prone to fatigue when acting eccentrically. Emphasizing ECC muscle actions during training has been shown to be more effective at eliciting strength gains than traditional ECC/CON actions and CON muscle actions alone (Brandenburg and Docherty, 2002). Based on the emergence of research which supports the utilization of ECC muscle actions for a variety of outcomes, programs which emphasize ECC actions through resistance training methods have become increasingly popular.

Physiology of Muscular Activation

Concentric

CON muscle action is characterized by the muscle fibers generating sufficient force to overcome an external load and shortening in length. This shortening is attributed

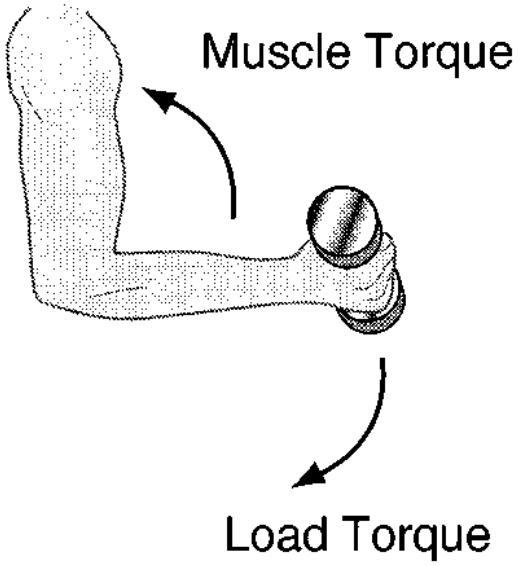


Figure 1. Muscle force versus Load Relationship. When the force exerted by the muscle is greater than that of the resistance force, concentric muscle action results. When the force exerted by the muscle is equal to that of the resistance force, isometric muscle action results. When the force exerted by the muscle is less than that of the resistance force, eccentric muscle action results (adapted from Enoka, 1996).

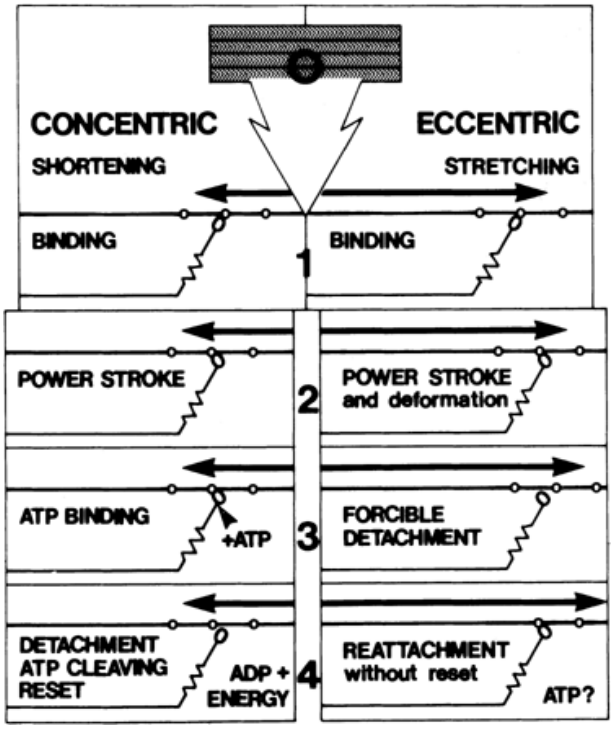


Figure 2. Myofilament activity during concentric and eccentric action. In the left column, concentric muscle action requires ATP for the detachment of the myosin head from the actin filament. In the right column, the separation of the myosin head from the actin filament comes as result of forcible detachment during eccentric muscle action.

to the sliding-filament theory, which refers to the protein filaments actin and myosin within a muscle sliding over one another (Baechle and Earl, 2000; Huxley and Hanson, 1954) (Figure 3). During this process, calcium is released from the sarcoplasmic reticulum into the myofibril and binds with troponin. This triggers a movement in the tropomyosin which is situated along the actin filament, which in turn allows for the myosin cross-bridge head to bind to actin. The hydrolysisof ATP provides energy for the myosin head to flex, pulling the actin filament over the myosin filament and shortening the length of the sarcomere. Another molecule of ATP is required for the chemical detachment of the myosin head from the actin filament and for it to re-cock in preparation for the next attachment and flexion. This process is repeated continually throughout the muscular contraction as long as calcium and ATP are present. As the actin are "ratcheted" over the myosin, force is developed and the muscle shortens. Because of the cyclical nature of this process, more rapid movements result in diminished force capabilities. Billeter and Hoppeler (1992) attribute this to fewer crossbridge formations at a given time during higher velocity contractions. Therefore, there is an inverse relationship between force production capability and the velocity of contraction during concentric muscle actions. This is not the case with eccentric actions. In fact, during lengthening actions force increases as velocity increases. These force-velocity relationships are shown in Figure 4.

Eccentric

ECC muscle action occurs when an external load overcomes the force produced by an active muscle and the muscle is forcibly lengthened. This process and the resulting physiological responses are very different from those of CON muscle contractions. The

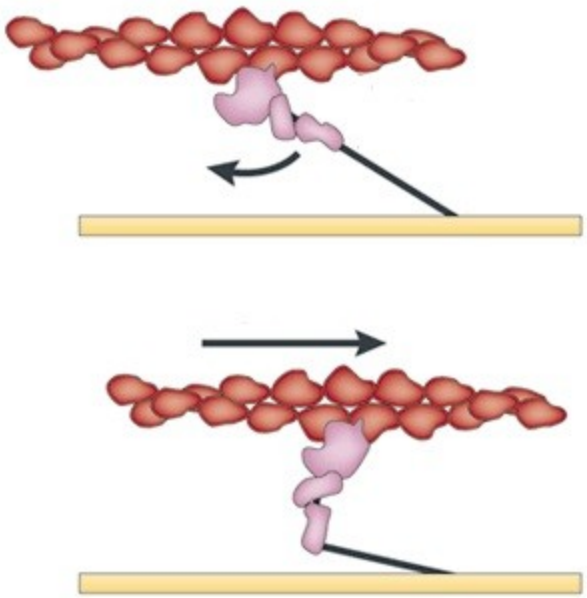


Figure 3. Representation of the filament action during the Sliding Filament Theory. This image depicts the attachment of the myosin head to the actin filament. Upon attachment the myosin head ratchets allowing the actin filament to slide over the myosin, resulting in a shortening of the sarcomere (concentric contraction) (adapted from Spudich, 2001).

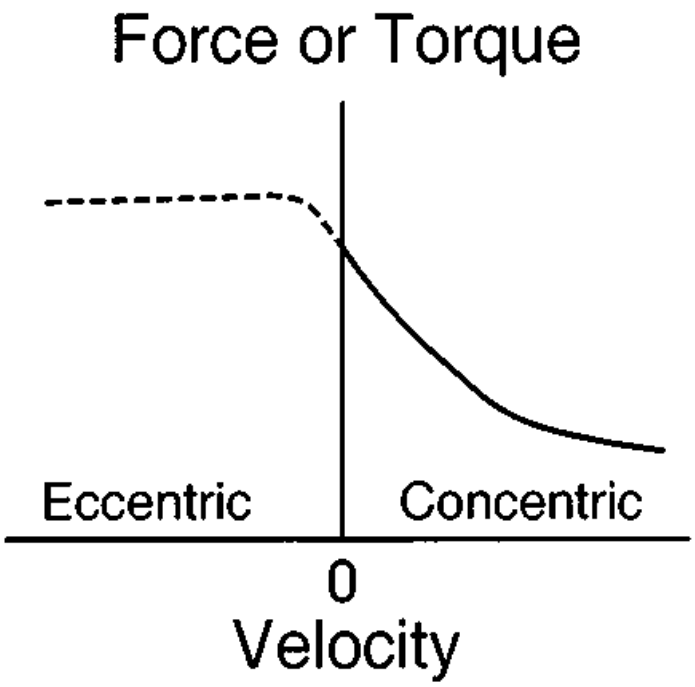


Figure 4. Force velocity curve for CON and ECC muscle actions. During ECC muscle action, force remains relatively unaffected by velocity. Whereas during CON muscle action, as velocity increases force capabilities decrease (Enoka, 1996).

process by which ECC muscle actions occur also creates greater damage to the structures of the muscle which, in turn, leads to increased pain as well as adaptation (Friden and Lieber, 2001).

According to the sliding filament theory (Huxley and Hanson, 1954), during a CON muscle action, actin and myosin filaments are bonded to create muscle contraction and this bond is released by ATP. During an ECC muscle action, however, this bond is broken through mechanical, rather than chemical, means (Flitney and Hirst, 1978). Whereas the CON muscle action calls for ATP to bind to the myosin head, triggering its release from the actin filament and subsequent re-cocking, it is proposed that during ECC action the myosin head is essentially torn from the actin. The mechanical disruption leads to damage to the excitation-coupling processes and may be one of the major mechanisms behind the differing characteristics associated with ECC actions (ie: force capabilities, force-velocity curve, fatigue, neural patterns) when compared to CON actions, as well as the divergent adaptations seen as a result of CON and ECC training.

Physiological Comparison Between CON and ECC Muscle Action

Research has examined metabolic and physiological effects of resistance training with CON muscle actions compared with ECC muscle actions. Hollander et al. (2008) conducted a study with the purpose of determining whether muscle contraction type (CON or ECC) or loading (absolute or relative) has greater impact on the perceptual and metabolic responses to resistance training. Seven resistance-trained men (age = 25.71 $\pm$ 2.17 year) volunteered for the study. Subjects were tested for CON one-repetition maximum (1RM) in six exercises: lat pull-down (LTP), leg press (LP), bench press (BP), leg extension (LE), military press (MP), and leg curl (LC). ECC 1RMs were estimated as

20% greater than CON 1RM for each exercise. Following 1RM testing, subjects completed 2 testing sessions in random order: a CON-only session and an ECC-only session. For each session, participants were assessed prior to exercise and after each set for rating of perceived exertion (OMNI-Res), rating of pain (CR-10), and heart rate (HR). Venous blood samples were taken prior to exercise, immediately after the session, and 15 minutes after the exercise session and analyzed for lactate, adrenocorticotropic hormone (ACTH), and cortisol. Two (trial) by 24 (time point) repeated-measures ANOVA was used to analyze variables collected after each set of exercise. Two by three repeated measures ANOVA was used to analyze blood markers. There were no differences between CON and ECC trials for RPE and CR-10. HR was significantly ($p<0.05$) higher following every exercise except LTP in the CON as compared to the ECC protocol. Lactate levels were significantly higher immediately and 15 minutes following CON training than ECC training at the same time points. Neither ACTH nor cortisol levels changed over time in either trial. The results of this study indicated that at fairly light intensities, CON and ECC training bouts elicited similar RPE and pain perceptions under a similar relative load (%ECC 1RM = %CON 1RM + 20%). This suggests that overloading the ECC phase with 20% above that of CON load results in a comparable perceptual experience. What may be important to note, however, is that heart rate remained lower in all but one exercise following ECC exercise as compared to CON exercise despite a 20% greater load. This holds potentially important clinical value, as this may indicate ECC exercise is a safer or potentially more effective modality than CON exercise for certain populations.

Durand et al. (2003) described hormonal responses resulting from CON and ECC muscle actions. For this study, 10 healthy, recreationally trained men (24.7 $\pm$ 1.2 years) completed two trials consisting of only CON or ECC muscle actions at the same absolute workload. Participants completed four sets of 12 repetitions at 80% 1RM with 90 seconds of rest between sets in the bench press, leg extension, military press, and leg curl exercises. Blood samples were taken immediately prior to exercise, as well as immediately and 15 minutes following exercise and analyzed for lactate, growth hormone (GH), testosterone (T), and free testosterone (FT). Hormonal concentrations were analyzed through separate two x three (trial x time) repeated measures ANOVAs. Both conditions (muscle action) produced significant ($p<0.05$) increases in lactate immediately post exercise as compared with baseline measures, with CON producing greater increases immediately post exercise and 15 minutes post exercise than ECC. The same trend was evident for GH. Testosterone and FT were both increased significantly immediately following both protocols with no differences between training modality. This study demonstrated that at the same absolute workload, GH response and lactate response were greater for CON muscle actions. This may be attributed to the fact that, in general, the relative workload at a given absolute weight would be lower for the ECC action, therefore eliciting a lesser hormonal response. Interestingly though, T and FT levels were not different between groups. The authors concluded that these hormones were not reactive to the additional stress under the CON condition. This leaves one to speculate what may happen if the relative intensity of the loads were equated between muscle actions and provides groundwork for future research.

In fact, a group of researchers (Kraemer et al., 2006) sought to explore hormonal responses to CON and ECC muscle actions under the same relative load with a similar research design to that of Durand (2003). Seven young (25.71 $\pm$ 2.17 years), healthy men with recreational weightlifting experience volunteered for the study. Participants completed two trials, one under CON conditions one under ECC conditions, with the same exercises, number of repetitions, and number of sets (four sets of 10 repetitions of lat pull-down, bench press, leg press, leg extension, military press, and leg curl with 90 seconds of rest between sets). One-repetition maximum was directly measured for CON action in each exercise and ECC 1RM was calculated at 120% CON 1RM based on previous literature (Bamman, 2001). Intensity for each exercise was 65% of measured (CON) or calculated (ECC) 1RM. Blood samples were taken immediately prior to exercise, as well as immediately and 15 minutes following exercise and were analyzed for lactate, hemoglobin, hematocrit, GH, T, and FT. Hormonal responses were measured through separate two x three (trial x time) repeated measures ANOVAs. Lactate rose significantly ($p<0.05$) in both trials, with CON (578% increase) resulting in significantly greater increases than ECC (324% increase) both immediately following and 15 minutes following exercise (see Figure 5). GH levels were significantly higher immediately following exercise under both conditions (CON = 567%, ECC = 824%), but there was not a statistical difference between trials. This trend was similar for FT. Total testosterone was not elevated as a result of either intervention. These data imply that under the same relative load, hormonal responses are similar between CON and ECC muscle actions. It must be noted, however, that the training intensity was very low for these recreationally trained men. The authors discuss this as a potential limitation,

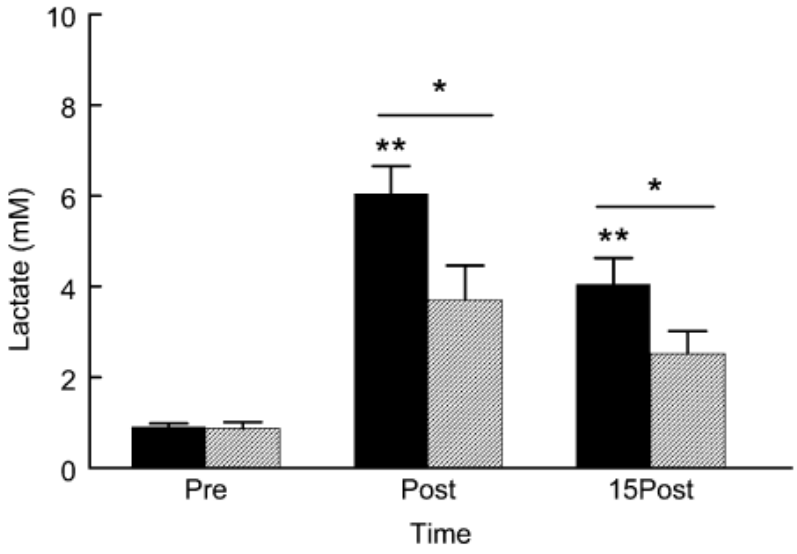


Figure 5. Lactate concentrations resulting from concentric and eccentric muscle action over time. Lactate concentrations (mean ± SE) for CON (solid bar) and ECC (hatched bar) trials. *Significantly different from pre values. **Significantly different between CON and ECC trials (Bamman, 2001).

as the training stimulus proved insufficient to generate a significant response in T. However, these data suggest that (a) 120% of CON 1RM is a sufficient estimate of ECC 1RM and (b) hormonal responses are similar between CON and ECC muscle actions under the same moderate relative load.

Neural Activation During CON and ECC Muscle Action

A motor unit is defined as a motor neuron and all of the muscle fibers it innervates (Baechle and Earl, 2000) (Figure 6). An action potential is transmitted via the motor neuron, signaling the release of acetylcholine, which diffuses across the neuromuscular junction leading to a contraction of the muscle fiber (Figure 7). This occurs concurrently across all muscle fibers in a motor unit. A single action potential leads to a twitch. Repeated action potentials before the muscle is able to relax results in twitch summation, which leads to the muscle producing greater force. If the interval time between action potentials is sufficiently short, the twitches merge into tetanus of the muscle fibers which results in the maximal force generating capability of a motor unit (Baechle and Earl, 2000). In order to increase muscular force, there must be either an increase in the frequency of activation of the motor units or an increase in the number of motor units activated within a muscle.

