January 2013

Comparisons of acute neuromuscular fatigue and recovery after maximal effort strength training using powerlifts

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Comparisons of Acute Neuromuscular Fatigue and Recovery After Maximal Effort Strength Training Using Powerlifts

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Exercise Science
College of Education
University of South Florida

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Date of Approval:
March 22, 2013

Keywords: resistance training, bench press, deadlift, squat, programming

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Abstract

Neuromuscular fatigue is associated with a decrease in velocity. Following powerlift training, the extent to which fatigue affects the performance velocity of each lift after a specified recovery interval has not yet been investigated.

Purpose

To assess the level of acute neuromuscular fatigue, as measured by a decrease in peak velocity, as a result of maximal effort strength training sessions with each powerlift.

Methods

Twelve resistance trained males (22.8 ± 2.6 yrs; 177.1 ± 6.7 cms; 83.0 ± 12.6 kgs) participated in a randomized crossover design with three conditions: Squat (SQ), Bench Press (BP), and Deadlift (DL). Subjects' relative strength included the ability to successfully complete at least 1.5x their bodyweight in the squat exercise. Initially, baseline peak velocity (PV) was measured for each lift at 60% 1RM via a TENDO unit. One training session occurred each Monday for 3 consecutive weeks (1 week for each lift). Each training session consisted of a 1RM of the designated lift followed by 4 sets of 2 repetitions at 92.5% and 4 sets of 3 repetitions at 87.5%. Following training sessions, each lift PV was measured at 24, 48, and 72 hours post-training to compare with baseline

measures and determine recovery. Data was analyzed using a repeated measures ANOVA (p<.05).

Results

SQ: No significant differences in PV of the SQ and DL following SQ training at each time point compared to baseline. Bench press PV significantly declined following squat training (Baseline = 1.069 m/s; 24 hours = 0.974 m/s [p = 0.019]; 48 hours = 1.015 m/s [p = 0.034]; 72 hours = 0.970 m/s [p = 0.004].

BP: No significant differences in PV of the SQ and DL following BP training at each time point compared to baseline. Bench press PV significantly declined only at 24 hours following BP training (Baseline = 1.069 m/s; 24 hours = 0.988 m/s [p = 0.004]).

DL: No significant differences in PV of the DL following DL training as compared to baseline. Squat PV significantly declined at 24 hours following the DL training (Baseline = 1.384 m/s; 24 hours = 1.315 m/s [p = 0.032]. Similar to SQ, PV of the BP significantly declined only at 24 hours following DL training (Baseline = 1.069 m/s; 24 hours = 0.979 m/s [p < 0.001]).

Conclusions

Bench press PV was significantly decreased 24-hours following each of the three powerlifts as compared to baseline values. Interestingly, there were no changes in squat and deadlift PV following training of that specific lift.

Practical Applications

Regardless of the powerlift trained, bench press PV at 60% was compromised 24-hours later. Therefore, following training of any powerlift, more than 24-hours may be needed to optimize performance in the BP at submaximal intensities.

Chapter 1:

Introduction

The moment exercise begins the neurophysiologic state is altered (Boyas and Gueval, 2011), even if the exerciser does not consciously interpret any fatiguing effects. This phenomenon is known as neuromuscular fatigue. A consensus of the specific definition of neuromuscular fatigue does not exist, as evidenced by the many definitions existing in the scientific literature (Enoka, 1992; Enoka, 2008; Boyas, 2011; Hakkinen, 1988; Walker, 2011). Lepers et al. (2002) state "Neuromuscular fatigue can be defined as any exercise induced reduction in maximal voluntary force" while a review by Enoka (2008) says "the term muscle fatigue denotes a transient decrease in the capacity to perform physical activity." While many definitions exist, a central theme of neuromuscular fatigue in exercise seems to involve a decrease in muscular force production and velocity of shortening after exertion through voluntary muscle action.

There are multiple physiological sites that can contribute to fatigue. Central fatigue refers to a decrement in any of the fatigable sites located proximal to the neuromuscular junction. Peripheral fatigue differs in that it refers to decrements in sites located at and distal to the neuromuscular junction. In a review by Boyas and Guevel (2011), 9 sites were determined to contribute to neuromuscular fatigue and are as follows: 1) activation of the primary cortex; 2) propagation of the command from the central nervous system (CNS) to the motorneurons (pyramidal pathways); 3) activation of the motor units and muscles; 4) neuromuscular propagation, including neuromuscular junction propagation; 5) excitation-contraction coupling; 6) availability of metabolic substrates; 7) state of the intracellular medium; 8) performance of the contractile apparatus; and 9) blood flow. Sites 1-3 are central and 4-9 are peripheral sites that may contribute to fatigue. The specificity of fatigue at these sites has been show to be task dependent and greatly depend on athletic background, type of load, volume of loading, and fiber composition of the worked muscle (Linnamo, 1997; Enoka, 2008; Hakkinen, 1988). How the central and peripheral sites are affected by strength training is of great importance when programming periodized training routines.

Many resistance training programs are designed using the barbell squat, deadlift, and bench press. Together these exercises are commonly referred to as “core lifts” because of the fundamental role they play in many programs. They are compound, multi-joint resistance barbell movements used in the sport of power lifting as the basis of competition. But, depending on program variables, athletes from a variety of sports to the recreational weightlifter may use all three of these movements and variations to meet individual goals in maximal strength, speed strength, strength endurance, and muscle hypertrophy (Campos et al., 2002). Due to their compound nature, high totals of relative weight can be lifted using these exercises causing acute decreases in maximal voluntary contraction and strength (Hakkinen et al., 1993).

Performance measurements to identify fatigue may be of great importance to certain populations while being relatively easy to obtain. Sanchez-Medina and Gonzalez-Badillo (2011) measured repetition velocity of the barbell bench press and squat during resistance training with a linear velocity transducer while also measuring blood lactate and ammonia. This study found a strong correlation between the loss of mean propulsive velocity and metabolite buildup during training. Results support the validity of using velocity loss, or workout performance, as a means of measuring neuromuscular fatigue.