Motor units are generally activated in a specific order; the smaller and weaker are activated first with the larger more powerful units being activated as force requirements increase. This order of activation is known as the size principal (Baechle and Earl, 2000). In general, smaller and weaker motor units containing Type I (slow-twitch) fibers have

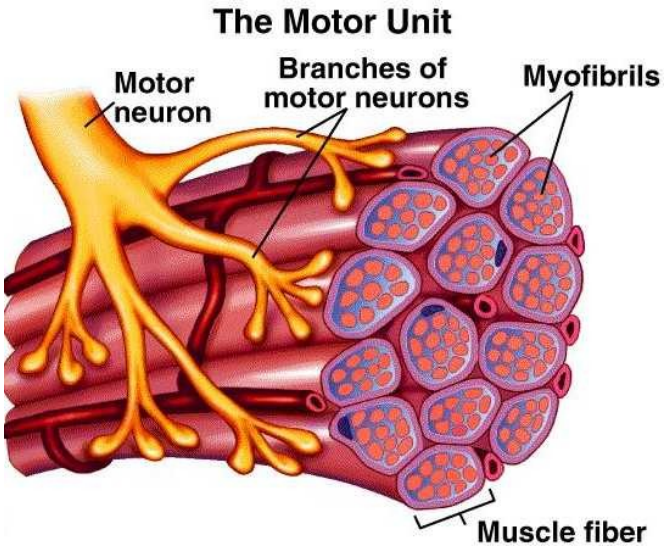


Figure 6. Motor Unit (Baechle and Earl, 2000).

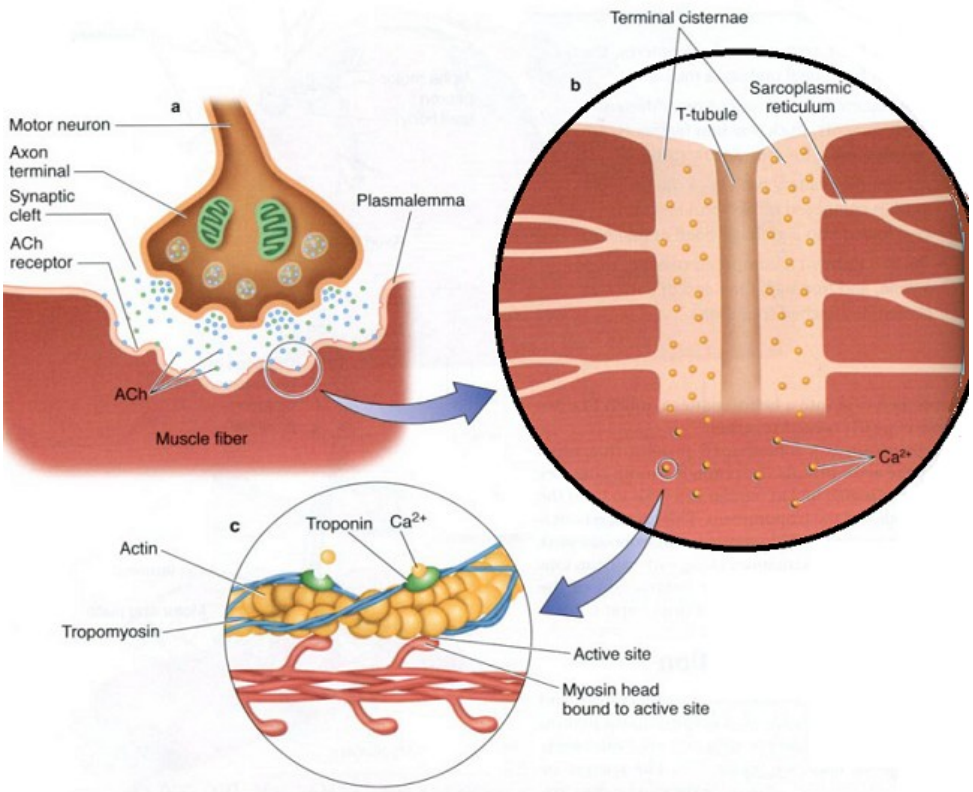


Figure 7. Excitation Coupling Contraction. (a) Action potential travels from the motor neuron to the muscle fiber through the synaptic cleft with the assistance of neurotransmitter acetylcholine. (b) Calcium is released from the sarcoplasmic reticulum. (c) Calcium binds to the tropomyosin allowing the myosin head to bind to the actin filament (Baechle and Earl, 2000).

lower recruitment thresholds and firing rates, while motor units containing Type II (fast-twitch) muscle fibers have higher thresholds and are therefore more difficult to activate (Figure 8). In order for maximal force to be generated by a muscle, all motor units must be activated. In most humans, motor units are activated in sequential order; the lower threshold units must be activated prior to the higher threshold, more powerful units. However, there is research suggesting that an adaptation of resistance training is developing the ability to recruit the higher threshold motor units more readily and efficiently (Sale, 1987). Further, Enoka (1996) suggests that this recruitment pattern may differ for muscles acting eccentrically (Figure 9). Research has also indicated that it is nearly impossible to fully activate the entire motor unit pool during maximal voluntary ECC muscle actions despite the fact that ECC strength is typically 120% that of concentric strength (Tesch, Dudley,Duvoisin, Hather, Harris, 1990).

Enoka (1996) wrote a review article concluding that there are major differences between CON and ECC muscle actions in terms of neural activation strategies. Previous research has suggested that neural factors may lead to increases in strength in both untrained (Komi, 1986) and trained populations (Edgerton, 1986) as well as increased efficiency in lifting a submaximal load (Ploutz, Tesch, Biro, Dudly 1994). These neural factors may include increased synchronization of the motor units (Milner-Brown, Stein, Conwit, 1975) and neural inhibition of the antagonist muscles (Pensini, Martin, Maffiuletti, 2002). However, research suggests differences between the neural components involved in CON and ECC muscle actions (Enoka, 1996; Abbruzzese, Morena, Spadavecchia, Schieppatit , 1994; Nardone, Romano, Schieppati, 1989).Using evidence from a number of articles, Enoka (1996) concludes that (a) ECC contractions

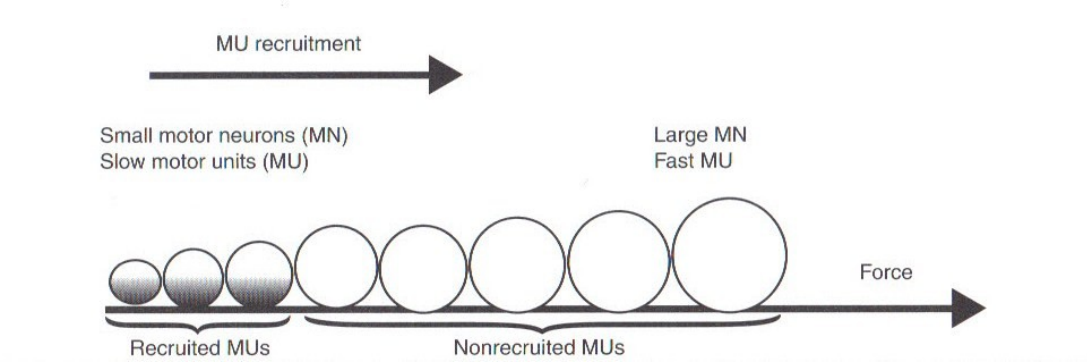


Figure 8. Corridor Theory. In response to lower stimuli, smaller, type I muscle fibers are recruited. As type I muscle fibers fatigue or the stimuli or force requirement increases, larger type II muscle fibers are recruited (Zatsiorsky and Kraemer, 2006).

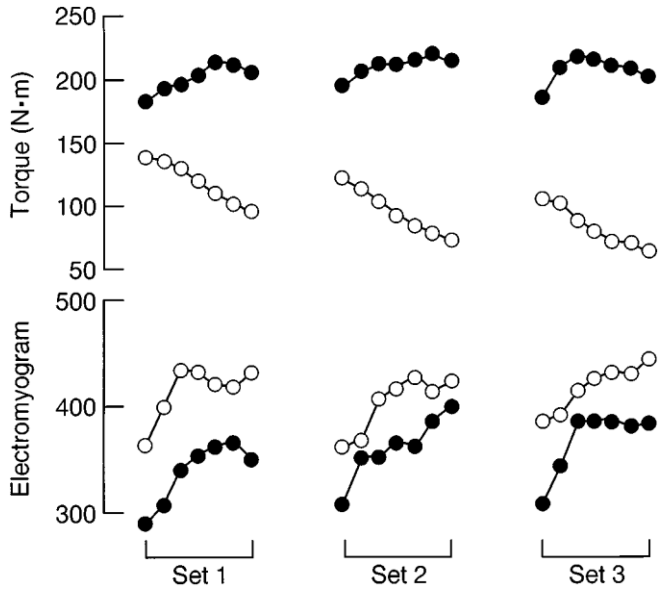


Figure 9. Torque exerted by knee extensor muscles and EMG recorded in vastus lateralis muscle during 3 sets of 32 maximal contractions on an isokinetic device. Closed dot = ECC, Open dot = CON (Enoka, 1996).

differ neurologically from CON contractions in the amount of muscle action occurring during maximal voluntary contraction, (b) submaximal ECC muscle actions elicit different recruitment patterns of motor units as compared to submaximal CON actions, (c) there is a decreased size of action potentials evoked by transcranial and peripheral nerve stimulation during ECC contractions, and (d) ECC muscle actions are more resistant to fatigue than CON contractions.

In 1989, Nardone and colleagues examined the recruitment patterns of motor units for shortening (CON) and lengthening (ECC) muscle actions. Electromyography (EMG) data for motor unit activation in the soleus, gastrocnemius medialis, and gastrocnemius lateralis muscles of five participants (four females, one male) between the ages of 22 and 39 years were collected during plantar flexion and dorsiflexion exercise. Participants were seated with their knees flexed at 110 degrees with their foot in a "mould" that provided 100 Newtons of resistance to the plantar flexion movement. Participants were asked to plantar flex at speeds ranging from 10 to 70 degrees/second. They were then asked to return to the dorsiflexed position by gradually reducing the activation of the extensor muscles. The anterior muscles of the lower leg remained inactive throughout the duration of the movement. Wires from a multipolar electrode were inserted into the posterior leg muscles and were bent into hooks to prevent movement. The discharges of a total of 99 motor units from the soleus, and gastrocnemius medialis and lateralis of the participants were studied under six conditions: isotonic shortening (planar flexion), isotonic lengthening (dorsiflexion), plantar flexion and dorsiflexion performed subsequently, maintained plantar flexion for "a few" seconds of duration, isometric effort, and ballistic isometric and isotonic efforts. The motor units were classified based on the

phase during which they were active: S (shortening/plantar flexion), S+L (plantar and dorsal flexion), and L (lengthening/dorsiflexion). Based on these criteria, the soleus muscle had 54% of its motor units active during S, 32% during S+L, and 15% during L. The results for the muscles of the gastrocnemius were combined: 26% of all motor units were active during S, 24% during S+L, and 50% during L. Interestingly, the higher threshold motor units were selectively activated during ECC muscle actions. Additionally, the rate of action potentials was lower during ECC actions as compared to CON. The authors concluded selective activation of the higher threshold motor units during lengthening muscle actions was divergent from the normal neural activation pattern during CON contractions. This provided evidence of differing neural patterns being utilized during ECC muscle actions and offered potential reasons for increased training effects which will be discussed later in this review.

Abbruzzese et al. (1994) conducted a study in which they compared the response of the biceps brachii and brachioradialis muscles to brain stimulation during CON and ECC muscle actions. Eight participants were observed during elbow flexion (CON) and elbow extension, or braking the fall of the weight (ECC) exercises. Electrical (three participants) and magnetic (seven participants) brain stimulation were used to evoke motor response in the muscles. Additionally, the radial nerve was stimulated in three participants to evoke a peripheral reflex (Hoffman, or H, reflex). The authors examined evoked motor potentials (MEPs) resulting from brain stimulation in both the biceps brachii and brachioradialis muscles during concentric and eccentric muscle actions. There was no statistical difference between electrical stimulation and magnetic stimulation so the data were collapsed. The researchers reported MEPs evoked during

muscle lengthening were "substantially smaller" than those evoked during contraction for both muscles observed. It was also noted that for the three subjects in which the H reflex was stimulated, the reflex was far greater during CON contractions than observed during muscle lengthening: approximately a 47% difference. These differences, according to the authors, imply a modulating factor which influences the firing of motor units under CON and ECC conditions. It was stated that there may be a reduced motoneuron excitability during active muscle lengthening. In fact, the authors suggested there is a specific "setting" of the motoneuron pools driven by the motor cortex during braking (ECC) muscle activation. This provides further evidence of differing motor recruitment principles during CON and ECC muscle actions.

Fatigue Mechanisms During CON and ECC Muscle Action

Tesch et al. (1990) compared fatigue patterns for repeated bouts of CON and ECC muscle actions. Force and EMG patterns were examined for 14 healthy males during three bouts of 32 unilateral maximal CON or ECC knee extensions separated by two days. The CON testing was done first for all subjects because a previously conducted study (Colliander and Tesch, 1987) concluded that CON muscle performance did not affect subsequent ECC performance. At the beginning of both testing sessions, an isometric effort was performed. There was no statistical difference between force output for these two days, indicating no performance benefit or decrement from the first to the second session. Testing was conducted on an isokinetic dynamometer with an angular velocity of 180 deg/sec. Integrated EMG (IEMG) readings were taken for the rectus femoris and the vastus lateralis muscles. Participants were instructed to perform 32 maximal voluntary repetitions in three separate bouts with 60 seconds of rest between

each bout. ECC torque was significantly greater than CON torque across all bouts. Interestingly, while CON torque decreased nearly linearly between 34-47% for each bout, ECC torque actually increased slightly within each bout, but did not significantly change between bouts. Therefore, the difference between CON and ECC torque increased over each bout. Conversely, the IEMG was significantly greater for both the rectus femoris and vastus lateralis during CON contractions as compared to the ECC actions. Vastus lateralis IEMG did not change over any of the sets of exercise for CON or ECC actions. Rectus femoris IEMG showed a significant decrease across CON bouts, but did not change over ECC bouts. At the beginning of exercise, the ratio between IEMG and torque was twofold greater during CON contractions than during ECC actions. The IEMG/torque ratio increased significantly during each bout of CON exercise, but remained constant for ECC exercise, resulting in a fivefold greater IEMG/torque ratio for CON exercise (Figure 10). The authors stated there was a significant difference between the fatigue patterns induced by CON and ECC muscle actions. While CON exercise resulted in decreased force production and increased IEMG/torque ratio, repeated ECC bouts resulted in virtually no signs of fatigue (ie: decreased force, increased IEMG, increased IEMG/torque ratio). The relatively fast movement speed examined in this study induced virtually no central or peripheral fatigue resulting from ECC muscle actions, in stark contrast to the seemingly peripheral fatigue resulting from CON contractions.

While the protocol used in the study conducted by Tesch et al. (1990) failed to illicit fatigue during ECC muscle actions, Binder-Macleod et al. (1996) examined the fatigue patterns of ECC and CON contractions of the quadriceps femoris during

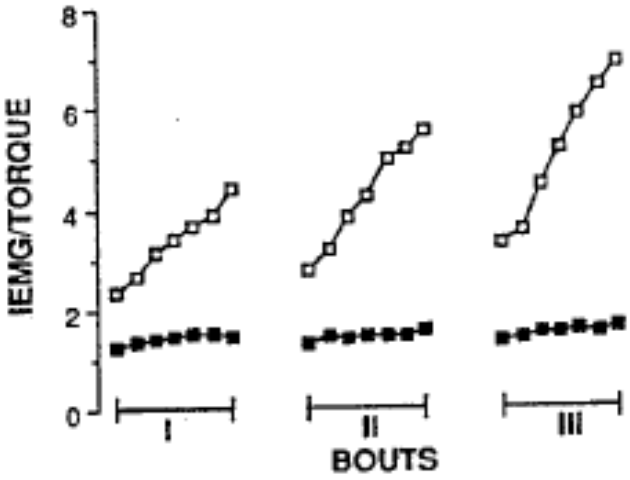


Figure 10. IEMG/Torque Ratio during CON (open) and ECC (shaded) exercise (Tesch, 1990).

electrically stimulated knee extension exercises. Ten people (five male, five female, age = 27.3 $\pm$ 2.6 years) participated in this experiment. Participants attended four sessions: a familiarization/training session, a non-fatiguing testing session, and separate fatiguing sessions for CON and ECC muscle actions, performed in selectively randomized order (five performed the CON session first followed by the ECC, the other five did the reverse). During the fatigue protocols, 180 repetitions were performed either CON or ECC with no rest interval. Electrodes stimulated a contraction of the quadriceps femoris at various intervals while the knee was passively flexed (ECC) or extended (CON) at 100 degrees/second. The electrical stimulation evoked a force equivalent to approximately 20% of voluntary isometric force and remained constant throughout the fatigue-inducing session. The contrast between the decline in force throughout the CON and ECC protocols was stark. During the CON protocol, force decreased linearly over the first 40 contractions, with no additional decrease in force observed after the 80th repetition. Conversely, ECC force rose over the first 15 repetitions before declining linearly over the next 165. Though each condition yielded approximately the same decrease in force (~40%) over 180 repetitions, the rate of fatigue was much higher during the CON session. The total decrease in force was seen after 80 repetitions in CON actions as opposed to 180 repetitions required during ECC action (Figure 11). It should also be noted that force values were approximately 2.25 times greater for ECC actions. This protocol provided sufficient stimulus to fatigue the muscles whether acting CON or ECC. However, the data suggest very different patterns of fatigue for these types of muscle action. These data provide additional support to the argument that muscles acting eccentrically are less prone to fatigue.