While many studies have measured neuromuscular fatigue and recovery in exercise using various methods (Walker, 2009; Marshall, 2012; Strojnik, 2008; Lepers, 2002; and Gauche, 2009), training protocols may lack practicality and are generally isolation movements which can be necessary to understand certain fatigue mechanisms. Few of these studies' design protocols (Sanchez-Medina, 2011; Hakkinen, 1988) used dynamic, multi-joint movements that are a fundamental part of practical strength training. There is no current study that compares acute neuromuscular fatigue and recovery in maximal effort strength training using all of the powerlifts. Furthermore, investigation is needed on how each movement may acutely affect the performance of future power lift training to optimize strength training programming and periodization.

Purpose

The purpose of the study was to compare the level of acute neuromuscular fatigue caused by each power lift after a high intensity, maximal effort strength training session while volume and relative intensity is equated for each lift. Additionally, we investigated the acute neuromuscular fatigue of one power lift and how this fatigue affects the performance of each power lift after specified recovery intervals. When programming for strength training, adequate knowledge of the contribution each lift has on acute neuromuscular fatigue and the subsequent effect on future training performance may help individuals optimize program design.

Study Variables

The independent variable in this study is the type of barbell strength movement that is executed. There will be three levels of this independent variable that will be completed by each of the participants in a crossover, randomized study design. These components include the back squat, deadlift, and bench press. The back squat was instructed to a parallel depth with the barbell placed on the subjects' chosen location on the trapezius and upper back area. The stance width for the back squat was near shoulder width and also up to the lifter and his comfort level within the shoulder width range. Measurements of stance width were recorded for each participant to ensure a consistent stance throughout training and measurements for the squat. The deadlift was performed in a conventional stance and foot and hand placement was measured for consistency. Subjects were instructed to complete the lift by extending hips forward and locking out the shoulders in a posterior retracted position, then the bar was lowered and released to the floor. Bench press instruction included a full range of motion of the bar from the starting point to the lockout point. Subjects were instructed to touch the bar to their lower chest or sternum with a slight pause, without bouncing off the torso, and to raise the bar with maximal effort to a fully locked-out arm position. Measurements of hand placement on the bar were taken to increase consistency as well. The dependent variable in this study was the peak velocity measurement with the TENDO Power and Speed analyzer for the back squat, deadlift, and bench press.

Hypotheses

Ho1: There will be no difference in peak velocity in the deadlift exercise 24 hours after an acute bout of deadlift training as compared to baseline values.

Ho2: There will be no difference in peak velocity in the bench press exercise 24 hours after an acute bout of deadlift training as compared to baseline values.

Ho3: There will be no difference in peak velocity in the squat exercise 24 hours after an acute bout of deadlift training as compared to baseline values.

Ho4: There will be no difference in peak velocity in the deadlift exercise 48 hours after an acute bout of deadlift training as compared to baseline values.

Ho5: There will be no difference in peak velocity in the bench press exercise 48 hours after an acute bout of deadlift training as compared to baseline values.

Ho6: There will be no difference in peak velocity in the squat exercise 48 hours after an acute bout of deadlift training as compared to baseline values.

Ho7: There will be no difference in peak velocity in the deadlift exercise 72 hours after an acute bout of deadlift training as compared to baseline values.

Ho8: There will be no difference in peak velocity in the bench press exercise 72 hours after an acute bout of deadlift training as compared to baseline values.

Ho9: There will be no difference in peak velocity in the squat exercise 72 hours after an acute bout of deadlift training as compared to baseline values.

Ho10: There will be no difference in peak velocity in the deadlift exercise 24 hours after an acute bout of Bench press training as compared to baseline values.

Ho11: There will be no difference in peak velocity in the bench press exercise 24 hours after an acute bout of Bench press training as compared to baseline values.

Ho12: There will be no difference in peak velocity in the squat exercise 24 hours after an acute bout of Bench press training as compared to baseline values.

Ho13: There will be no difference in peak velocity in the deadlift exercise 48 hours after an acute bout of Bench press training as compared to baseline values.

Ho14: There will be no difference in peak velocity in the bench press exercise 48 hours after an acute bout of Bench press training as compared to baseline values.

Ho15: There will be no difference in peak velocity in the squat exercise 48 hours after an acute bout of Bench press training as compared to baseline values.

Ho16: There will be no difference in peak velocity in the deadlift exercise 72 hours after an acute bout of Bench press training as compared to baseline values.

Ho17: There will be no difference in peak velocity in the bench press exercise 72 hours after an acute bout of Bench press training as compared to baseline values.

Ho18: There will be no difference in peak velocity in the squat exercise 72 hours after an acute bout of Bench press training as compared to baseline values.

Ho19: There will be no difference in peak velocity in the deadlift exercise 24 hours after an acute bout of squat training as compared to baseline values.

Ho20: There will be no difference in peak velocity in the bench press exercise 24 hours after an acute bout of squat training as compared to baseline values.

Ho21: There will be no difference in peak velocity in the squat exercise 24 hours after an acute bout of squat training as compared to baseline values.

Ho22: There will be no difference in peak velocity in the deadlift exercise 48 hours after an acute bout of squat training as compared to baseline values.

Ho23: There will be no difference in peak velocity in the bench press exercise 48 hours after an acute bout of squat training as compared to baseline values.

Ho24: There will be no difference in peak velocity in the squat exercise 48 hours after an acute bout of squat training as compared to baseline values.

Ho25: There will be no difference in peak velocity in the deadlift exercise 72 hours after an acute bout of squat training as compared to baseline values.

Ho26: There will be no difference in peak velocity in the bench press exercise 72 hours after an acute bout of squat training as compared to baseline values.

Ho27: There will be no difference in peak velocity in the squat exercise 72 hours after an acute bout of squat training as compared to baseline values.