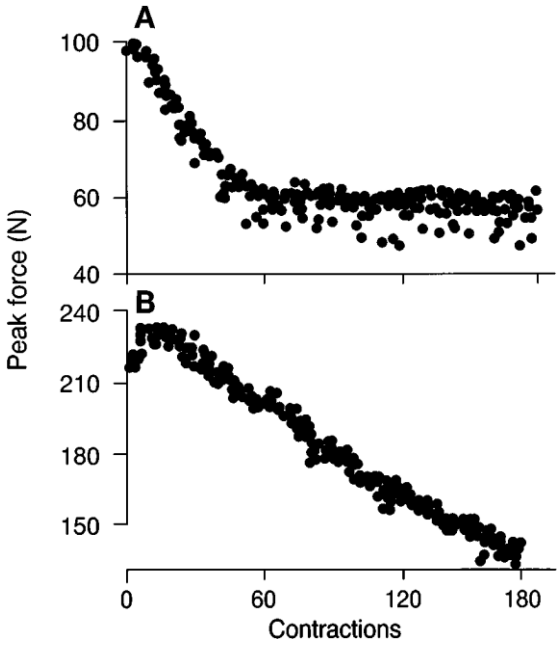


Figure 11. Decline in force during CON (A) and ECC (B) contractions of the quadriceps femoris (Binder-Macleod et al., 1996).

In addition to understanding the fatigue rates of different muscle actions, it is important to explore how training may impact rate of fatigue. Hortobagyi and colleagues (1996) conducted a training study over 12 weeks which compared ECC and CON isokinetic training in terms of adaptations of muscular strength, muscular hypertrophy, and neural recruitment. Twenty-one young (mean age= 21 years) healthy sedentary males were randomly assigned into one of three groups: ECC training , CON training , or control. Subjects were tested at baseline, week six (midpoint), and week 12 for isometric, ECC isokinetic, and CON isokinetic strength and EMG. Additionally, a percutaneous muscle biopsy was obtained from the vastus lateralis. Training consisted of either CON or ECC knee extensions for four to six sets of 8-12 repetitions three times per week. Group by testing mode by time repeated measures ANOVA was used to examine force ratios and EMG ratios. The ECC group improved ECC strength by 116% and isometric strength by 45% from pre- to post-test. The CON group increased CON and isometric strength by 53% and 36%, respectively. Mode-specific EMG activity was increased significantly more as a result of ECC training (86% increase from pre- to post-test) than CON training (12% increase from pre- to post-test). Additionally, over the course of the 12-week study, ECC training showed a fatigue rate of 3% (an increase in force from the beginning to the end during a given session), where the CON training resulted in a -12% fatigue rate. The fatigue rates between modalities were significantly different. Type II muscle fiber area also increased in the ECC group during the study 10.3 times from pre- to post-testing. CON did not yield hypertrophic gains and there were significant ($p<0.05$) group differences. The findings which stand out from this study are that (a) ECC training yielded a 3.5 times greater increase in mode-specific strength than did CON training, (b)

ECC training resulted in an approximately 10 times greater increase in type II muscle fiber area than CON training, (c) fatigue rate was significantly different between ECC and CON muscle actions in any given exercise session, and (d) ECC training resulting in a significantly higher ability to activate muscle as shown on EMG data when compared to CON training. These findings allude to ECC training being a superior stimulus for eliciting muscular strength and muscular hypertrophy, as well as decreasing fatigue and increasing motor unit recruitment when compared with CON training.

An additional study by Hortobagyi et al. (2001) further elucidated the prospect that ECC training is more effective at increasing neural activation as compared with CON training. This short-term study compared the effects of one week of ECC resistance training to one week of standard resistance training in young (age = 20.9 years $\pm$ 1.2 years) sedentary women. Participants were assigned to either seven consecutive days of standard (n = 10) or ECC training (n = 10), or a non-exercising control group. CON and ECC three-repetition maximum (3RM) of the knee extensors, CON and ECC isokinetic strength of the knee extensors, isometric strength of the knee extensors, and surface (EMG of the vastus lateralis, vastus medialis, and biceps femoris were measured before and after training.. Training consisted of five to six sets of 10-12 quadriceps contractions at approximately 60% 1RM. The participants assigned to the standard group performed typical knee extensions on a Cybex weight stack machine (CON extension followed by ECC flexion). Those in the ECC overload group performed the extension phase and then the weight stack was loaded with an additional 40-50% of the weight to overload the ECC phase. Training volume was equated between paired subjects in each group (i.e., if a subject in the standard group performed five sets of 12 repetitions, 23 kg

for both the CON and ECC phases for a total of 2760 kg, the paired ECC subject would perform five sets of 10 repetitions, 23 kg for the CON phase and 32 kg ECC for a total of 2750 kg). Group by contraction mode repeated measures ANOVA were used to analyze the changes in 3RM, isokinetic and isometric forces, and EMG activity. In the 3RM, the ECC trained group increased ECC strength significantly ($p<0.05$) more than the standard training group (ECC = 27%, standard = 11%). Both groups increased CON strength by the same magnitude (ECC = 26%, standard = 27%). The ECC trained group also demonstrated a significantly greater increase in ECC isokinetic strength (ECC = 149 N, standard = 64 N) and isometric strength as compared to the standard training group (ECC = 58 N, standard = 27 N). Additionally, the ECC trained group demonstrated significantly greater increases than the standard training group as indicated by greater increases in EMG activity during the ECC, isokinetic and isometric tests. The results of this study demonstrated that training with ECC overload generates greater ECC and isometric strength, similar increases in CON strength, and greater EMG activity during ECC and isometric testing. This study again illustrated that ECC training leads to an enhanced ability to activate muscle than elicited by concentric training. Furthermore, these adaptations occurred following only 1-week of training at a light intensity indicating eccentric training modality is a safe, effective alternative for a wide array of populations.

Taken together, the aforementioned studies by Hortobagyi (1996; 2001) indicate that ECC muscle actions are not only effective in increasing muscular strength and hypertrophy, but seem to suggest an increased neural drive as demonstrated by EMG data. An increased ability to recruit muscle is a known byproduct of resistance training

(Baechle and Earl, 2000), but the difference between muscle actions in terms of increases in EMG activity was notable in these studies by Hortobagyi and colleagues.

Physiologic Adaptations to CON and ECC Muscle Action

A number of studies have shown ECC training to be effective at improving muscular hypertrophy and strength. Vikne et al. (2006) conducted a study comparing a training protocol which utilized CON muscle contractions to one utilizing ECC muscle actions. In this study, 17 resistance trained males (26.9 $\pm$ 3.4 years) trained for 12 weeks using either CON or ECC muscle actions of the elbow flexors. Muscular hypertrophy, strength, and maximum angular velocity were assessed prior to and following the training intervention. Participants trained two to three times per week, alternating between "maximum loads" (4-8RM) and medium loads (85-90% of maximum loads). The ECC lifts were to last 3.5 seconds per repetition. Paired samples t-tests were utilized to compare means for each variable between groups. Maximum angular velocity was equally affected by each protocol. Strength in the CON maximum test was improved ($p<0.05$) similarly between conditions (CON = 18%, ECC =14%). However, ECC training resulted in greater increases in ECC strength (26%) than did CON training (9%). Finally, ECC training increased cross-sectional area of the elbow flexors (11%) and type I and type II fibers whereas there were no significant changes with the CON trained group. These data demonstrate that this particular ECC training protocol was more effective for inducing muscular hypertrophy, and CON and ECC strength than the CON protocol.

Recovery from CON and ECC Muscle Action

A study by Newton et al. (2008) examined the responses of trained and untrained men to an acute bout of ECC resistance exercise. Fifteen trained men (28.2 $\pm$ 1.9 years) and 15 untrained men (30.0 $\pm$ 1.5 years) volunteered to participate. The exercise bout consisted of 10 sets of six maximal voluntary ECC repetitions of the elbow flexors on an isokinetic dynamometer at 90 degrees per second. Measures of maximal voluntary isometric and isokinetic torque, range of motion (ROM), upper arm circumference, plasma creatine kinase activity (CK), and muscle soreness were recorded at the initial training session and five days following the training bout. Two-way repeated measures ANOVA were utilized to compare mean differences in each measure over time. Interactions were followed up with one-way measures ANOVAs to locate significant differences over time. Both groups decreased work over the course of the 10 sets, with the untrained group (33%) decreasing significantly ($p<0.05$) more from baseline as compared to the trained group (22%). Isometric peak torque was significantly decreased in both groups immediately after exercise, with the untrained group experiencing a significantly greater decrease (untrained = 47%, trained = 25%). This relationship persisted for each subsequent testing session, with the trained group returning back to baseline strength on day three and the untrained group remaining 30% weaker than baseline on day five. Isokinetic torque exhibited the same relationship between trained and untrained subjects as isometric torque. ROM also decreased in both groups, but returned to baseline in the trained group by day two, while the untrained group did not return to baseline until day five. There were significant group differences for every measure following exercise. The trained group also experienced a significantly lower

increase in arm circumference as compared to the untrained group (peak increase, trained = 5mm, untrained = 11mm). CK activity was also significantly lower in the trained group, with a peak increase of approximately twice the baseline level as compared to the 20-fold difference demonstrated by the untrained group. Soreness was increased in both groups and remained present until day five, with no differences between groups. The importance of this study, particularly as it pertains to the current study, is that it outlines the recovery process of trained and untrained individuals. The finding that muscular strength returns to baseline two days prior to the cessation of soreness is important in designing future research studies and training programs. Additionally, this study suggests that men with resistance training experience are less susceptible to muscular damage induced by a single bout of maximal ECC exercise than those who are untrained.

Prediction Equations

In designing a resistance-training exercise program, it is important to have either a directly measured or an estimated value of the maximum amount of weight a person can lift in a given exercise. Most resistance programs are based on percentages of this maximum. There have been a number of prediction equations and tables published which are useful in estimating an individual's one-repetition maximum (1RM) in a particular exercise from the number of repetitions completed at a submaximal weight (Landers, 1985; Mayhew, Ball, Arnold, Bowen 1992; Brzycki, 1993; Chapman, Whitehead, Binkert, 1998). There are various reasons, both clinical and practical, for estimating 1RM from submaximal testing rather than performing the actual maximal testing. From a safety standpoint, performing a 1RM test may be contraindicated or dangerous in some populations including children, older adults, those with orthopedic issues, those with high

blood pressure, or those whom are unfamiliar with an exercise. In these instances, performing a 1RM test may present a danger to the individual and would not be recommended. From a practical perspective, 1RM testing is often a process which requires a significant amount of time for warm-up, loading and unloading weights, and sufficient attempts to ensure an accurate value is determined. There should also be a very heavy emphasis on proper technique due to the heightened potential for injury. Strength or fitness professionals may find 1RM testing to be a cumbersome process, particularly if they have a number of participants or clients to test. Therefore, the development of prediction models offers a safer and more time-efficient way to derive 1RM.

Mayhew et al. (1992) developed an equation to predict CON 1RM of an individual based on the number of repetitions completed at a submaximal weight in the bench press exercise. For the initial study and development of the prediction equation, 184 men and 251 women enrolled in a college fitness course were trained using various resistance training modalities (i.e., dumbbells, barbells, and Nautilus equipment) for 14 weeks, then tested for 1RM on the bench press. Participants were then asked to complete as many repetitions as possible in one minute at a randomly assigned percentage of their 1RM ranging from 55%-95%. It was noted that most participants experienced muscular fatigue before reaching the time limit. Though men were significantly stronger than women across every weight, the regression curves (Figure 12) were not different between men and women so data were collapsed to form one exponential equation:

$$\text{Percent 1RM} = 52.2 + 41.9\, e^{-0.055\ \text{reps}}$$

This equation had a high correlation coefficient ($r = 0.80$) and a standard error of $\pm$ 6.4%, meaning the percent 1RM could be fairly accurately determined by the number of

repetitions completed. The percent of 1RM was then entered into the following formula to predict 1RM:

1RM Bench press (kg) = rep weight (kg)/(predicted percent 1RM/100)

This equation was applied to the original sample population and the correlation between predicted and measured 1RM was r = 0.98 with a standard error of the estimate of $\pm$ 4.8kg. The investigators then applied the equations to three different cross-validation groups: Group 1 was comprised of 70 men and 101 women randomly selected from a subsequent fitness course. Group 2 was composed of 25 high school male athletes and 74 high school male non-athletes. Group 3 consisted of 56 first year players from an NCAA Division II football team. When applied to Group 1, the correlations between predicted 1RM and actual 1RM were r = 0.96 and r = 0.90 for men and women, respectively. The correlation coefficients were r = 0.97 and r = 0.95 respectively for the trained and untrained high school males of Group 2. When applied to Group 3, the equations produced a prediction of 1RM with r = 0.95 correlation to measured 1RM. The regression equations were not significantly different between any of the cross-validation groups, nor were they different from the original equation. These data demonstrate submaximal testing can be used to predict 1RM in the bench press exercise across a variety of subgroups. One important note about this study is that it suggests an exponential relationship between 1RM and the number of submaximal repetitions to fatigue. The authors noted that it is very close to a linear relationship, but that an exponential relationship seems to fit the data more accurately. This differed from previous models developed by Sale and MacDougall (1981), Landers (1985), and

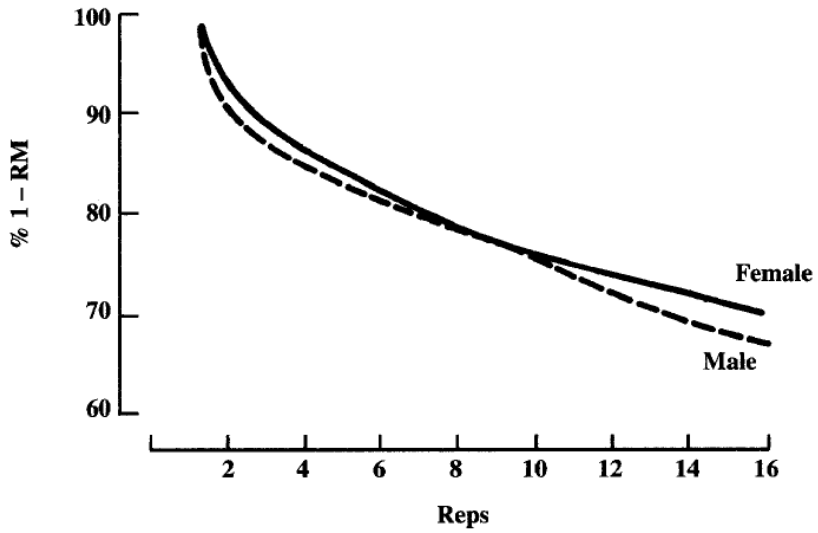


Figure 12. Relationship between percent 1RM and repetitions in the bench press in college men and women (Mayhew et al., 1992).

Brzycki (1993) showing a linear relationship between 1RM and the number of repetitions possible at a given percentage of 1RM.