Conceptual Model

The foundation for this investigation was partially based on prior research in acute neuromuscular fatigue and partially based on the common thoughts of many advanced strength training practitioners. While fatigue is extremely complex with many variables, there is a wealth of research investigating the phenomenon. In a high set, maximal strength squat training session, Hakkinen et al. (1988) observed an initial decrement in peak isometric strength with a gradual climb in recovery while keeping peripheral metabolite buildup minimal due to 3 minute recovery periods and low repetition sets. By day 2 of recovery, male subjects were at 97.1% of their baseline strength levels. Fatigue was measured using isolated knee extension.

Other studies have investigated fatigue and recovery while using knee extension (Walker et al., 2009), leg press (Ide et al., 2011), and cycling (Lepers et al., 2002) while sometimes using isometric knee extensions or other isolated movements to measure fatigue (Bigland-Ritchie et al., 1978). These studies provide the basic concepts to move toward more practical exercise protocols that consist of compound and dynamic movements while also using a more practical approach of taking measurements of acute fatigue using these same compound and dynamic movements. The current study's protocol was chosen based on practical strength training methods used with powerlifts and partly based on the need to elicit appropriate amounts of fatigue in each subject.

Operational Definitions

There are terms that must be defined in order to fully understand the study. A "1 RM" refers to the one repetition maximum weight a subject can complete without being able to complete a second repetition or rise any further in weight. "Core lifts" refer to the barbell back squat, barbell deadlift, and barbell flat bench press. These movements can also be summarized as "powerlifts". "Maximum voluntary contraction" or "MVC" is the conscious maximal effort to contract given muscle groups to their fullest extent.

Assumptions

It was assumed that the subjects will follow the dietary instructions given to them and they will record their nutrition intake appropriately. Adequate calories and macronutrients play a large role in recovery and subjects were told to follow their normal strength training diet throughout the duration of the study. Another assumption is that the subjects exerted maximum effort during training and during baseline/recovery measurements. Strong verbal encouragement was used to assist the participant.

Limitations

There are limitations in this investigation that will not be adequately controlled. Participants were asked to complete many sets using maximal and near maximal resistances. The number of sets in this range will likely be higher than the experienced strength training participants are accustomed to which may lead to the failure of repetitions in later sets. This failure of a repetition may influence the data validity. In a maximal strength squat training protocol, Hakkinen et al. (1988) used 20 sets x 1 repetition x 100% of 1RM to induce fatigue while allowing 3 minute rest intervals between sets. There was a gradual decrease in force exertion over the 20 sets, but adjustments in weights were made as necessary. This also reduced metabolite buildup that is seen with peripheral fatigue. Resistance was lowered after any instance of failure as well as lowered if the subject perceived failure of a future set to attempt to reduce the effects of this limitation. A 5% reduction in weight occurred following any instance of failure, which follows procedures successfully used in loading protocols by McCaulley et al. (2008).

Delimitations

The delimitations in this study included participant characteristics. Participants were only selected if they were male with at least 2 years of resistance training experience. Each participant must have been able to back squat 1.25 times their bodyweight at or below parallel and regularly incorporate the deadlift and bench press in their training. Additionally, exercises were chosen to limit the scope of the study to power lifting exercises only. The bar peak velocity used to measure neuromuscular fatigue was also a specific limitation of the study. There are other forms of fatigue measurement (Izquierdo, 2009; Byrne, 2004) but this study is limited to these specific modes.

Significance

The amount to which the powerlifts contribute to acute neuromuscular fatigue depends greatly on subjective factors of the individual and the training session. Elements involved such as prior training experience, intensity, volume, and personal stress factors play an enormous role in how fatigued one will become after training (Enoka, 2008; Linnamo, 1997) and if the fatigue effects will last long enough to affect a future training session or performance. To create data that is practical and useful to individuals who program strength training for themselves or for others, comparing the core lifts duration of fatigue, while keeping volume and relative intensity equal between lifts, may be useful. It may also be useful to better understand the "fatigue relationship" that may exist between exercises. Power lifters, strongmen, strength coaches, strength and power athletes, recreational weight trainers, and more may benefit from such knowledge.

Many studies have investigated fatigue using isolated movements (Walker, 2009; Marshall, 2012; Gauche, 2009) either in the training protocol or as testing measures. There are studies that use dynamic, multi-joint movements in their training protocols (Hakinnen, 1988; Sanchez-Medina, 2011) and few who use these movements in the training protocols and as a means of testing (Sanchez-Medina, 2011). Practical strength training individuals in many environments use multi-joint barbell exercises as the basis of their exercise programs (Hoffman, 2004), but it would seem useful to study these popular movements in training as well as in testing. There is no current study, to the best of our knowledge, which compares the effects of fatigue among all of the powerlifts on future training sessions.

Theoretically it seems plausible the demands of movements with more motor units and larger muscle mass involved, like the squat and dead lift, would achieve a greater amount of fatigue due to the amount of work that can be completed by experienced individuals and overall stress to the lifter. It is also worth theorizing the bench press could see greater amounts of local fatigue due to less motor units and smaller muscle groups being used for the same amount of volume. Literature has shown the velocity of the bench press repetition declines significantly greater than the back squat during training sessions of varying repetition and set schemes (Sanchez-Medina, 2011). But to what extent does fatigue and recovery, after a specific lift is the focal point of a maximal strength training session, affect the future performance of all three lifts? How far should a maximal strength training effort of one lift be separated from a future training session of another power lift? These questions are fundamental to people designing training programs and are worth further investigation. Therefore, the aim of this study was to compare acute neuromuscular fatigue between maximal effort strength training sessions of each power lift and the subsequent performance effect fatigue and recovery has on the future training session of all three powerlifts.

Chapter 2:

Literature Review

Neuromuscular fatigue has been studied over many decades and continues to be an extremely complex phenomenon. Research has shown the effects exercise has on the physiological processes of the body that enable a person to repeat that activity. Any exercise induced reduction in maximal voluntary contraction can be defined as fatigue (Lepers, 2009). The contribution of the central factors (sites proximal to the neuromuscular junction) and peripheral factors (sites at and distal to the neuromuscular junction) has been and continues to be investigated (Boyas, 2011).

Laurnet and colleagues (2011) tested a “PRS” (perceived recovery status) scale to assess fatigue, subjectively. A scale of 1-10, with 1 being “Very poorly recovered/Extremely tired” and 10 being “Very well recovered/highly energetic”, was used to assess the subjective feelings of 16 subjects before four bouts of intermittent sprinting. Scale responses were compared with sprint performance to interpret validity of the PRS. Results indicated subjects were accurately able to assess themselves with corresponding sprint times correlating with the responses. This study was able to test a measurement based on how each participant felt at that time and validate the possibility of its use as a means of assessing fatigue and predicting performance (Laurent, 2011).

An early study looked at the effects of neural output by measuring surface EMG activity during sustained isometric contractions of the leg extensors (Bigland-Ritchie, 1978) and found the considerable role central fatigue plays in force loss**.** This was found by observing a correlation in the decline in force loss with a similar decline in neural output through surface EMG output. However, some subjects showed a decrease in force production and maintained neural drive showing neural output is only one of many factors involved in fatigue during isometric contractions.

The isometric force production of the leg extensors were once again apart of the measurement of neuromuscular fatigue in a study by Lepers and colleagues (2002), but the training protocol was aerobic. Nine endurance trained subjects completed five hours of 55% of maximum aerobic power on a bicycle ergometer. Maximum voluntary contraction (MVC) and EMG activity of the leg extensors were measured pre-, mid-, and post-exercise with the mid-exercise measurement occurring every hour. There was a gradual decline in MVC throughout the protocol while a decrease in EMG activity was not seen overall until the latter stages. The suggestion from these results is moderate aerobic activity seems to induce peripheral fatigue first, followed by central fatigue factors.

Babault et al. **(**2005) used maximal concentric and isometric exercise of the leg extensors to compare fatigue involved with each type of contraction. MVC of the leg extensors and EMG activity of the vastus lateralis were measured as well as muscle activation through the twitch-interpolation technique and an electrically evoked double twitch. Results indicated a similar decrease in MVC between the concentric and isometric contractions, showing overall fatigue of each was similar. But, there were differences in site specific fatigue, centrally and peripherally, between the two contractions. MVC declined gradually for the concentric protocol while EMG activity remained unchanged, indicating greater peripheral fatigue factors contributing to the MVC decline. Isometric contractions also had a similar decline in MVC while incurring a decrease in EMG amplitude as well, suggesting greater central origins of fatigue.

Another study used full range muscle movement, eccentric and concentric combined during the repetition, bilaterally in the leg extensors to compare maximal strength loading and explosive strength loading in men and women (Linnamo, 1998). Surface EMG activity from the vastus lateralis, vastus medialis, and biceps femoris were recorded and blood lactate was measured throughout the experiment. Results indicated blood lactate increased in both loads but was higher in the maximal strength loading. EMG activity, in men, was also decreased in both loads but was lower in the explosive strength loading. Central fatigue played a greater role in explosive type loading while maximal strength loading evoked both peripheral and central fatigue. A possible issue with this design is the set and repetition scheme used. Both loads completed five sets by ten repetitions but the maximal strength load completed a 10 repetition maximum and the explosive strength load used 40% of their 1RM to perform the repetitions as fast as possible. Although a 10RM can be used to increase maximal strength, research has shown lower repetition schemes produce greater maximal strength increases (Campos, 2002). Repetition schemes in and around the 10 repetition range are typically used for muscle hypertrophy training (McCaulley, 2009), partly due to the metabolite buildup elicited in that range. To encompass maximal strength training as provoking high levels of blood lactate may be misleading. This design seems to be closer to practical exercise by using full range movement as well as comparing common strength loading patterns, but an isolated movement was still used as opposed to multi-joint, dynamic movements that are commonly used as the basis of strength programming.

A common strength training protocol, using a high-load and low repetition scheme, in the leg extensors was used to measure acute fatigue. Walker and colleagues (2009) examined MVC, resting double-pulse twitch force, and voluntary activation to assess fatigue. The participants in this design were resistance trained, lending potentially more useful data to weight training practitioners. Four sets of three repetitions at 85% of the subject's 1RM were performed during the session with single- and double-pulse stimulations occurring between each set to measure involuntary force production, while double-pulse stimulations were also applied during the loading. MVC decreased -11.8%, resting double-pulse twitch decreased -10.6%, and voluntary loading decreased -2.1% in response to the loading. The MVC assessment measures total neuromuscular fatigue while the twitch stimulations measure involuntary force of muscle fibers, isolating peripheral fatigue. Voluntary activation declined and the neural deficiency was speculated be caused by deficiencies at the spinal or supraspinal levels (central fatigue). Walker (2009) also discussed the possibility of a safety mechanism playing a role in the incomplete voluntary activation, possibly from feedback of the muscle afferents or Golgi tendon, to reserve force if needed (Walker, 2009). The interesting aspect of this data is how it was derived from practical strength training protocols to assess fatigue levels at different sites.

Practical protocols were also seen with Ide et al. (2011) when they examined acute recovery of strength and power in two different movement velocities of repetitions, slow vs. fast. Nineteen male subjects were divided into either a slow velocity (six second repetitions) or fast velocity (one and a half second repetitions) group for a single exercise bout. The resistance protocol consisted of five sets of twelve repetition maximums of the leg press and leg extension with 50 seconds rest between sets and two minutes between exercises in the session. Results indicated decrements in 1RM leg press immediately post exercise and the fatigue was still present from 24-48 hours later but was more evident in the fast velocity group. Only the fast velocity group showed decrements in power measurements in the countermovement jump after both groups showed a decrement immediately post-training. This study was interesting because it also displays the possible causes that exercise intensity and loading type plays in fatigue (Enoka, 2008). It also incorporated a multi-joint movement, the leg press, as part of the training protocol which lends itself to being closer to practical strength training sessions.