Sale and MacDougall (1981) described the relationship between an individuals' 1RM and the number of repetitions as nearly linear. Based on these observations, Brzycki (1993) developed a prediction equation and a reference table useful in predicting 1RM from the number of repetitions completed at a given submaximal weight. He noted that the near-linear relationship became less accurate after 10 repetitions, therefore the equation should only be used in situations in which fatigue occurred within 10 repetitions. Based on his observations of Sale and MacDougall's work, Brzycki developed the following equation to predict 1RM from the number of repetitions an individual was able to complete at a given load:

$$\text{Predicted 1RM} = \text{Weight Lifted}/(1.0278 - 0.0278X)$$

$$X = \text{the number of repetitions performed}$$

Based on this formula, Brzycki created a table (Table 1) that provides a practical and useful tool for strength professionals and those who wish to develop resistance training programs for individuals for whom 1RM testing may be contraindicated or time-prohibitive. One potential limitation of the Brzycki equation and table is that no muscle group or specific exercise is indicated for its use, unlike that presented by Mayhew (1992), which specifically applies to the bench press. The generality of Brzycki's formula and table allows for application to any given resistance exercise, but as Neyroud et al. (2013) suggest, different muscle groups may fatigue at different rates. Therefore, the number of repetitions an individual can complete at a given percentage of 1RM in one exercise may be different than the number of repetitions that can be completed at the

	Repetitions											
Wt (lb)	1	2	3	4	5	6	7	8	9	10	11	12
20	20	21	21	22	23	23	24	25	26	27	28	29
25	25	26	26	27	28	29	30	31	32	33	35	36
30	30	31	32	33	34	35	36	37	39	40	42	43
35	35	36	37	38	39	41	42	43	45	47	48	50
40	40	41	42	44	45	46	48	50	51	53	55	58
45	45	46	48	49	51	52	54	56	58	60	62	65
50	50	51	53	55	56	58	60	62	64	67	69	72
55	55	57	58	60	62	64	66	68	71	73	76	79
60	60	62	64	65	68	70	72	74	77	80	83	86
65	65	67	69	71	73	75	78	81	84	87	90	94
70	70	72	74	76	79	81	84	87	90	93	97	101
75	75	77	79	82	84	87	90	93	96	100	104	108
80	80	82	85	87	90	93	96	99	103	107	111	115
85	85	87	90	93	96	99	102	106	109	113	118	122
90	90	93	95	98	101	105	108	112	116	120	125	130
95	95	98	101	104	107	110	114	118	122	127	132	137
100	100	103	106	109	113	116	120	124	129	133	139	144
105	105	108	111	115	118	122	126	130	135	140	145	151
110	110	113	116	120	124	128	132	137	141	147	152	158
115	115	118	122	125	129	134	138	143	148	153	159	166
120	120	123	127	131	135	139	144	149	154	160	166	173
125	125	129	132	136	141	145	150	155	161	167	173	180
130	130	134	138	142	146	151	156	161	167	173	180	187
135	135	139	143	147	152	157	162	168	174	180	187	194
140	140	144	148	153	158	163	168	174	180	187	194	202
145	145	149	154	158	163	168	174	180	186	193	201	209
150	150	154	159	164	169	174	180	186	193	200	208	216
155	155	159	164	169	174	180	186	192	199	207	215	223
160	160	165	169	175	180	186	192	199	206	213	222	230
165	165	170	175	180	186	192	198	205	212	220	229	238
170	170	175	180	185	191	197	204	211	219	227	235	245
175	175	180	185	191	197	203	210	217	225	233	242	252
180	180	185	191	196	203	209	216	223	231	240	249	259
185	185	190	196	202	208	215	222	230	238	247	256	266
190	190	195	201	207	214	221	228	236	244	253	263	274
195	195	201	206	213	219	226	234	242	251	260	270	281
200	200	206	212	218	225	232	240	248	257	267	277	288
205	205	211	217	224	231	238	246	255	264	273	284	295
210	210	216	222	229	236	244	252	261	270	280	291	303
215	215	221	228	235	242	250	258	267	276	287	298	310
220	220	226	233	240	248	256	264	273	283	293	305	317
225	225	231	238	245	253	261	270	279	289	300	312	324
230	230	237	244	251	259	267	276	286	296	307	319	331
235	235	242	249	256	264	273	282	292	302	313	325	339
240	240	247	254	262	270	279	288	298	309	320	332	346
245	245	252	259	267	276	285	294	304	315	327	339	353
250	250	257	265	273	281	290	300	310	322	333	346	360
255	255	262	270	278	287	296	306	317	328	340	353	367

Figure 13. Predicted 1-RM from Reps to Failure (adapted from Bryzcki, 1993).

same percentage of 1RM in a different exercise. A number of factors may account for differences including the availability of synergist muscles and differing muscle fiber types, so one must exercise caution when applying a broad formula to a number of unique exercises and muscle groups. Still, Brzycki's formula and table provide a readily usable tool for practitioners.

A study by Chapman and colleagues (1998) examined the efficacy of the 225-lb repetitions to fatigue bench press protocol for the prediction of 1RM that is common in college and professional football. The goal of the test is to predict one's 1RM based on the number of times he can successfully lift 225 pounds. In this study, 98 NCAA Division II football players participated in 1RM testing and the 225-lb repetitions to fatigue in random order on two days separated by three days' of rest. During the 225-lb repetitions to fatigue test, no time limit was given, but participants lowered the bar to the chest and raised the bar until the arms were extended as many times as possible without chest bounce, the feet moving, or the gluteus maximus leaving the bench. Correlations were observed to determine if the 225-lb repetitions to fatigue test was effective in predicting 1RM and if training experience was associated with 1RM. The data showed that the 225-lb repetitions to fatigue test was highly correlated ($r = 0.92$, $p < 0.001$) and training experience was moderately correlated ($r = 0.35$, $p < 0.001$) to 1RM bench press. Regression analysis showed the 225-lb protocol was more effective in predicting 1RM for participants that completed 0-10 repetitions ($R^2 = 0.85$) than for those completing 11-21 repetitions ($R^2 = 0.76$). These data suggest that for participants who were able to complete 0-10 repetitions with 225 pounds, the protocol is a reasonably accurate way to predict 1RM. However, as the authors point out, the 225-lb repetitions to fatigue

protocol might not be appropriate for all: obviously for those whose 1RM falls below 225 pounds, but also for those able to complete more than 10 repetitions. The authors did mention that the submaximal testing was a much faster and easier process to manage than the 1RM testing, an obvious benefit when dealing with a large number of participants.

Summary

Resistance training has been shown effective in eliciting numerous health benefits. Additionally, training which emphasizes the ECC action in an exercise has shown benefits beyond traditional resistance exercise (ECC/CON, with the CON being the limiting factor) and CON only. Among other benefits, ECC training yields greater increases in muscular strength (Vikne et al., 2006; Hortobagyi et al., 1996) and hypertrophy (Vikne et al., 2006; Hather, 1991) than CON training: two benefits which are important for athletes as well as the general population. Based on this evidence, a resistance training regimen which incorporates ECC-emphasized exercises provides the stimulus for the greatest adaptation. Though a training program with an ECC component yields the greatest physiological response, there is a practical issue which arises; 1RM testing for ECC exercise can prove difficult in a practical environment. A 1RM is a critical tool in program design, allowing the practitioner to calculate percentages for lifts and design a scientifically-based program. However, 1RM testing is a process that requires a great deal of time, technique, and manpower to maximize safety and accuracy. Prediction models (Landers, 1985; Mayhew et al., 1992; Brzycki, 1993; Chapman, Whitehead, and Binkert, 1998) have been successful in estimating 1RM for standard lifts in which the CON component is the limiting factor. These models provide a safer, faster method for estimating 1RM. But nothing in the current literature exists to predict a 1RM

for ECC exercises. Because of the nature of the muscle action, and the fact that load capabilities are generally much greater under ECC conditions, special equipment or a great deal of manpower are required to properly test for ECC 1RM. The risk of injury is relatively high. Therefore, a prediction equation which would allow the practitioner to estimate ECC 1RM from CON 1RM or from submaximal efforts would be extremely beneficial.

Chapter 3

METHODS

Study Purpose

The purpose of this study was to compare CON and ECC muscle actions in terms of absolute strength in the bench press exercise as tested by a 1RM. A secondary purpose of this study was to compare CON and ECC muscle actions in terms of the number of repetitions completed in the bench press at four different intensities of 1RM (60%, 70%, 80%, and 90% of muscle action-specific 1RM). The tertiary purpose of the present study was to predict ECC 1RM from CON values including 1RM, 90% 1RM, 80% 1RM, 70% 1RM, and 60% 1RM. An additional purpose was to determine whether repetitions completed at an absolute weight could be used to predict ECC 1RM. This chapter describes the participants, methods, and instruments used to test the study aims.

Participants

Thirty males between the ages of 19 and 40 years with a self-report of at least one year of resistance training experience volunteered to participate in this study. Resistance training experience for this study was defined as having performed the bench press exercise a minimum of once per week during the past year. Participants were recruited from Physical Education and Exercise and Wellness classes on the Arizona State University Polytechnic campus. Recruitment methods included recruitment flyers (Appendix A) and direct invitations using a standard oral recruitment script (Appendix B). Exclusion criteria included orthopedic injuries and pain in the upper extremities within the past year, current hypertension (defined as resting blood pressure higher than 160/90 mmHg), and cardiovascular risk factors as reported as one or more items selected

on the Physical Activity Readiness Questionnaire (PAR-Q) (Appendix C). Based on the exclusion criteria, three potential participants responding to the recruitment materials were excluded from participation.

Pilot Testing/Training

A previous study (Carothers et. al, 2008) conducted in the same laboratory by the same research team and using the same equipment and methodology for testing CON, ECC, and ECC-CON muscle actions on the bench press served as pilot testing. All research assistants who were not part of the previous study were briefed on the study protocol and trained on how to perform specific tasks such as spotting participants during lifts, how to load and unload the weights, and how to administer the warm-up protocol.

Protocol

This study consisted of six testing sessions per subject lasting four weeks. All testing was performed on the Arizona State University Polytechnic campus in the Chandler-Gilbert Community College Human Performance Laboratory. The temperature in the laboratory was kept at 68 degrees Fahrenheit controlled by a central air conditioning unit. Prior to testing, participants read and signed an informed consent form (Appendix D) which was approved by the Arizona State University Institutional Review Board (Appendix E). A Continuing Review Form was also filed (Appendix F). Participants were invited to ask questions regarding the study prior to signing the forms. After reviewing and signing the informed consent form, participants were measured for anthropometric measures of height, weight and body composition. Body composition was measured for percent fat and lean muscle mass in a BOD POD body composition system (Life Measurements, Inc., Concord, CA).

Following anthropometric measures in the initial session and prior to weight lifting in each subsequent session, participants performed a general cardiovascular warm-up by pedaling a Monark (Varberg, Sweden) cycle ergometer for five minutes at 90 revolutions per minute. During each session, the cycle ergometer warm-up was followed by a bench press weight lifting warm-up protocol (Baechle & Earle, 2000) consisting of 10, 5, and 3 repetitions at self-selected, but increasing, loads for a traditional bench press exercise (characterized as the ECC [lowering] phase immediately followed by the CON contraction [raising]). Repetitions were completed in succession without rest and at least one minute of rest was given between each set.

The initial two sessions included the cycle ergometer and weightlifting warm-up followed by testing 1 repetition maximum in either CON or ECC bench press tested in random order as determined by the flip of a coin. Participants were allowed to practice each method of lift with the unloaded barbell to become accustomed to the timing of the lifts and become comfortable with how the mechanical hoist operated. The CON bench press was performed with the participant supine on a bench and pushing the barbell from a resting position on the chest to complete extension of the elbows. The weight was passively lowered to the chest prior to each repetition via mechanical hoist (2000lb Minsize Electric Rope Hoist, Northern Tool and Equipment, Burnsville, MN) which was mounted on a 2000lb capacity gantry crane (see Figure 13). A failed repetition was defined as the participant being unable to completely extend the elbows to complete the CON bench press movement. The ECC bench press consisted of lowering a barbell with a weight from a fully extended elbow position to the chest in a continuous, smooth, controlled manner for three seconds as determined by a countdown in correspondence to

a Korg MA-30 Ultra Compact digital metronome (Melville, NY). The barbell and weight were then returned to the starting position via mechanical hoist. A failed ECC repetition was defined as the participant being unable to control the velocity of the descent of the bar at any time or allowing the barbell to touch the chest before the full three second count expired. Participants were given two to five minutes of rest between 1RM attempts, with two minutes being the minimum amount of rest and participants being required to begin the next set within five minutes. Participants were able to begin the next set when they were ready within this timeframe. Two to six attempts were performed to determine each participant's 1RM weight. The greatest weight attained in each lift was used as the 1RM.

The third through sixth sessions included the cycle ergometer and weight progression warm-up protocols followed by maximal repetition testing. Each of the four testing days was used to find the number of repetitions the participant was able to complete for one ECC and one CON percentage (60%, 70%, 80%, and 90%) of each respective 1RM test. The order of exercise as well as percentage of 1RM was randomized without replacement. Percentage values with either ECC or CON were written on strips of paper from which the participants blindly picked when they arrived for testing. Participants were aware of the percentage and the amount of weight at which they were being tested. Once a specific percentage/test combination was performed it was removed from the choice selections for the subsequent visits until each participant completed each percentage for each test. All sets were performed to volitional fatigue, defined as the first failed repetition in the set. Ten minutes of rest were given between

sets at all percentages. The number of repetitions completed at each percentage of 1RM was recorded.

Safety Precautions

To ensure the safety of all participants, stringent measures were taken. Trained spotters were used during all warm-up sets as well as all testing sets on the bench press. Additionally, at the commencement of each testing session the mechanical hoist was lowered to the appropriate height, with the barbell lightly touching the participant's chest. The cable was marked with a small piece of tape, indicating where the operator should stop the hoist. This ensured that the cable would prevent the bar from falling onto the participant in the event of a failed lift. Gym chalk was available for participants who wished to use it to decrease the likelihood of the bar slipping from their hands, but was not mandatory.

Statistical Analyses

Data were analyzed using SPSS software (version 19.0; SPSS, Inc., Chicago, IL.). Data were examined for normality using test statistics for skewness and kurtosis as well as visual inspection of the data. Data which were not normally distributed were transformed using logarithmic transformation. Analyses were performed on transformed data where appropriate. Means and standard deviations are reported for normally distributed data. Medians and their interquartile range are reported for non-normally distributed data. Descriptive data are reported for participant characteristics for anthropometric measures and age. A paired t-test was run to compare CON 1RM and ECC 1RM. Paired t-tests were also used to examine differences in the number of repetitions completed at each percentage (60%, 70%, 80%, and 90%) of 1RM between

CON and ECC. Regression analysis was used to predict ECC 1RM from CON 1RM as well as to predict ECC 1RM from repetitions completed at absolute weights (130-150lbs and 155-175lbs) both concentrically and eccentrically.

Chapter 4

RESULTS

Participant Characteristics

A total of 32 healthy college-aged, males were recruited for this study. During the testing period, two participants were unable to complete the study, both due to noncompliance in attending all testing sessions. Data represents a total of 30 individuals. Participants ranged in age from 19-40 years. Based on the inclusion criteria, each participant had been actively weightlifting at least once a week for a least one year prior to testing. Baseline data for all participants are reported in Table 1.

Descriptive results

Participants for this study were of normal height, weight, and body fat. Participants were tested for concentric one-repetition maximum (CON 1RM) and eccentric one-repetition maximum (ECC 1RM) which served as the reference points in calculating the various intensities of each specific 1RM. Prior to further analyses, data were tested for normality. Both CON 1RM and ECC 1RM data were not normally distributed. Normality was determined by dividing skewness by standard error of skewness as well as dividing kurtosis by standard error of kurtosis (Table 2). Values greater than 1.96 were deemed not normal. Logarithmic transformations were performed on both CON 1RM and ECC 1RM which resulted in normal distribution.

CON 1RM vs. ECC 1RM

The primary aim of the study was to determine whether there was a difference between CON and ECC strength. First, we tested whether 1RM differed between the two

Table 1

Participant Demographics

Measure	Baseline Measures
Age (years)	24.63 ± 5.6
Weight (lb)	184.57 ± 25.20
Height (in)	70.32 ± 2.59
Body Fat (%)	18.39 ± 6.80

Results are reported as Mean ± Standard Deviation.

Table 2

CON and ECC 1RM Descriptives

	Mean (lbs) ± SD	Median (lbs)	IQ-R	Skewness	SE of Skewness	Kurtosis	SE of Kurtosis
CON 1RM*	205.83 ± 58.43	190	71.25	1.27	0.427	1.324	0.833
ECC 1RM*	255.17 + 68.37	245	88.75	0.874	0.427	0.141	0.833
ln CON 1RM+	5.29 ± 0.26	5.25	0.36	0.715	0.427	0.01	0.833
ln ECC 1RM+	5.51 ± 0.26	5.5	0.36	0.367	0.427	-0.434	0.833

*Data prior to logarithmic transformation
+Data following logarithmic transformation (ln = natural log)

IQ-R: Interquartile Ratio
SE: Standard error

muscle actions. A paired t-test was run on the transformed data and showed a significant ($t=11.561$, $p < 0.05$) difference in 1RM between the CON (205.83 $\pm$ 58.43lbs) and ECC (255.17 $\pm$ 68.37lbs) muscle actions. These data indicate ECC strength is approximately 124% of that of CON strength in the measured exercise (Table 3).

Repetitions Completed for CON vs. ECC

Then we tested whether there were differences between CON and ECC repetitions completed at various intensities of mode-specific 1RM. Paired t-tests revealed a significant difference ($p < 0.05$) between muscle action in the number of repetitions completed at 90% of mode-specific 1RM (ECC = 7.67 $\pm$ 3.24, CON = 4.57 $\pm$ 2.21). There were no differences between the number of repetitions completed concentrically and eccentrically at other tested intensities (Table 3). Figure 14 displays the number of repetitions for CON and ECC at each tested intensity. A visual inspection further confirms the rate of fatigue for each type of muscle contraction was similar and is tightly aligned with relative intensity.