The use of multi-joint, dynamic training movements was also used in a study by Sanchez-Medina et al. (2011). This study was particularly interesting because it analyzed the loss of velocity of specific exercises (mechanical) and measured it against metabolic responses typically seen with fatigue. Subjects were professional firefighters or candidates with at least three to five years of resistance training experience and were divided into a bench press group and a full squat group. 21 training sessions were completed with different repetition schemes at different intensities for both groups over approximately eight weeks. Analysis of velocity in the bench press and squat with countermovement jump height being taken before and after each training protocol, as well as velocity measurements of the exercises during the training protocol. Mean velocity loss of each repetition occurred after three sets were observed, loss of velocity pre and post exercise, and countermovement jump height was significantly reduced during this study. The results showed a nearly perfect correlation between mean propulsive velocity over three sets and the peak blood lactate accumulation post-exercise. These findings validated the use of analyzing the decrease in velocity of repetitions during training as a means of measuring acute neuromuscular fatigue.

There is a major practical implication of the results of this study. Strength coaches viewing their athletes during training could gain a further understanding of when fatigue is occurring acutely to predict when it may become chronic, leading to overreaching and overtraining. Weight trainers could assess themselves very easily during training and understand when fatigue is occurring. The loss in bar velocity in powerlifts also has major implications in the current investigation.

Maximum strength and power repetitions have been studied, as seen by the previous literature (Ide, 2011). McCaulley et al. (2009) studied the effects of strength, power, and hypertrophy on acute hormonal and neuromuscular response. This particular design had practical implications in that it used the three common training styles used in the daily undulating periodization model, which has been shown to elicit greater strength gains in trained subjects compared to linear periodization (Rhea, 2002). Ten experienced males were used in this study with at least two years of resistance training experience. Subjects completed four protocols in a randomized, crossover design on separate days. A hypertrophy day consisting of four sets of 10 repetitions of squats at 75% of 1RM, a strength day consisting of 11 sets of three repetitions of squats at 90% of 1RM, a power day made of eight sets of six repetitions of jump squats at a maximum power (bodyweight) load, and a control group that rested. Total testosterone, cortisol, sex hormone binding globulin were taken pre- and immediately post-exercise, 60 minutes post-, 24 hours, and 48 hours after training. Peak force, rate of force development, and muscle activity of the vastus medialis and biceps femoris was measured during a maximum isometric squat. Hypertrophy training was the only style that elicited markedly different blood hormone levels than the rest/control group. The strength and hypertrophy group elicited declines in maximum peak isometric force while RFD recovered more quickly in the hypertrophy group. This may indicate the possibility of greater central fatigue being induced by heavy strength training compared to hypertrophy training being that hypertrophy training is known to cause higher levels of muscle damage and peripheral fatigue, due to higher volume eccentric contractions (Proske, 2001).

Metabolites affecting peripheral factors of fatigue were discussed in a review by Allen, Lannergren, and Westerblad (1995). Reductions in force production and velocity of shortening along with prolonged relaxation were components of decreased muscular performance related to peripheral fatigue. Changes in the H+, inorganic phosphate, ATP, and ADP metabolites and changes in the sarcoplasmic reticulum (SR) Ca2+ are seen to lead to changes in force production and velocity of shortening. Reduced maximum force was attributed to the effects of the H+ and inorganic phosphate accumulation. Reduced velocity of shortening was partly explained by the effects of H+ in skinned muscle fibers, while also showing that ADP not only slowed velocity but accumulated greater than previous measurements suggested. The changes in Ca2+ were seen as being unimportant for velocity of shortening. Prolonged relaxation of the muscle was seen to occur because of the slowing of the rate of decline of myoplasmic calcium retention and the slowing of cross-bridging detachments, which both can be affected by H+. This review also discussed the effectiveness of a muscle in a repeated movement is reduced if the corresponding antagonist muscle group is not completely relaxed.

Few studies have measured dynamic, multi-joint movements and the corresponding neuromuscular fatigue, as seen in the previous literature. Hakkinen and colleagues (1988), using ten male and nine female strength athletes, studied maximum effort strength training (20 sets x 1 repetition x 100% 1RM) in the barbell squat and the subsequent neuromuscular fatigue response. They found this type of loading caused considerable acute neuromuscular fatigue that was displayed by decreases in measured force production and voluntary neural activation. These measurements were done using a dynamometer on bilateral isometric leg extensions and surface EMG activity of the vastus lateralis, vastus medialis, and biceps femoris. Significant decreases in EMG activity as well as isometric force occurred for both men and women, with men taking longer to recover than females. This could be due to the greater loads the men were able to lift causing larger decrements of fatigue. An interesting aspect of this study is maximal force values were, on average, 97.1% for males and 98.3% for females of baseline measures on the second day of recovery. Hakkinen et al. (1988) were able to quantify fatigue in maximal strength training in a practical, compound strength training movement using EMG and isometric force. Interestingly, the researchers were able elicit large decrements in neuromuscular fatigue, while keeping blood lactate levels minimal with the current training protocol. This may imply a greater contribution of central fatigue to maximal strength training in high load/low repetition protocols.

With the greater amount of literature in neuromuscular fatigue using the isolated leg extensions as training protocols to measure the amount fatigue, one can see the need to apply more practical training methods. Knowing the amount of fatigue incurred by each person is dependent on many subjective variables (Linnamo, 1997), comparisons of fatigue responses of dynamic, multi-joint movements that are commonly used together in practical programming may be useful.

Chapter 3:

Participants

12 resistance trained males between 21 and 28 yrs of age were selected for this investigation and were recruited by word of mouth. Part of the inclusion criteria for subjects to participate included being able to perform the barbell back squat with at least 1.25 times their bodyweight to parallel. That is, the proximal extremity of the femur at the hip joint and the distal extremity of the femur must be parallel to the ground at the bottom of the squat position. The deadlift and bench press must have been a part of the subject's regular training routine but there were no specific weight requirement for each of these lifts. This helped ensure subjects have adequate resistance training and proper experience to execute the training protocols correctly. There was a specific relative strength requirement for the squat (1.25x bodyweight to parallel) because it is typically viewed as the most technical of the three powerlifts. This also helped ensure proper training experience by being able to complete higher relative loads. Participants who met these criteria completed a personal and medical history form. The personal history form included information such as name, address, and experience in resistance training (refer to appendix B). The medical history form is a pre-activity screening questionnaire based off the American Heart Association/American College of Sports Medicine

guidelines that designates risk stratification categories for atherosclerotic cardiovascular disease. For a description of these risk stratifications, refer to table 1 below.

Table 1: ACSM Risk Stratification

Risk Stratification	Description
Low Risk	Asymptomatic men who have less than or equal to 1 cardiovascular risk factors*
Moderate Risk	Asymptomatic men who have greater than or equal to 2 cardiovascular risk factors*
High Risk	Individuals who have diagnosed medical conditions (cardiovascular, pulmonary, or metabolic disease) or one or more signs and symptoms*

*Refer to the Pre-Activity Screening Questionnaire in Appendix C.

Only those participants that were classified as low risk according to the American Heart Association/American College of Sports Medicine were eligible to participate in this investigation. Each participant was asked to not use any ergogenic aid or nutritional supplementation, other than protein supplements and multi-vitamins, which may have an effect on their performance and recovery during the study. Subjects were given 30g of whey protein after each of the three training protocols as a way of standardizing immediate post workout nutrition and optimizing nutrient timing. Table 2 below summarizes participant characteristics who took part in the present study:

Table 2: Participant Characteristics

Age (y)	Height (cms)	Weight (kgs)	Squat 1RM (lbs)	Bench Press 1RM (lbs)	Deadlift 1RM (lbs)
22.8 ± 2.6	177.1 ± 6.7	83.0 ± 12.6	355 ± 48.22	290 ± 48.07	417 ± 81.04

Values are means ± standard deviations

Equipment

This study used a TENDO Power and Speed Analyzer which was able to measure average power, peak power, average velocity, and peak velocity. For this study, only the peak velocity measurement was used. The unit was attached to the bar (weightless) and the velocity of the bar was computed in meters/seconds.

Procedures

Initially, 12 resistance trained subjects had baseline measurements taken for each of the powerlifts on week 1, which was 1 week prior to strength training sessions. Each subject was instructed to cease physical activity 72 hours prior to testing (*Appendix A, Table 6*). Each individual was asked to only participate in lower exertion types of physical activity outside of the study, as well as abstaining from using alcohol. Subjects were placed in a randomized crossover study design and placed into a different condition (each core lift) each week using a random number generator (http://andrew.hedges.name/experiments/random/). A back squat condition, deadlift condition, and bench press condition performed that specific exercise each training session. There were 3 fatiguing training sessions (one session for each lift) separated by 7 seven days for 3 sequential weeks. After each training session, 3 days of recovery measurements were taken at 24, 48, and 72 hours. Relative volume and intensity was equated among each subject within each of the three lift protocols. The back squat was instructed to be executed to parallel (proximal head of the femur even with distal head and parallel to the ground) with the barbell placed on the subjects' chosen location on the trapezius and upper back area. The stance width for the back squat was generally near shoulder width and up to the lifter and his comfort level. Measurements of stance width were recorded for each participant to ensure a consistent stance throughout training and measurements for the squat. The deadlift was performed in a conventional stance and foot and hand placement will be measured for consistency. Subjects were instructed to complete the lift by extending hips forward and locking out the shoulders in a posterior retracted position, then the bar can be lowered and released to the floor. Bench press instruction included a full range of motion of the barbell from the starting point to the lockout point. Subjects were instructed to touch the barbell to the lower chest or sternum with a slight pause, without bouncing off the torso, and to raise the barbell with maximal effort to a fully locked-out arm position. Measurements of hand placement on the barbell were taken to increase consistency as well. If there was a break in form or failure of any lift, the lift was cancelled and a 5% reduction in weight occurred for the next repetition. Participants were also asked to keep a nutrition log (#1) for Monday-Wednesday and

Saturday during week 2. They were instructed to keep dietary intake similar to this intake for the duration of the study.

Training Protocol

Three fatiguing training sessions (one session for each lift) were conducted and separated by 7 days. Each group began training sessions with a light, dynamic warm-up of bodyweight squats and arm circles. Subjects then worked up to a 1 RM following the same protocol used by McBride, et al. (2002). After a single maximal effort repetition was completed, subjects then completed 4 sets of 2 repetitions at 92.5% of the tested 1 RM. This was followed by 4 sets of 3 repetitions at 87.5% of the tested 1 RM. Repetitions are meant to be maximal or near maximal but without failure. Weights were adjusted as needed to ensure these constructs were met. If there was failure on a repetition, a 5% reduction in weight occurred to accommodate the next repetition if it was still in the same intensity range (McCaulley, 2008). This protocol was chosen arbitrarily, partly based on practical strength training methods used with powerlifts and partly based on the need to elicit appropriate amounts of fatigue in each subject. It would not be uncommon to see similar repetition ranges being done at these percentages in a practical power lifting training session. However, training with this volume or multiple sets of these high effort repetitions is typically perceived as being sub-optimal due to the amount of fatigue that occurs. Therefore, this protocol was selected to intentionally induce central and peripheral fatigue to ensure appropriate stress for testing while attempting to adhere to a practical design. Verbal encouragement and training music was used to help each participant meet the demands of the training protocol and elicit maximal efforts. Subjects were instructed to stay under control during the eccentric phase and to lift concentrically as fast as possible. A qualified Certified Strength and Conditioning Specialist (CSCS) and spotters were used to ensure each lift requirement was properly met. There were atleast three minute and no more than five minute rest intervals between each working set to help phosphocreatine energy system recovery and reduce the amount of acute peripheral fatigue and metabolite buildup. This was to help increase the overall performance and work completed during the training sessions. Protocol constructs done by Hakinnen et al. (1988) consisted of 20 sets of 1 repetition at 100% of 1 RM. This construct elicited considerable acute neuromuscular fatigue without having considerable metabolite accumulation after blood analysis using 3 minute rest intervals. After the working sets were completed subjects received 30g of Dymatize ELITE whey protein isolate to consume immediately and optimize nutrient timing consistency.