Prediction Equations

Regression analysis revealed that CON 1RM was a highly significant predictor of ECC 1RM ($b=1.004$, $p<.001$, $R^2 = 0.83$). The equation is presented in Table 4. Predicted ECC 1RM values for a range of CON 1RM are listed in Table 5. Because submaximal weights were derived from 1RM, each percentage of CON 1RM was also a predictor of ECC 1RM. However, there were no significant correlations between repetitions to fatigue at any of the intensities of CON 1RM and ECC 1RM ($p > 0.05$). Conversely, correlation analysis showed that ECC 1RM was accurately predicted by the number of repetitions completed under both CON and ECC conditions at various absolute weights

(130-150lbs and 155-175lbs). All prediction equations are presented in Table 4. In both CON and ECC conditions, heavier loads (155-175lbs) resulted in higher r-squared values

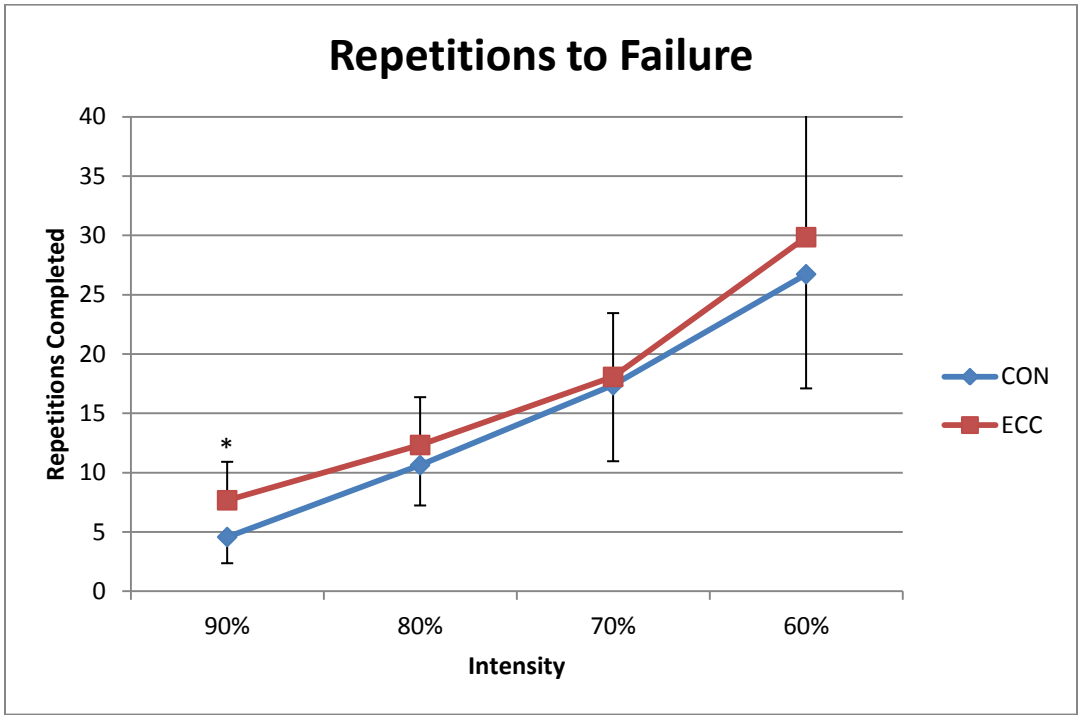
Table 3

Weights and Repetitions Completed at Various Intensities of 1RM

CON	Wt ± SD	Reps ± SD	ECC	Wt ± SD	Reps ± SD
1RM	205.83 ± 58.43	1 ± 0	1RM	255.17 ± 68.37	1 ± 0
90%	185.5 ± 52.92	*4.57 ± 2.21	90%	230.0 ± 61.65	*7.67 ± 3.24
80%	164.83 ± 46.67	10.63 ± 3.4	80%	204.17 ± 54.54	12.33 ± 4.03
70%	144 ± 41.11	17.37 ± 6.41	70%	178.67 ± 47.72	18.07 ± 5.38
60%	123.33 ± 34.85	26.73 ± 9.63	60%	153.17 ± 41.35	29.85 ± 10.39

* Significantly different
Note: All ECC weights significantly greater than CON weights at same intensity
Weight (Wt) listed in pounds
Repetitions (Reps) refers to the number of successful repetitions prior to a failed repetition

Figure 14



* Significant difference in repetitions completed at 90% 1RM

Table 4

Prediction Equations for ECC 1RM

Input	Equation
CON 1RM	y = 108.74 + 1.004 (CON 1RM)
Reps @ CON 130-150lbs	y = 184.012 + 1.015 (Reps)
Reps @ CON 155-175lbs	y = 202.958 + 1.019 (Reps)
Reps @ ECC 130-150lbs	y = 187.167 + 1.005 (Reps)
Reps @ ECC 155-175lbs	y = 199.805 + 1.009 (Reps)

* All equations from back-transformed calculations

Table 5

Predicting ECC 1RM from CON 1RM

CON 1RM	Pred. ECC 1RM
135	244
155	264
175	284
195	305
215	325
235	345
255	365
275	385
295	405
315	425

* All weights listed in pounds

** All predictions based on back-transformed calculations

(CON R^2 = 0.79, ECC R^2 = 0.53) when predicting ECC 1RM as compared to lighter loads (130-150lbs) (CON R^2 = 0.54, ECC R^2 = 0.21) (Table 6).

Table 6

Predicting ECC 1RM from repetitions completed at absolute weights

	Weight (lbs)	N	Duplicates*	Analysis n	r^2	Intercept	b	se	t	p-value
ECC weight										
	130-150	25	6	19	0.21	5.232	0.005	0.002	2.126	0.048
	155-175	21	0	21	0.53	5.272	0.009	0.003	2.713	0.014
CON weight										
	130-150	29	5	24	0.54	5.215	0.015	0.003	5.058	<.001
	155-175	20	1	19	0.79	5.313	0.019	0.002	7.94	<.001

*Where values were duplicated for a participant, lower %RM was used in analysis.

Chapter 5

Discussion

The present study examined the differences between CON and ECC bench press in terms of 1RM and the number of repetitions completed at various percentages (90%, 80%, 70%, 60%) of mode-specific 1RM. The study also sought to determine whether ECC 1RM could be accurately predicted from CON 1RM and/or the number of repetitions completed with a given weight both concentrically and eccentrically.

The findings of this study were that a) ECC 1RM was significantly ($p < 0.05$) greater than CON 1RM, b) there were no differences between the number of repetitions participants were able to complete at the same relative load between ECC and CON, c) CON 1RM, as well as the number of repetitions completed at specific loads during CON and ECC conditions, were all significant ($p < 0.05$) predictors of ECC 1RM.

Difficulties of Testing ECC 1RM and Repetitions to Fatigue

Because of the nature of ECC muscle action, particularly in the bench press exercise, it can be difficult to distinguish between a successful repetition and an unsuccessful repetition. The weight is being lowered toward the chest due to gravity. The participant must control the descent throughout this movement for a repetition to be deemed successful. Because of the difficulty determining the success of an ECC repetition, there are very few known studies (Carothers et al., 2008) examining ECC 1RM or ECC repetitions to fatigue utilizing free weights.

Testing on an isokinetic dynamometer allows for participants to complete any number of repetitions, as long as the participant is able to continue moving the tested limb due to the fact that the dynamometer controls the speed of the limb movement but does not provide an external load. Therefore, as the limb fatigues the dynamometer accommodates, providing less resistance to maintain a constant speed. This modality does not allow for a "failed" repetition the way that free weights do, so it is not possible to test repetitions to volitional fatigue (characterized by failure to complete the exercise) on an isokinetic dynamometer and a 1RM test would not be a valid measure as the torque output would change throughout the movement.

Free weight exercises such as the bench press generally consist of moving an external load which is unchanging (isotonic). Because the weight does not change to accommodate fatigue, once the force capabilities of a fatiguing muscle or group of muscles fall below the requirements of the external load, the individual will be unable to successfully complete the repetition. A failed repetition is fairly easy to distinguish if the muscle is acting concentrically. In the standard bench press exercise, for example, if the failure occurs during the CON phase, the bar will stop ascending and will eventually descend back toward the chest. However, because the ECC portion of the bench press exercise requires controlled descent of the bar toward the chest, it may be difficult to determine if the muscles are lowering the load in a controlled manner or if the force capabilities of the muscles have been exceeded by the load and the weight is simply falling toward the chest. This example demonstrates why it can be difficult to determine

whether a repetition was successfully performed eccentrically, or if gravity simply moved the bar toward the chest. Another factor which complicates ECC testing with free weights is the necessity of returning the weight to the starting position without requiring CON muscle action. This can only be done with a spotter or team of spotters or with mechanical assistance, as was utilized in this study. This can prove challenging for researchers. The difficulty in clearly distinguishing between a successful ECC repetition versus simple gravity, along with the challenge of returning the load to the start position between each repetition likely explain why previous research has not focused on measuring ECC 1RM or ECC repetitions to fatigue with free weights.

With these issues considered, the research team set forth the guidelines for determining a "successful" ECC repetition. The subject was to lower the bar toward the chest in a smooth, continuous motion over a three second duration in cadence with a digital metronome. The three second ECC phase was selected as an average between previously reported methods which ranged from two seconds (Hollander et al., 2008) to four seconds (Vikne et al., 2001). The same tester was responsible for determining the success of every repetition for every participant to maximize intra-rater reliability. Though there was a subjective component to this method (see limitations), the use of a singular trained tester and digital metronome minimized error in determining the success of a repetition.

CON 1RM vs ECC 1RM

Based on previous research (Bamman, 2001; Enoka, 1996; Hollander et al., 2008; Hortobagyi & Katch, 1990), it was hypothesized that ECC strength (measured as ECC 1RM) would be approximately 120% of CON strength (measured as CON 1RM). These data support the hypothesis, as ECC 1RM (255.17 $\pm$ 68.37lbs) was approximately 124% of CON 1RM (205.83 $\pm$ 58.43lbs), a statistically significant ($p < 0.05$) difference. This strength difference falls in line with previous research and establishes the present research design, particularly the protocol for testing ECC repetitions, as a valid measure of ECC strength.

Repetitions to Fatigue

No known studies compare the number of repetitions participants can complete in a given exercise with an equated relative load concentrically and eccentrically. Studies comparing fatigue patterns between CON and ECC muscle actions have been performed using isokinetic dynamometry (Binder-Macleod et al., 1996; Hortobagyi et al., 1998; Hortobagyi et al., 2001; Tesch et al., 1990), but testing the number of repetitions that can be completed prior to volitional fatigue, as characterized by the inability to complete a repetition, is difficult and has not been previously done to our knowledge.

Previous research has focused on decreases in muscular force as a result of repeated bouts of CON and ECC exercise as measured by isokinetic dynamometry, but as previously stated, not on how many repetitions can actually be completed. Tesch et al. (1990) showed no force decreases as a result of three bouts of 32 maximum voluntary ECC repetitions, as compared to the same number of CON repetitions, which resulted in

34%-47% decreases in force. Binder-Macleod et al. (1996) showed very different patterns of fatigue between CON and ECC exercise over the course of 180 invoked knee extensions, with CON resulting in a very sharp decline in force over the first 40 repetitions and no further force decreases after the 80th repetition, and ECC showing a linear decrease from the 15th to the 180th repetition. Contractions were invoked at 20% of maximum voluntary isometric force. Force outputs were statistically greater in ECC actions than CON actions for both of these studies. Taken together, these studies indicate that not only can the muscle produce more force eccentrically, but it can maintain force production over a longer period of time under ECC conditions as compared to CON. What remains to be seen, however, is whether this apparent heightened resistance to fatigue results in a greater number of ECC repetitions that can be completed in a free weight exercise when compared to CON repetitions, particularly under the same relative intensities. A key difference between isokinetic dynamometry and free weight lifting revolves around the possibility of a failed repetition: a participant may exhibit fluctuations of force throughout a set of isokinetic exercise, but will still be able to complete the prescribed set. Whereas, if there is a sufficient decrease in force during a set of free weight exercise, the repetition will be unsuccessful and the set is terminated.

The present study indicates that with an equated load (i.e., equal percentage of mode-specific 1RM), there is a significant difference between the number of repetitions that can be completed concentrically and eccentrically at 90% 1RM (CON = 4.57 reps $\pm$ 2.21 ECC = 7.67 reps $\pm$ 3.24). There were no differences in repetitions to fatigue at any

other intensity of 1RM (60%, 70%, 80%), though there was a trend toward a higher number of repetitions being completed eccentrically at 80% 1RM ($p = 0.058$) (Table 3). This seems to support existing research which suggests differences between CON and ECC actions in terms of fatigue rate. Studies by Enoka (1996), Tesch et al. (1990), and Binder-Macleod (1996) all indicated that muscles acting eccentrically are slower to fatigue. What is unclear throughout the research, though, is how this slower fatigue rate, which was observed largely through isokinetic testing and EMG data, very sensitive measures, translates to actual repetitions of an exercise an individual is able perform, which is the practical application of the science. The issue remains unclear as noted by the fatigue curves displayed in Figure 14 indicating similar rates of fatigue between CON and ECC contractions at the tested intensities.

This is the first known study to directly measure ECC 1RM and test participants at various intensities of that 1RM using free weights. This allows for a truly equated testing load, which has not been present in studies that estimated ECC 1RM (Hollander et al., 2008) or used isokinetic dynamometry (Tesch et al., 1990; Binder-Macleod, 1996). With an equated load, differences between CON and ECC performance capabilities are minimized. Of note, however, is that while we did control for the duration of the ECC repetitions, we did not control for the amount of time to complete the CON repetitions. Research is still unclear regarding an accepted methodology for the duration of ECC repetitions, with previous studies ranging from two seconds (Hollander et al., 2008) to four seconds (Vikne et al., 2001). Such a wide range of time under tension during a

repetition could lead to major differences in the number of repetitions one is able to complete. We feel that three seconds was an appropriate duration for ECC repetitions, but acknowledge that further research is required to determine the optimal amount of time under tension during ECC exercise. Our data show that under free weight conditions and with an equated load, there remains a different fatigue rate between CON and ECC actions. The fact that there was a significant difference at 90% 1RM, followed by decreasing differences at 80%, 70%, and 60% seems to be similar to the pattern of fatigue shown by Binder-Macleod et al. (1996) (Figure 11).

Predicting ECC 1RM

When designing an effective resistance training program, it is important to utilize scientifically-based principles in the program design. Of these principles, intensity of the exercise is paramount. In resistance training, intensity is often defined as the percentage of one's 1RM. Therefore, most practitioners measure or estimate 1RM for a given exercise and calculate intensity based on that value. There are a number of benefits to estimating one's 1RM: safety, time, and simplicity among them. Prediction equations (Brzycki, 1993; Mayhew, 1992) have been used in predicting 1RM from the number of repetitions completed. The National Football League uses a similar equation to predict upper body strength for draft prospects, which was validated by Chapman et al. (1998). However, each of these prediction equations applies to traditional resistance training exercise such as the bench press, in which the concentric force capabilities are the

limiting factor. There is no known equation which has been show to accurately predict ECC 1RM.

Because ECC exercise has been shown effective in producing a number of desirable performance outcomes (Vikne et al., 2006; Hortobagyi et al., 1996; Hather, 1991), it is logical that such training be incorporated into exercise programs. Therefore, ECC 1RM should be tested or estimated to ensure any program design is based on scientific principles. Because of the challenges associated with measuring ECC 1RM, the unfamiliarity of most exercisers with the process, and the need for strict adherence to a testing protocol, a model which can accurately predict ECC 1RM is a valuable tool for any clinician or practitioner that prescribes resistance training exercises. In the present study, ECC 1RM was accurately predicted in three ways: from CON 1RM, from the number of repetitions completed *concentrically* at two absolute loads (130-150lbs and 155-175lbs), and from the number of repetitions completed *eccentrically* at two absolute loads (130-150lbs and 155-175lbs), for a total of five prediction equations.

CON 1RM was a very strong predictor of ECC 1RM ($R^2 = 0.83$), as expected. Hortobagyi & Katch (1990) indicated that individuals with greater strength concentrically demonstrated greater strength eccentrically and vice-versa when compared to individuals with less strength. Our data suggest the same: CON strength is highly correlated to ECC strength. Because testing CON strength is a more familiar process to most practitioners and exercisers, ECC testing requires more resources (multiple spotters or equipment), and

ECC loads are heavier, increasing the risk of injury and muscular soreness, a tool that allows for the use of a CON 1RM to predict ECC 1RM is desirable.