Baseline and Recovery Measurements

Each participant had baseline measures taken one week prior to the first exercise protocol (refer to *Appendix A-Table A1)*. During this time, measures of peak velocity were recorded using the TENDO Power and Speed Analyzer for each lift starting with the back squat, bench press, and the deadlift.

The baseline and recovery measurement days began with a light, dynamic warm-up of bodyweight squats and arm circles. The warm-up was followed by three sets of five repetitions at 40-50% of 1RM. Subjects then were assigned a load of 60% of 1RM to complete 5 repetitions to achieve the highest peak velocity possible. Three minute rest periods were assigned before each performance set and between exercises. No more than 5 performance repetitions at 60% of 1RM were allowed for each lift during each measurement day. This load percentage was used to assign a load that is light enough to not greatly enhance fatigue while being heavy enough to require effort and to show possible performance decrements. Each lift was performed throughout a full range of motion while the TENDO Power and Speed Analyzer recorded peak velocity (meters/second) of each repetition during the concentric portion of the movement. The repetition with the highest performance of each lift was recorded and used as their measurement number for that day. The difference in bar velocity between baseline to recovery measurements was compared to determine the extent each lift is affected during the days following a maximal effort strength training session of each specific lift.

Statistical Analysis

The current study was a randomized, crossover design and used an analysis of variance (ANOVA) with repeated measures to analyze the possible differences between the independent variable levels. The ANOVA was used to control for alpha inflation of the subsequent univariate analysis of variance (ANOVA). To control for alpha inflation of the ANOVA, the Bonferroni test was utilized. Alpha was set at .05. Mean differences between baseline and post-exercise measurements of the dependent variables were compared. Also, mean differences between baseline and post-exercise measurements of each level of the independent variable were compared.

Chapter 4

Results

Ho_1 stated there will be no difference in peak velocity in the deadlift exercise 24 hours after an acute bout of deadlift training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 24 hours after deadlift training as compared to baseline values (BL: 1.491 ± .1484, 24hrs: 1.398 ± .1914, p=0.093). Based on the findings, we fail to reject the null hypothesis.

Ho_2 stated there will be no difference in peak velocity in the bench press exercise 24 hours after an acute bout of deadlift training as compared to baseline values. Peak velocity of the bench press exercise was significantly lower 24 hours after deadlift training as compared to baseline values (BL: 1.069 ± .1555, 24hrs: .979 ± .1422, p=0.0001). Based on the findings, we reject the null hypothesis.

Ho_3 stated there will be no difference in peak velocity in the squat exercise 24 hours after an acute bout of deadlift training as compared to baseline values. Peak velocity of the squat exercise was significantly lower 24 hours after deadlift training as compared to baseline values (BL: 1.382 ± .1761, 24hrs: 1.315 ± .1532, p=0.032). Based on the findings, we reject the null hypothesis.

Ho_4 stated there will be no difference in peak velocity in the deadlift exercise 48 hours after an acute bout of deadlift training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 48 hours after deadlift training as compared to baseline values (BL: 1.491 ± .1484, 48hrs: 1.468 ± .1909, p=0.705). Based on the findings, we fail to reject the null hypothesis.

Ho_5 stated there will be no difference in peak velocity in the bench press exercise 48 hours after an acute bout of deadlift training as compared to baseline values. No statistically significant differences were found in the peak velocity of the bench press exercise 48 hours after deadlift training as compared to baseline values (BL: 1.069 ± .1555, 48hrs: 1.034 ± .1573, p=0.275). Based on the findings, we fail to reject the null hypothesis.

Ho_6 stated there will be no difference in peak velocity in the squat exercise 48 hours after an acute bout of deadlift training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 48 hours after deadlift training as compared to baseline values (BL: 1.382 ± .1761, 48hrs: 1.346 ± .1440, p=0.229). Based on the findings, we fail to reject the null hypothesis.

Ho_7 stated there will be no difference in peak velocity in the deadlift exercise 72 hours after an acute bout of deadlift training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 72 hours after deadlift training as compared to baseline values (BL: 1.484 ± .1484, 72hrs: 1.465 ± .1580, p=0.633). Based on the findings, we fail to reject the null hypothesis.

Ho_8 stated there will be no difference in peak velocity in the bench press exercise 72 hours after an acute bout of deadlift training as compared to baseline values. No statistically significant differences were found in the peak velocity of the bench press exercise 72 hours after deadlift training as compared to baseline values (BL: 1.069 ± .1555, 72hrs: .991 ± .1576, p=0.073). Based on the findings, we fail to reject the null hypothesis.

Ho_9 stated there will be no difference in peak velocity in the squat exercise 72 hours after an acute bout of deadlift training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 72 hours after deadlift training as compared to baseline values (BL: 1.384 ± .1761, 72hrs: 1.326 ± .1711, p=0.165). Based on the findings, we fail to reject the null hypothesis. Table 3 below summarizes the peak velocity results after the deadlift intervention:

Table 3: Deadlift Results

Deadlift Training			
	Squat Peak Velocity	Bench Press Peak Velocity	Deadlift Peak Velocity
Baseline	1.382 ± .1761	1.069 ± .1555	1.484 ± .1484
24hrs	**1.315 ± .1532***	**0.979 ± .1422***	1.398 ± .1914
48hrs	1.346 ± .1440	1.034 ± .1573	1.468 ± .1909
72hrs	1.326 ± .1711	0.991 ± .1576	1.465 ± .1580

*Denotes a significant difference as compared to baseline values (p< .05).

Ho_{10} stated there will be no difference in peak velocity in the deadlift exercise 24 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 24 hours after bench press training as compared to baseline values (BL: 1.491 ± .1484, 24hrs: 1.464 ± .1618, p=0.467). Based on the findings, we fail to reject the null hypothesis.