There are situations where 1RM testing is not practical or contraindicated. Populations with risk factors such as high blood pressure, heart conditions, or orthopedic injures are not advised to test for a 1RM. Additionally, testing 1RM on large groups such as athletic teams or classes may prove a time-consuming endeavor. In such circumstances, it is helpful to be able to predict 1RM from the number of repetitions that can be completed at a given weight. This study provides four such prediction models. ECC 1RM was predicted from the number of repetitions that were completed both concentrically and eccentrically at absolute weights 130-150lbs and 155-175lbs. Because of the relatively small sample size and limited number of data points, 20-pound ranges were clustered for use in the prediction models. Where there were duplicate data points within the same range for the same participant, the repetitions corresponding to the lower percentage of 1RM was used. Both weight clusters represent intensities ranging from 60% to 90% of 1RM for both CON and ECC, which provides a variety of repetitions, as well as representing a variety of ECC 1RMs.

The number of repetitions completed eccentrically at weights ranging from 130lbs to 150lbs predicted ECC 1RM with an R^2 of 0.21. As expected, the model is more accurate for heavier weights, which are closer to 1RM; repetitions completed eccentrically at weights 155-175lbs provide an $R^2 = 0.528$. These prediction models allow for submaximal testing to be performed eccentrically and provide a tool that can be

used for estimating ECC 1RM. However, these models still require the performance of ECC repetitions to failure, which can be difficult to test as previously stated. Therefore, it may be more practical to utilize models that can predict ECC 1RM from repetitions performed concentrically. In this study, the number of repetitions performed concentrically at loads ranging from 130-150lbs and 155-175lbs provided accurate predictions of ECC 1RM ($R^2 = 0.538$ and $R^2 = 0.788$, respectively). Again, the heavier loads are closer to 1RM and provide more accurate predictions. The utility of these tools for predicting ECC 1RM is that they save time, are safer for a more broad population, and, in the case of predicting ECC 1RM from concentric repetitions to failure, the test is more simply administered.

Strengths of the Study

This is the first known study that has compared the number of repetitions completed concentrically and eccentrically at a variety of equated intensities. Though there is not an accepted established method for testing ECC repetitions with free weights or in the bench press exercise in particular, the 1RM data suggest that our methodology is a valid measure of ECC strength. This study directly measured ECC 1RM through free weight exercise, a very practical application which is uncommon due to the logistical issues associated with the testing. The fact that we controlled for the duration of the ECC lifts was also a strength of this study.

Limitations of the Study

The fact that there was a subjective component in determining whether an ECC repetition was successful or not is a potential limitation of this study. However, this was ameliorated with the same tester being used for all repetitions for all subjects. It is also feasible that the bench press exercise, with weights restricted to five-pound increments, was not sensitive enough to detect small changes in fatigue. There was no attempt to rate or classify failed repetitions (i.e., half-way, nearly completed, not close, 1/4 of the way, etc.); each repetition was either successful or failed. This may have also affected the sensitivity of the measurement. There was no gradation for a failed repetition in this study which is a limitation as there may have been different times at which the muscles fatigued throughout a repetition.

Contributions of the Study

This is the first known study to directly measure ECC 1RM as well as ECC repetitions to fatigue with free weights and compare them to CON values, which provide a uniquely practical framework. The methods utilized in this study can be reproduced in any setting where a standard weightlifting bench is available and trained spotters are on hand, whereas previous studies examining fatigue under ECC conditions required the use of an isokinetic dynamometer. The 1RM data further supports previous data suggesting ECC strength is approximately 120% of CON strength. This study has yielded five prediction equations that can be used to predict ECC 1RM, tools that will save time and decrease injury potential.

Future Directions

There are a number of ways in which future research can build upon this study. If this study were reproduced, it may be beneficial to provide a reliability measure of 1RM data, such as pre- and post-testing. A future study should include an additional testing group in which repetitions to fatigue and CON 1RM are used to predict ECC 1RM. Comparing predicted ECC 1RM data to measured ECC 1M would provide cross-validation of the prediction equations created. This study isolated CON and ECC movements, but the standard bench press method is an ECC action as the barbell is lowered to the chest followed by a CON action as the bar is pressed away from the chest (ECC/CON): it may be interesting to add a ECC/CON component. Testing ECC/CON 1RM and repetitions to fatigue and comparing them to ECC and CON data would have practical application. Future studies should involve various populations for comparison, including athletes versus non-athletes, females versus males and those of differing ages such as the elderly versus younger populations. EMG data as well as hormonal markers would provide a better picture of the physiology underlying the fatigue, which would allow for manipulation of variables such as rest between repetitions, time under tension, and provide a more specific understanding of the fatigue mechanisms of each muscle action. This would provide not just a clinical understanding of fatigue and training, but would have very practical applications for those interested in maximizing muscular strength, endurance, and hypertrophy through resistance training. Larger sample sizes will also increase the accuracy of data, in particular the prediction equations, which will make them more effective for researchers and practitioners alike.

REFERENCES

Abbruzzese, G., Morena, M., Spadavecchia, L., Schieppati, M. (1994). Response of arm flexor muscles to magnetic and electrical brain stimulation during shortening and lengthening tasks in man. *Journal of Physiology, 481*(2), 499-507.

Baechle, T.R., Earle, R.W. (eds.). (2000). *Essentials of Strength Training and Conditioning, 2nd Edition.* Human Kinetics, Champaign, IL.

Bamman, M.M., Shipp, J.R., Jiang, J., Gower, B.A., Hunter, G.R., Goodman, A., McLafferty Jr., C.L., Urban, R.J. (2001). Mechanical load increases muscle IGF-I and adrogen receptor mRNA concentrations in humans. *American Journal of Endocrinology and Metabolism, 280*, E383-E390.

Billeter, R., Hoppeler, H. (1992). Muscular basis of strength. In: *Strength and Power in Sport,* P.V. Komi, ed. Boston: Blackwell Scientific. 39-63.

Binder-Macleod, S.A., Lee, S.C.K. (1996). Catchlike property of human muscle during isovelocity movements. *Journal of Applied Physiology, 80*(6), 2051-2059.

Brandenburg, J.P., and Docherty, D. (2002). The effects of accentuated eccentric loading on strength, muscle hypertrophy, and neural adaptations in trained individuals. *Journal of Strength and Conditioning Research, 16*(1), 25-32.

Brzycki, M. (1993) Strength testing. Predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance, 64*(1), 88-90.

Chapman, P.P., Whitehead, J.R. and Binkert, R.H. (1998). The 225-lb reps-to-fatigue test as a submaximal estimate of 1-RM bench press performance in college football players. *Journal of Strength and Conditioning Research, 12*(4), 258-261.

Colliander, E.B and Tesch, P.A. (1990). Effects of eccentric and concentric muscle actions in resistance training. *Acta Physiologicia Scandinavica, 140,* 31-39.

Cussler, E.C., Lohman, T.G., Going, S.B., Houtkooper, L.B., Metcalfe, L.L., ...Teixeira, P.J. (2003). Weight lifted in strength training predicts bone changes in postmenopausal women. *Medicine and Science in Sport and Exercise*, *35*(1), 10-17.

Durand, R.J., Castracane, V.D., Hollander, D.B., Tryniecki, J.L., Bamman, M.M., ...Kraemer, R.R. (2003). Hormonal responses from concentric and eccentric

muscle contractions. *Medicine and Science in Sports and Exercise, 35*(6), 937-943.

Edgerton, V.R., Roy, R.R., Gregor, R.J., Rugg, S. (1986). Morphological basis of skeletal muscle power output. In: *Human Muscle Power,* N.L. Jones, N. McCartney, A.J. McComas, eds. Champaign, IL: Human Kinetics. 43-64.

Enoka, R.M. (1996). Eccentric contractions require unique activation strategies by the nervous system. *Journal of Applied Physiology*, *81*(6), 2339-2346.

Fiatarone, M.A., O'Neill, E.F., Doyle Ryan, N., Clements, K.M., Solares, ...Evans, W.J. (1994). Exercise training and nutritional supplementation for physical frailty in very elderly people. *New England Journal of Medicine, 330*(25), 1769-1775.

Flitney, F.W., and Hirst, D.G. (1978). Cross-bridge detachment and sarcomere 'give' during stretch of active frog's muscle. *Journal of Physiology, 276*, 449-465.

Friden, J., and Lieber, R.L. (2001). Eccentric exercise-induced injuries to contractile and cytoskeletal muscle fibre components. *Acta Physiologicia Scandinavica, 171*, 321-326.

Hather, B.M., Tesch, P.A., Buchanan, P., Dudley, G.A. (1991). Influence of eccentric actions on skeletal muscle adaptations to resistance. *Acta Physiologicia Scandinavica, 143*, 177-185.

Hollander, D.B., Kilpatrick, M.W., Ramadan, Z.G., Reeves, G.V., Francois, M., ...Kraemer, R.R. (2008). Load rather than contraction type influences rate of perceived exertion and pain. *Journal of Strength and Conditioning Research, 22*, 1184-1193.

Hortobagyi, T., Devita, P., Money, J., Barrier, J. (2001). Effects of standard and eccentric overload strength training in young women. *Medicine and Science in Sports and Exercise, 33*(7), 1206-1212.

Hortobagyi, T., Hill, J.P., Houmard, J.A., Fraser, D.D., Lambert, N.J., Israel, R.G. (1996). Adaptive responses to muscle lengthening and shortening in humans. *Journal of Applied Physiology, 80*(3), 765-772.

Huxley, H. and Hanson, J. (1954). Changes in the cross-striations of muscle during contraction and stretch and their structural interpretation. *Nature, 173*, 973-976.

Ibanez, J., Izquierdo, M., Arguelles, I., Forga, L., Larrion, J.L., ...Gorostiaga, E.M. (2005). Twice-weekly progressive resistance training decreases abdominal fat and improves insulin sensitivity in older me with Type 2 diabetes. *Diabetes Care*, *28*, 662-667.

Janssen, I., Heymsfield, S.B., and Ross, R. (2002). Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of American Geriatric Society, 50*, 889-896.

Jurca, R., Lamonte, M.J., Barlow, C.E., Kampert, J.B., Church, T.S., and Blair, S.N. (2005). Association of muscular strength with incidence of metabolic syndrome in men. *Medicine and Science in Sports and Exercise, 37*(11), 1849–1855.

Komi, P.V. (1986). Training of muscle strength and power: interaction of neuromotoric, hypertrophic, and mechanical factors. *International Journal of Sports Medicine, 7*, 10-15.

Kraemer, R.R., Hollander, D.B., Reeves, G.V., Francois, M., Ramadan, Z.G. ,... Castracane, V.D. (2006). Similar hormonal responses to concentric and eccentric muscle actions using relative loading. *European Journal of Applied Physiology, 96*, 551-557.

Landers, J. (1985). Maximum based on reps. *National Strength and Conditioning Association Journal, 6*(6), 60-61.

Levinger, I., Goodman, C., Hare, D.L., Jerums, G., Selig, S. (2007). The effect of resistance training on functional capacity and quality of life in individuals with high and low numbers of metabolic risk factors. *Diabetes Care, 30*(9), 2205-2210.

Marcus, R.L., Smith, S., Morrell, G., Addison, O., Dibble, L.E., ...LaStayo, P.C. (2008). Comparison of combined aerobic and high-force eccentric resistance exercise with aerobic exercise only for people with type 2 diabetes mellitus. *Physical Therapy, 88*, 1345-1354.

Mayhew, J.L, Ball, T.E., Arnold, M.D., Bowen, J.C. (1992). Relative muscular endurance performance as a predictor of bench press strength in college men and women. *Journal of Applied Sport Science Research, 6*(4), 200-206.

Metter, E.J., Talbot, L.A., Schrager, M., Conwit, R. (2002). Skeletal muscle strength as a predictor of all cause mortality in healthy men. *Journal of Gerontology*, *57*(10), 359-365.

Milner-Brown, H.S., Stein, R.B., Lee, R.G. (1975). Synchronization of motor units: possible roles of exercise and supraspinal reflexes. *Electroencephalography and Clinical Neurophysiology, 38,* 245-254.

Morris, F.L., Naughton, G.A., Gibbs, J.L., Carlson, J.S., Wark, J.D. (1997). Prospective ten-month exercise intervention in premenarcheal girls: positive effects on bone and lean mass. *Journal of Bone and Mineral Research, 12*(9), 1453-1462.

Nardone, A., Romano, C., Schieppati, M. (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *Journal of Physiology, 409*, 451-471.

Newton, M.J., Morgan, G.T., Sacco, P., Chapman, D.W., Noska, K. (2008). Comparison of responses to strenuous eccentric exercise of the elbow flexors between resistance-trained and untrained men. *Journal of Strength and Conditioning Research, 22*(2), 597-607.

Neyroud, D. Ruttimann, J., Mannion, A.F., Millet, G.Y., Maffiuletti, N.A., Kayser, B., Place, N. (2013). Comparison of neuromuscular adjustments associated with sustained isometric contractions of four different muscle groups. *Journal of Applied Physiology, 114,* 1426-1434.

Pensini, M., Martin, A., Maffiuletti, N.A. (2002). Central versus peripheral adaptations following eccentric resistance training. *International Journal of Sports Medicine, 23,* 567-574.

Ploutz, L.L., Tesch, P.A., Biro, R.L., Dudly, G.A., (1994). Effect of resistance training on muscle use during exercise. *Journal of Applied Physiology, 76*, 1675-1681.

Proske, U., and Morgan, D.L. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *Journal of Physiology*, *537*(2), 333-345.

Sale, D.G. (1987). Influence of exercise and training on motor unit activation, *Exercise & Sport Science Reviews, 15*(1), 95-151.

Sale, D.G., MacDougall, D. (1981). Specificity in strength training: a review for the coach and athlete. *Canadian Journal of Applied Sport Science, 6*(2), 87-92.

Spudich, J.A. (2001). The myosin swinging cross-bridge model. *Nature Reviews Molecular Cell Biology*, *2*, 387-392.

Tesch, P.A., Dudley, G.A., Duvoisin, M.R., Hather, B.M., Harris, R.T. (1990). Force and EMG signal patterns during repeated bouts of concentric or eccentric muscle actions. *Acta Physiologica Scandinavica, 138,* 263-271.

Vikne, H., Refsnes, P.E., Ekmark, M., Medbo, J.I., Gundersen, V., Gundersen, K. (2006). Muscular performance after concentric and eccentric exercise in trained men. *Medicine and Science in Sports and Exercise*, *38*(10), 1770-1781.

Zatsiorsky, V.M., Kraemer, W.J. (eds.). (2006) *Science and Practice of Strength Training, 2nd Edition.* Human Kinetics, Champaign, IL.

APPENDIX A

RECRUITMENT FLYER

CAN YOU BENCH PRESS?

Want to participate in a research study?

I am a doctoral candidate in Physical Activity, Nutrition, and Wellness at ASU and I need your help. I'm looking for:

- Men Ages 18-40
- At least one year of bench press experience
- No injuries to the shoulders, elbows, or wrists in the past year
- No cardiovascular disease
- No high blood pressure

The study will consist of 6 sessions (approximately 15 minutes apiece after the initial session) over 4 weeks. You will be tested for your 1-Rep Maximum in the concentric (raising) and eccentric (lowering) bench press. You'll also be tested in the number of repetitions you can complete at different percentages of 1RM. You will also be tested for body fat percentage and get an explanation of all scores. Give me a call and come find out how much ya bench!



Steve (928)210-4342 sbkelly2@gmail.com
Steve (928)210-4342 sbkelly2@gmail.com
Steve (928)210-4342 sbkelly2@gmail.com
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Steve (928)210-4342 sbkelly2@gmail.com
Steve (928)210-4342 sbkelly2@gmail.com

Appendix B

Oral Recruiting Script

Recruiting Script

Comparison of Concentric and Eccentric Muscle Actions

Hi. My name is Steve Kelly and I'm a doctoral candidate in the Physical Activity, Nutrition, and Wellness program at ASU. I'm here to recruit participants for my dissertation project. I will be comparing concentric and eccentric muscle actions in the bench press exercise. The concentric phase just means the raising phase as you extend your arms. The eccentric phase is when you're lowering the bar toward your chest. I'm testing which action is strongest as well as if they fatigue at different rates, which will be tested by having you do repetitions to failure at different percentages of your one-repetition maximum. Participation will involve 6 sessions over the course of 4 weeks. The first session will be about 45 minutes long and will include a detailed explanation of the procedures, answering of any questions you may have, signing a waiver and a physical activity readiness questionnaire health screening form, measuring your height, weight, and body fat and testing your 1RM for either concentric or eccentric bench press, which will be decided by a coin flip. Before each session I will also measure your resting blood pressure to rule out the presence of high blood pressure. During the next session we will test your 1RM in the other action and will take around 15 minutes. The next four sessions will also be about 15 minutes each and will consist of a few warm-up sets followed by testing how many reps you can complete at different percentages of your 1RM.

I am looking for males between the ages of 18 and 40 who have been doing the bench press for at least one year, at least once a week. You also have to be upper-body injury free for the last year, particularly the shoulders, elbows, and wrists, and not have high blood pressure, or any symptoms of cardiovascular disease.

If you fit the criteria and are interested in participating, or just want more information, please put your name and email address/phone number on the paper going around and I will contact you soon. You can also call or text me at (928) 210-4342 or email me at stephen.b.kelly@asu.edu. Thank you for your time!

APPENDIX C

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Title: Comparison of Concentric and Eccentric Muscle Action

ID: _____ Date:_____

Physical Activity Readiness Questionnaire (PAR-Q)

Please read the questions carefully and answer each one honestly:
Type/Write Yes or No

_____ Has your doctor ever said that you have a heart condition and that you should only do physical activities recommended by a doctor?

_____ Do you feel pain in your chest when you do physical activity?

_____ In the past month, have you had chest pain when you were not doing physical activity?

_____ Do you lose your balance because of dizziness or do you ever lose consciousness?

_____ Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity?

_____ Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

_____ Do you know of any other reason why you should not do physical activity or weight lifting?

APPENDIX D

INFORMED CONSENT FORM

CONSENT FORM
COMPARISON OF CONCENTRIC AND ECCENTRIC MUSCLE ACTIONS

INTRODUCTION

The purposes of this form are to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study.

RESEARCHERS

Barbara Ainsworth PhD, MPH, Professor in the Healthy Lifestyles Research Center and Program in Exercise and Wellness, College of Nursing and Health Innovation, and Steve Kelly, doctoral candidate in the Physical Activity, Nutrition, and Wellness Program have invited your participation in a research study.

STUDY PURPOSE

The purpose of the research is to compare two different types of muscle action: concentric (when the muscle shortens), and eccentric (when the muscle lengthens). Concentric and eccentric will be compared in terms of strength and the number of repetitions you can complete before fatigue. Previous studies have shown that eccentric actions are capable of producing more force than concentric actions, but none have shown whether these two types of actions have different patterns of fatigue.

DESCRIPTION OF RESEARCH STUDY

If you decide to participate, then as a study participant you will join a study involving bench pressing movements with concentric and eccentric actions. Following completion of the Physical Activity Readiness Questionnaire and blood pressure measurement to determine eligibility for this study, you will complete a health history questionnaire. Then, you will be tested for height, weight, and body fat percentage in a Bodpod. After these tests, you will warm up by riding a stationary bicycle for five minutes. You will then warm up with some regular bench presses and then we will test your 1-repetition maximum (1RM) in the concentric bench press or eccentric bench press. This means we will find the most amount of weight you can do one time for each lift. The first session will be one 1RM test, then seven days later will be the other (the order will be determined by a coin flip). For concentric lifts, the bar will be lowered down to your chest with a mechanical winch. You will then press the bar up until your elbows are locked out. For the eccentric lift, you will lower the bar for seconds until it touches your chest. The bar will then be lifted off of you with the mechanical winch. After we have your 1RM we will test how many repetitions you can complete at different percentages of that 1RM, including 90, 80, 70, and 60% for both types of lift. Every participant will be tested for every lift. The number of repetitions you can complete and the total weight will be recorded. There will be six total sessions. The first session will be approximately 45 minutes. Each subsequent session will last approximately 15 minutes.

If you say YES, then your participation will last for 4 weeks at the Chandler-Gilbert Physical Education Center on the Williams campus. Approximately 50 subjects will be participating in this study.

RISKS

Potential risks associated with participation in this study are predominately muscular. With any type of weightlifting, there may be some muscular soreness. There is also the potential for damage to the joints, tendons, or ligaments of the upper body. As with any research, there is some possibility that you may be subject to risks that have not yet been identified. A mechanical crane and a trained spotter will be utilized during each repetition to ensure weights will not fall on you in the event of a failed repetition.

BENEFITS

The possible/main benefits of your participation in the research are increased strength in the bench press exercise, as well as contributing to the understanding of how muscles react to these different types of muscle actions.

NEW INFORMATION

If the researchers find new information during the study that would reasonably change your decision about participating, then they will provide this information to you.

CONFIDENTIALITY

All information obtained in this study is strictly confidential unless disclosure is required by law. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, Steve Kelly will immediately assign you a code, which will be used to identify you in all electronic data files. Your informed consent and any other documents containing your name will be kept in a locked filing cabinet in a private office located in the ASU Polytechnic Campus' Exercise andWellness building, which will be accessible only to members of the research team.

WITHDRAWAL PRIVILEGE

It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time. Your decision will not affect your relationship with Arizona State University or otherwise affect your grade or treatment in class.

COSTS AND PAYMENTS

There is no payment for your participation in the study.

COMPENSATION FOR ILLNESS AND INJURY

If you agree to participate in the study, then your consent does not waive any of your legal rights. However, no funds have been set aside to compensate you in the event of injury.

VOLUNTARY CONSENT

Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Steve Kelly, 7350 E. Unity Dr., Mesa, AZ 85212, (928) 210-4342, Stephen.b.Kelly@asu.edu

If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk; you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at 480-965 6788.

This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be given (offered) to you.

Your signature below indicates that you consent to participate in the above study.

_____	_____	_____
Subject's Signature	Printed Name	Date

INVESTIGATOR'S STATEMENT

"I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. These elements of Informed Consent conform to the Assurance given by Arizona State University to the Office for Human Research Protections to protect the rights of human subjects. I have provided (offered) the subject/participant a copy of this signed consent document."

Signature of Investigator_____
Date_____

APPENDIX E

INSTITUTIONAL REVIEW BOARD APPROVAL

Arizona State University Office of Research Integrity and Assurance P.O. Box 871103 Tempe, AZ 85287-1103 Phone: 480-965-6788 Fax: 480- 965-7772		*For Office Use Only:* H.S. #: Pre-Reviewer:

BIOSCIENCE APPLICATION HUMAN SUBJECTS

PROTOCOL INFORMATION

1.
Protocol Title: Comparison of Concentric and Eccentric Muscle Actions

Date of Request: 9/16/09

PRINCIPAL INVESTIGATOR (PI)

Please note that the PI's CV and human subject's protection training certification must be attached with this application.

2.
Name and Degree(s): Barbara Ainsworth, PhD, MPH

Department/Center: Physical Activity, Nutrition, and Wellness

Mailing Address: 7350 E. Unity Ave, Mesa, AZ 85212

Email: Barbara.Ainsworth@asu.edu Phone #: 480-727-1945 Fax: 480-727-1051

University Affiliation:
☒ Professor
☐ Associate Professor
☐ Assistant Professor
☐ Instructor
☐ Other: Please specify. ("Other" categories may require prior approval. Students cannot serve as the PI)

CO-INVESTIGATORS (CO-I)

- A Co-I is anyone who has responsibility for the project's design, implementation, data collection, data analysis, or who has contact with study participants.
- If the project involves medical procedures or patient care that the PI is not certified or licensed to conduct, a responsible physician or other certified or licensed professional must be included as a Co-I. The application must include a copy of supporting documentation for this individual (CV, license, board certification etc).

3. Name | Study Role | Affiliation | Department | Email/Tel/Fax | Student (yes/no)

Stephen Kelly | Data Collection | ASU | Ex.& Wellness | Stephen.B.Kelly@asu.edu | Yes

Laurie Black | Data Collection | ASU | Ex & Wellness | Laurie.E.Black@asu.edu | Yes

Bradley Warr | Data Collection | ASU | Ex & Wellness | bwarr@asu.edu | Yes

Brent Alvar | Data Collection | CGCC | Wellness | brent.alvar@cgcmail.maricopa.edu | NO

PROJECT FUNDING

4a) How is the research project funded? (A copy of the grant application **must** be provided prior to IRB approval)

☒ Research is **not funded** (Go to question 5)
☐ Funding decision is pending
☐ Research is **funded**

b) What is the source of funding or potential funding? (Check all that apply)

☐ Federal ☐ Private Foundation ☐ Department Funds
☐ Subcontract ☐ Fellowship ☐ Other

c) Please list the name(s) of the sponsor(s):

d) What is the grant number and title?

e) What is the ASU account number/project number?

f) Identify the institution(s) administering the grant(s):

SUMMARY OF PROTOCOL

Please include a summary for each of the questions. Use as much space as necessary **AND** attach a copy of the study proposal or protocol. If you attach a copy of the full proposal, place page and paragraph numbers from the proposal next to each question in this section to show precisely where information pertaining to each question can be found. Please note that information should be **consistent** between the proposal, consent form, and IRB application. **FOR ALL OF THE QUESTIONS, WRITE YOUR ANSWERS ON THE APPLICATION RATHER THAN SAYING SEE ATTACHED.**

5a) What is the hypothesis? The primary aim of the study is to examine whether there are differences in the number of repetitions completed at each percentage (60, 70, 80, 90%) of one-repetition maximum (1RM) between concentric (raising the bar from the chest) and eccentric bench press (lowering the bar to the chest). The secondary aim of the proposed study is to develop a prediction equation for estimating 1RM from the number of repetitions completed at various intensities on the eccentric bench press. The study aims will be achieved through testing 1RM as well as number of repetitions completed at a series of percentages of 1RM for concentric and eccentric actions. A tertiary aim is to explore whether there are differences between the concentric and eccentric bench presses in 1RM performance. Based on previous literature, it is hypothesized that the 1RM values for the eccentric bench press will be statistically greater than those in the concentric bench press. No studies have been published to assess how the repetitions to fatigue at various relative intensities (%1RM) differ between eccentric and concentric lifts, thus it is hypothesized that there will be no significant differences between the different muscle actions. It is also hypothesized that the prediction equation to estimate 1RM from the number of repetitions completed will be similar between exercises.

b) Describe study procedures and methodologies. Prior to being enrolled in the study, potential participants will be required to complete a physical activity readiness questionnaire (PAR-Q) to rule out subjects with cardiovascular risk factors which may prevent them from safely participating. Additionally, blood pressure will be measured prior to inclusion in the study as well as prior to each weightlifting session to rule our subjects with hypertension (defined as resting blood pressure greater than 160/90mmHg). Once subjects are deemed physically able to participate, they will read and sign an informed consent form which will be approved by the Arizona State University Institutional Review Board. Subjects will participate in a total of six testing sessions. The first session will include an oral and written description of the methods of the study, answering any questions participants may have, signing of informed consent, and measurements of height, weight, and body composition prior to any strength testing. Body composition will be measured in a BodPod system which simply requires participants to sit in a small chamber as body density is calculated. All data will be collected in the Chandler-Gilbert Community College Physical Education Center on the Williams campus. The initial two sessions will include warm-up followed by testing 1RM in either concentric or eccentric bench press (tested in random order) and will be separated by seven days.

Concentric bench press will be performed by pushing the barbell from a resting position on the chest to complete extension of the elbows. The weight will be passively returned to the chest following each repetition via mechanical crane. A failed repetition will be one in which the subject is not able to completely extend the elbows. Eccentric bench press will consist of lowering the barbell from a fully extended position to the chest in a controlled manner over three seconds as determined by a countdown in correspondence to a metronome. The weight will then be returned to the starting position via mechanical crane. A failed eccentric repetition is one in which the subject loses control of the weight at any time or allows the weight to touch the chest before the full three seconds. Subjects will be given 2 to 5 minutes of rest between attempts. Weights will continue to increase until participants fail twice at a weight. The greatest value successfully lifted in each exercise will be used as the 1RM. Warm-up for all testing sessions will be comprised of 5 minutes of pedaling a cycle ergometer at 75-90 rpm and 3 sets of 10, 5, and 3 repetitions respectively of standard (eccentric followed by concentric) bench press at 60, 75, and 90% of estimated 1RM respectively.

The third through sixth sessions will include warm-up followed by maximal repetition testing at one ECC and one CON percentage. 60, 70, 80, and 90% of mode-specific 1RM will be tested for each exercise. The order of exercise as well as percentage of 1RM will be randomized without replacement so that all percentages of each exercise will be completed by each participant. All sets will be performed to volitional fatigue, meaning subjects will complete as many repetitions as possible until they are unable to perform a valid repetition. When failure occurs, subjects will be "spotted" by the mechanical crane. This will prevent the weight from falling upon the subject. 8 to 10 minutes of rest will be given between sets. The number of repetitions completed at each percentage of 1RM will be recorded as the dependent variable.

c) What is the participant selection? 50 males (aged 18-40 years) with a self-report of at least one year of resistance training experience will serve as subjects. Resistance training experience will be defined as having performed the bench press exercise a minimum of once per week. Orthopedic injuries to the upper extremities within the past year , current hypertension, and coronary heart disease signs and symptoms identified by the PAR-Q will serve as exclusionary criteria. Injuries will include self reported and physician diagnosed (ie: shoulder pain, etc.). This will be self-reported on the PAR-Q. Subjects will be recruited from Arizona State University's Polytechnic campus as well as from local fitness clubs.

d) What is the statistical design? A 2 x 4 (Muscle Action x Intensity) two-way analysis of variance will be used to examine differences in the number of repetitions completed at each percentage of 1RM between CON and ECC. Simple regression analysis will be used to develop equations for predicting 1RM from number of repetitions to failure at each intensity.

e) Describe whether the study involves randomization to control/intervention groups. All subjects will complete all testing conditions. The order in which they perform 1RM testing will be randomized. The repetitions to fatigue at each percentage of 1RM will also be performed in random order.

f) How will study results be used? The results of this study will be submitted to a peer-reviewed journal for publication. Results will also be presented at professional conferences.

DATA SAFETY MONITORING BOARD (DSMB)

6a) Does the study have a Data Safety Monitoring Board?
☐ Yes (prompt submission of DSMB reports is required) ☒ No

b) If no, what is the structure/plan to report serious adverse events to the ASU IRB? Any injuries incurred as a result of this study will be immediately reported to the appropriate member of the IRB committee via email. Follow-up emails and phone calls will take place as necessary.

STUDY DURATION

7a) What is the expected duration of the study through data analysis? (Attach a timeline, if applicable) Data collection will begin as soon as IRB approval is received and subjects are recruited. We anticipate analysis will be concluded by December 31, 2009.

b) What is the expected date that recruitment will begin? (must be after the submission date) As soon as approval is received.

STUDY SITES

8a) Where will the study be conducted? (Check all that apply)
☒ On campus (Please indicate building(s) and room number (s) when known) In the Physical Education Center on the
Chandler-Gilbert Community College Williams campus

☐ Off campus (Please provide location and letter of permission, where applicable)

b) Is this study being reviewed by another IRB? ☐ Yes ☒ No

Status of other IRB review: ☐ Approved ☐ Pending ☐ Not yet submitted ☐ Attached

INTERNATIONAL RESEARCH

9a) Does this study include an international site? ☐ Yes (list country) ☒ No

9b) If this is an international study, please provide a statement including the following items:

- The investigator's familiarity with the culture in which the study in taking place.
- Cultural norms and how this study may affect an individual's standing in his/her community.
- The standard of care in the community, how it differs from the proposed research procedures, and a plan for the continuation of care once the research is complete.

RESEARCH PARTICIPANT INFORMATION

10a) What are the inclusion criteria? (Use an expended list and attach a secondary sheet with explanation, where applicable. If you attach a secondary sheet, reference on which page the information can be found.)
Subjects will be males ages 18-40 with a self-report of at least one consecutive year of resistance training in the bench press exercise who are not at risk for cardiovascular disease or hypertension.

b) What are the exclusion criteria? Orthopedic injuries (previously diagnosed by a physician or self-reported) to the upper extremities within the past year, failure to pass the PAR-Q, and/or high resting blood pressure will exclude potential participants from this study.

c) Please explain recruitment procedures in detail. (A copy of the recruitment materials must be attached.) Subjects will be recruited from classes in the program in exercise and wellness, College of Nursing and Health Innovation, with the co-investigators delivering an oral script with permission from each course's instructor. Additionally, fliers will be posted on the ASU Polytechnic and Chandler-Gilbert Community College campuses. (Script and flyer attached)

d) What is the expected duration of participation of each participant? (total and at each session) Each subject will be involved in the study for approximately 4 weeks. This will include 6 testing sessions which will be approximately 15 minutes each, except for the initial session. The initial session, which is included in the 6, will involve collecting more variables and will last approximately 45 minutes.

e) What is the expected number of individuals to be screened for enrollment? 200

f) What is the **maximum** number of individuals to be enrolled? (This includes individuals who drop out) 50

g) What is the approximate number of: 50 Males 0 Females

h) Indicate the age range of the participants that you plan to enroll in your study.
18 to 40

i) What is the race of participants? Race will not be a factor.

j) Does the study target any of the following participants? ☐ Yes (please check all that apply) ☒ No

☐ Children (under 18)
☐ Decisionally impaired
☐ Prisoners or detainees
☐ Pregnant women
☐ Economically disadvantaged
☐ Persons at high risk of becoming detained or imprisoned
☐ Fetuses
☐ Patients, if yes – what is the status of their health?
☐ Native Americans
☐ Non-English speakers (Include copy of all materials in language of participants)

k) If **any** of the above categories have been checked, please state how you will protect the rights and privacy of these individuals.

l) Does the study involve participants who have **low-literacy**? ☐ Yes ☒ No (If yes, please describe how investigators will ensure the participants' understanding of the research):

m) Does the study involve participants who are **students or faculty** of ASU? ☒ Yes ☐ No (If yes, please state the investigator's involvement in the participant's education/employment): Participants may include students enrolled in courses in which the investigators are instructors. However, participation in this study will have no effect on students' grades.

COMPENSATION

11. Will any type of compensation be used? (e.g. money, gift, raffle, extra credit, etc)

a) ☐ Yes (Please describe what the compensation is): ☒ No (go to question 12)

b) Explain why the compensation is reasonable in relation to the experiences of and burden on participants.

c) Is compensation for participation in a study or completion of the study? (Note: participants must be free to quit at any time without penalty).

☐ Participation ☐ Completion

d) If some or all participants are economically disadvantaged, explain how the compensation is provided in such as a way that participants cannot refuse the request to participate?

RISKS AND BENEFITS

Please reference the proposal, where applicable and answer the questions below.

12a) What are potential risks to participants? As with any study of this nature, the risks are predominantly limited to musculoskeletal damage and soreness.

b) What steps will the investigators take to reduce risks? Proper warm-up will be employed in order to minimize the risk for musculoskeletal damage. This includes a general warm-up on a cycle ergometer to increase blood flow and muscle temperature as well as a muscle-specific warm-up for the muscles of the bench press exercise. Additionally, the inclusion criteria require participants to be experienced in the tested movement and not have hypertension or signs and symptoms of coronary heart disease. This will alleviate potential damage caused by inexperience and will minimize muscular soreness. The use of the mechanical crane as well as a trained spotter will be utilized during each repetition to ensure weights will not fall on subjects in the event of a failed repetition.

c) What are any potential benefits to participants? Participants will be tested and made aware of their scores for body composition and 1RM in the concentric and eccentric bench press.

d) Please note how the results of the study will affect the health and welfare of the general public. This study will provide insight into differences in muscle contraction type in terms of fatiguability and strength. The implications include future design of resistance training programs.

e) What are the types of incentives, if any, will participants receive? None

f) What are the costs, if any, to participants? (This should be mentioned in the consent form): None

CONFIDENTIALITY

13a) Describe the steps you will take to ensure the confidentiality of the participants and data. Each participant will be given a code number which will appear on all forms and data sheets. Signed informed consent forms and hard data sheets will be kept in a locked filing cabinet in Dr. Barbara Ainsworth's office, Room 106 in the Exercise and Wellness building, which is accessible only to members of the research team. All electronic copies will be stored on a password-protected computer accessible only to members of the research team.

b) How will you safeguard data that includes identifying or potentially identifying information (e.g. coding)? Each subject will be given a code number during the initial visit, which will serve as an identifier for the remainder of the study. The master list which matches subjects' names to their code numbers will be destroyed immediately upon completion of data collection.

c) When will identifiers be separated or removed from the data? All identifiers other than the designated code number will be removed from both hard and electronic copies of data sheets.

d) Where on campus will you store the data and media and ensure its security (videotapes and/or audiotapes)? Data will be stored in a password-protected computer and stored in Dr. Barbara Ainsworth's office, Room 106.

e) How long do you plan to retain the data? Data will be retained for 5 years following final analysis and kept in Dr. Barbara Ainsworth's office.

f) How will you dispose of the data? Hard copies will be shredded and incinerated and electronic copies will be deleted and removed from electronic recycle bins.

g) Is a certificate of confidentiality required? ☐ Yes ☒ No

HIPAA

14a) Are any of the data coming from covered entities under Health Insurance Portability and Accountability Act (HIPAA)? ☐ Yes ☒ No (If yes, please describe):

b) Is a data use agreement required? ☐ Yes ☐ No

c) Is a HIPAA Waiver of Authorization being requested? ☐ Yes ☐ No

DATA SOURCES AND USES

15a) Please check all the ways that you will obtain data: (Copies of written and oral questions must be provided for ASU IRB review and approval prior to implementation.)

☐ Interviews
☐ Focus Groups
☐ Medical Records
☐ Registries
☒ Questionnaires/Surveys
☐ Public Records
☐ Biological Specimens
☒ Other Direct observation

b) How will the data be used? (Check all that apply)

☒ Dissertation
☐ Thesis
☒ Results released to participants/parents
☐ Results released to agency or organization
☐ Other *(please describe):*
☒ Publication/journal article
☐ Undergraduate honors project
☐ Results released to employer or school
☒ Conferences/presentations

INFORMED CONSENT

16. Describe the procedures you will use to **obtain and document informed consent and assent**. **Attach copies of the forms that you will use.** In the case of secondary data,

please attach original informed consent or describe below why it has not been included. Fully justify any request for a waiver of written consent or parental consent for minors. (The ASU IRB website has additional information and sample consent and assent forms.) Subjects will read and sign consent forms prior to any data collection. Participants will be made aware of any potential risks and benefits of the study as well as intended uses of data. They will be informed that they may withdraw from the study at any point with no negative consequences. Participants will be welcomed to ask any questions. When all questions are answered, each participant will sign the IRB-approved informed consent form and be provided with a copy. This will occur prior to any testing.

INVESTIGATIONAL NEW DRUG OR DEVICE

17a) Does this study involve an investigational new drug (within the meaning of 21 U.S.C. 355(i) or 357(d)) or a significant risk device (as defined in 21 CFR 812.3(m)?
☐ Yes ☒ No (If no, go to question 18. If unsure, go to: www.fda.gov/oc/ohrt/irbs/).

b) What is the drug or device?

c) Has the 30-day interval required for investigational new drugs and for significant risk devices elapsed, or has the FDA has waived that requirement?

d) If the 30-day interval has expired, has the FDA requested that the drug or device be withheld or restricted for use in human subjects? ☐ Yes ☐ No

DRUGS

18. What are the drugs to be used and in what dosage? (If no drugs will be used, please write N/A.) N/A

RADIATION

19a) Will ionizing radiation (x-rays and or radiopharmaceuticals) be used? ☐ Yes ☒ No (If yes, include a copy of the radiation certification).

b) Will non-ionizing radiation (MRI, ultrasound, lasers, ultraviolet) be used? ☐ Yes ☐ No

BIOLOGICAL MATERIALS

20a) Will biological materials be collected from subjects or given to subjects? ☐ Yes ☒ No (If no, please skip to question 21)

b) Provide a description of the material (blood, tissue, vectors, antibodies, etc.) that will be used:
c) If the study involves human blood, do you have the required ASU Biosafety disclosure on file? ☐ Yes ☐ No
(If yes, what is the biosafety disclosure number?)
(If yes, when and how are the samples to be destroyed? Note: an active protocol is required the entire period that the samples are retained)

d) Will any of the material being used in the study come from a third party? ☐ Yes ☐ No (If yes, attach copy of the Material Transfer Agreement if required.)

e) Does this study involve transfer of genetic material of animal tissue into humans? ☐ Yes ☐ No
(If yes, please cite the ASU Institutional Biosafety Disclosure number).

GENETIC ANALYSIS

21a) Does this study involve genetic analysis? ☐ Yes ☒ No (If no, please skip to question 22).

b) What sources of genetic material will be studied (blood, tissue, DNA)?

c) Please specify whether the genetic analysis involves pedigree, positional cloning, mutational polymorphism, or gene therapy research.

d) Please specify whether:
☐ Stored samples already exist
☐ Samples will be collected specifically for this study
☐ Stored samples already exist from a previously approved study
☐ Samples collected are part of a routine clinical procedure
☐ Samples are discarded, already existing, and de-identified

e) If stored samples will be used, did participants consent to the use of their stored sample(s)?
☐ Yes ☐ No (If yes, was the consent prospective to collection of the sample, or retrospective of the collection of the sample?)

f) Will any identifiers be maintained? ☐ Yes ☐ No (If yes, please specify)

g) When will samples be destroyed or discarded?

h) Are any of the diseases being studied considered preventable? ☐ Yes ☐ No

i) Is there a possibility of an incidental finding of a genetic condition? ☐ Yes ☐ No
If so, is there a plan to disclose this to the individual?

j) Will this information be kept confidential from third parties such as employers, or insurance companies, or will findings be included in the participant's medical record for clinical treatment?

k) How will other risks (e.g. discovery of information regarding paternity or ancestry) be disclosed to subject?

CONFLICT OF INTEREST AND COMMERCIALIZATION

22a) Does any member of the research team have a potential conflict of interest with this study that could affect study participants and/or study outcome? For more information about examples of conflicts of interests, please visit the ASU objectivity website: http://researchintegrity.asu.edu/objectivity/index.htm

☐ Yes ☒ No (If yes, please describe and disclose in the consent form)

b) Does the PI or Co-I have a current conflict disclosure questionnaire on file at the ASU Office of Research Integrity and
Assurance?

☒ Yes ☐ No (Review ASU's objectivity in research policy: http://www.asu.edu/aad/manuals/rsp/rsp206.html)

c) Among the research team, is there any financial association that could affect any of the following:
the study outcome, data analysis, enrollment of subjects, study design?

☐ Yes ☒ No (If yes, please describe and disclose in the consent form)

d) Are there any plans for commercial development related to the findings of this study?

☐ Yes (If yes, please describe.) ☒ No

e) Will the investigator or member of the investigator's family financially benefit if the findings are commercialized?

☐ Yes (If yes, please describe.) ☒ No

f) Will participants financially benefit if the findings are commercialized?

☐ Yes (If yes, please describe.) ☒ No

g) If there are conflicts of interests, please describe the ways in which the researchers will minimize harm to research subjects and/or the objectivity of research.

TRAINING

23. The research team must document completion of human subjects training.

Please provide the date that the PI and Co-Investigators completed the training.

(Attach a copy of the NIH Certificate for Human Participants Protections Education for Research Teams or CITI Training: http://researchintegrity.asu.edu/irb/training/for the PI and Co-Investigators. Training must be within the past 3 years)

REQUIRED SIGNATURES

24. By signing this application form:
- I agree to accept responsibility for the rights and welfare of the human subjects involved with this study.
- I believe that the benefits outweigh the risks to the participants in this study.
- I agree to comply with Arizona State University IRB policies and procedures.
- I certify that, to the best of my knowledge, I am in compliance with the Department of Health and Human Services policies and procedures regarding the protection of human subjects.

Principal Investigator Date

Attach a copy of the PI's CV unless one is already on file with the Research Compliance Office.

Department Chair/Dean Date Print Department Chair/Dean Name

(If the PI is the Department Chair or Dean, the application must be signed by another authorized Department/ School/College level Administrator)

FOR OFFICE USE:	This application has been reviewed by the Arizona State University IRB: ☐ Full Board Review ☐ Expedite Categories:_____ ☐ Exempt Categories: _____ ☐ Approved ☐ Deferred ☐ Disapproved ☐ Project requires review more often than annual Every months
Signature of IRB Chair/ IRB Member:	Date:

APPENDIX F

CONTINUING REVIEW FORM

CONTINUING REVIEW FORM- IRB

- In accordance with Federal Regulations 45CFR46, the IRB must review nonexempt protocols at least annually, or more frequently if warranted.
- Please type your responses in the boxes provided. Use as much space as necessary (the boxes will expand). Please answer each question – if a question is not applicable, please put N/A in the box.
- Studies that are in the data analysis phase are considered open, researchers must complete this form.

1. Principal Investigator	
Principal Investigator: Barbara Ainsworth	
ASU department address: 7350 E. Unity Ave. Mesa, AZ 85212	
E-mail address: Barbara.Ainsworth@asu.edu	
Phone number: 480-727-1945	Fax Number: 480-727-1051
Co-Investigator(s) Name(s) and Contact Information: Stephen Kelly Stephen.B.Kelly@asu.edu; Laurie Black Laurie.E.Black@asu.edu; Bradley Warr bwarr@asu.edu; Brent Alvar brent.alvar@cgcmail.maricopa.edu	

2. Protocol Information
2a) Title of protocol: Comparison of Concentric and Eccentric Muscle Actions
2b) HS #:
2c) If project is funded or funding is being sought, provide list of all sponsors and grant numbers: Please indicate the grant status for each source of funding: ☐ Active ☐ Pending
2d) ASU account number/project number: 0909004356
2e) Location(s) of research activity: Arizona State University Polytechnic Campus, Mesa, AZ
2f) IRB approval dates from additional institutions: **Please note that copies of current IRB approvals from additional institutions are required.*

3. Protocol Status
3a) Active: ☒ Yes ☐ No (If no, submit a close out report: http://researchintegrity.asu.edu/humans/forms 3b) Please indicate remaining duration of the study: 5 months
4. Participant Information

4a) Is this study closed to enrollment of new subjects: ☒ Yes ☐ No
4b) Total number of participants approved for the study (to be enrolled): N/A
4c) Number of participants enrolled during the **past approval period**: 50
4d) Total number of participants enrolled **since study began**: 35
4e) Total number of participants screened in the past approval period (if applicable): 50
4f) Of the total participants screened in the past approval period, what percentage has been ineligible to participate in the study (if applicable)? 30
4g) Number of participants who withdrew from the study: 5 Please state the reason(s) the participant(s) withdrew. Non-attendance
4h) Number of participants still to be enrolled: 0 (If this brings the sample to greater than what is listed in 4b, submit a request for modification see 7c).
4i) Participant enrollment breakdown by gender, age and ethnicity: (This information is required for all studies that are NIH-sponsored. It is recommended, but not required, that other researchers provide this information). 35 males aged 18-40 years (ethnicity not a variable)

5. Data Sources Check all categories that apply to your protocol:	
☒	Human subjects intervention with use of informed consent form
☐	Discarded, identified pathological materials, no intervention
☐	Genetic analysis
☒	Interviews or questionnaires
☐	Medical records or other records from human subjects
☐	Other please specify:

6. Adverse Events or Unexpected Problems

Have there been any complaints from subjects in the past approval period?
Yes If yes, describe ☒ No

) Have there been any ***adverse events*** or unexpected problems in the past approval period?
Yes ☒ No
If yes, please explain in detail and indicate when the IRB was notified of the event or problem. If the IRB was not notified, please explain why this was not done.

) Does the study have a Data Safety Monitoring Board (DSMB)? ☐ Yes ☒ No
If yes, please indicate the date of the last DSMB review:

Please note that investigators are required to submit DSMB reports to the ASU IRB at the time they are made available to the investigator.

7. Protocol Modifications or Revisions

) Have there been any modifications or revisions to the protocol in the past approval period?
Yes ☒ No
If yes, please indicate the date of the approval from the Committee for the modification or revision and provide a brief description.

) Have there been any deviations from the approved protocol? ☐ Yes ☒ No
es, please describe to self-report the protocol violation.
) Do you want to add any new co-investigators to the study? ☐ Yes ☒ No
If yes, submit their names and copies of the human subjects training required by the IRB: http://researchintegrity.asu.edu/training/humans
) Do you wish to submit a modification at this time? ☐ Yes ☒ No
If yes, please describe the modification request and rationale for the changes:

8. Current Consent Form

) Please attach a copy of your current consent form for renewal if you are enrolling new subjects.

) Is this the original consent form or a revised form? ☐ Original ☐ Revised (If revised, please provide date of ASU IRB approval for the revision. Attach a copy of the stamped form and unstamped form)

9. Protocol Progress Report

Please submit a ***detailed*** progress report. The progress report must be substantive and complete, and include the goal(s) of the study, findings to-date, and plans for the next year/review period. If this project is funded, please send a copy of the most recent progress report that was sent to the funding agency: **Data has been collected following the approved protocol on 35 males aged 18-40 years. No further data will be collected. The goal of the study is to describe the relationship between concentric and eccentric muscle actions. Data analysis is ongoing. Data and results will be presented as part of a doctoral**

dissertation and submitted for publication in a professional journal.

10. Publications, Presentations and Recent Findings

10a) Have there been any presentations or publications resulting from this study during the past approval period? ☐ Yes ☒ No If yes, please submit a copy of the abstract, or the publication, with this application.

10b) Have there been any recent findings either from this study, or a related study (through a literature review for example), that would have an effect on this study's risk/benefit analysis?
☐ Yes ☒ No
If yes, please describe and cite references:

11.Conflicts of Interest and Commercialization

11. Does any member of the research team have a potential conflict of interest with this study that could affect study participants and/or study outcome? For more information about examples of conflicts of interests, please visit the ASU objectivity website: http://researchintegrity.asu.edu/coi
☐ Yes (If yes, please describe and disclose in the consent form) ☒ No

b) Does the PI or Co-I have a current conflict disclosure form on file at the ASU Office of Research Integrity and Assurance?
☐ Yes ☐ No

c) If there are conflicts of interests, please describe the ways in which you have and will minimize harm to research subjects and/or the objectivity of research.

12. Training

18. T The research team must document completion of human subjects training from within the past 3 years.
Attach a copy of the training certificates from the members of the research team:
http://researchintegrity.asu.edu/training/humans

13. Required Signatures

FOR IRB USE Chair or Committee member name: Signature: Date:

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