Ho_{11} stated there will be no difference in peak velocity in the bench press exercise 24 hours after an acute bout of bench press training as compared to baseline values. Peak velocity of the bench press exercise was significantly lower 24 hours after bench press training as compared to baseline values (BL: 1.069 ± .1555, 24hrs: .988 ± .1659, p=0.004). Based on the findings, we reject the null hypothesis.

Ho_{12} stated there will be no difference in peak velocity in the squat exercise 24 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 24 hours after bench press training as compared to baseline values (BL: 1.384 ± .1761, 24hrs: 1.377 ± .1754, p=0.824). Based on the findings, we fail to reject the null hypothesis.

Ho_{13} stated there will be no difference in peak velocity in the deadlift exercise 48 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 48 hours after bench press training as compared to baseline values (BL: 1.491 ± .1484, 48hrs: 1.511 ± .1508, p=0.467). Based on the findings, we fail to reject the null hypothesis.

Ho_{14} stated there will be no difference in peak velocity in the bench press exercise 48 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the bench press exercise 48 hours after bench press training as compared to baseline values (BL: 1.069 ± .1555, 48hrs: 1.020 ± .1816, p=0.052). Based on the findings, we fail to reject the null hypothesis.

Ho_{15} stated there will be no difference in peak velocity in the squat exercise 48 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 48 hours after bench press training as compared to baseline values (BL: 1.382 ± .1761, 48hrs: 1.338 ± .1745, p=0.136). Based on the findings, we fail to reject the null hypothesis.

Ho_{16} stated there will be no difference in peak velocity in the deadlift exercise 72 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 72 hours after bench press training as compared to baseline values (BL: 1.491 ± .1484, 72hrs: 1.486 ± .1368, p=0.946). Based on the findings, we fail to reject the null hypothesis.

Ho_{17} stated there will be no difference in peak velocity in the bench press exercise 72 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the bench press exercise 72 hours after bench press training as compared to baseline values (BL: 1.069 ± .1555, 72hrs: 1.047 ± .1449, p=0.232). Based on the findings, we fail to reject the null hypothesis.

Ho_{18} stated there will be no difference in peak velocity in the squat exercise 72 hours after an acute bout of bench press training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 72 hours after bench press training as compared to baseline values (BL: 1.382 ± .1761, 72hrs: 1.369 ± .1775, p=0.689). Based on the findings, we fail to reject the null hypothesis.

Table 4 below summarizes the results of peak velocity after the bench press intervention:

Table 4: Bench Press Results

Bench Press Training			
	Squat Peak Velocity	Bench Press Peak Velocity	Deadlift Peak Velocity
Baseline	1.382 ± .1761	1.069 ± .1555	1.491 ± .1484
24hrs	1.377 ± .1754	**0.988 ± .1659***	1.464 ± .1618
48hrs	1.338 ± .1745	1.020 ± .1816	1.511 ± .1508
72hrs	1.369 ± .1775	1.047 ± .1449	1.486 ± .1368

*Denotes a significant difference as compared to baseline values (p< .05).

Ho_{19} stated there will be no difference in peak velocity in the deadlift exercise 24 hours after an acute bout of squat training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 24 hours after squat training as compared to baseline values (BL: 1.491 ± .1484, 24hrs: 1.445 ± .1723, p=0.318). Based on the findings, we fail to reject the null hypothesis.

Ho_{20} stated there will be no difference in peak velocity in the bench press exercise 24 hours after an acute bout of squat training as compared to baseline values. Peak velocity of the bench press exercise was significantly 24 hours after squat training as compared to baseline values (BL: 1.069 ± .1555, 24hrs: 0.974 ± .1780, p=0.019). Based on the findings, we reject the null hypothesis.

Ho_{21} stated there will be no difference in peak velocity in the squat exercise 24 hours after an acute bout of squat training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 24 hours after squat training as compared to baseline values (BL: 1.382 ± .1761, 24hrs: 1.401 ± .1593, p=0.569). Based on the findings, we fail to reject the null hypothesis.

Ho_{22} stated there will be no difference in peak velocity in the deadlift exercise 48 hours after an acute bout of squat training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 48 hours after squat training as compared to baseline values (BL: 1.491 ± .1484, 48hrs: 1.489 ± .1558, p=0.969). Based on the findings, we fail to reject the null hypothesis.

Ho_{23} stated there will be no difference in peak velocity in the bench press exercise 48 hours after an acute bout of squat training as compared to baseline values. Peak velocity of the bench press exercise was significantly lower 48 hours after squat training as compared to baseline values (BL: 1.069 ± .1555, 48hrs: 1.015 ± .1681, p=0.034). Based on the findings, we reject the null hypothesis.

Ho_{24} stated there will be no difference in peak velocity in the squat exercise 48 hours after an acute bout of squat training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 48 hours after squat training as compared to baseline values (BL: 1.382 ± .1761, 48hrs: 1.362 ± .2136, p=0.687). Based on the findings, we fail to reject the null hypothesis.

Ho_{25} stated there will be no difference in peak velocity in the deadlift exercise 72 hours after an acute bout of squat training as compared to baseline values. No statistically significant differences were found in the peak velocity of the deadlift exercise 72 hours after squat training as compared to baseline values (BL: 1.491 ± .1484, 72hrs: 1.469 ± .1557, p=0.564). Based on the findings, we fail to reject the null hypothesis.

Ho_{26} stated there will be no difference in peak velocity in the bench press exercise 72 hours after an acute bout of squat training as compared to baseline values. Peak velocity of the bench press exercise was significantly lower 72 hours after squat training as compared to baseline values (BL: 1.069 ± .1555, 72hrs: 0.970 ± .1551, p=0.004). Based on the findings, we reject the null hypothesis.

Ho_{27} stated there will be no difference in peak velocity in the squat exercise 72 hours after an acute bout of squat training as compared to baseline values. No statistically significant differences were found in the peak velocity of the squat exercise 72 hours after squat training as compared to baseline values (BL: 1.382 ± .1761, 72hrs: 1.342 ± .1500, p=0.173). Based on the findings, we fail to reject the null hypothesis.

Table 5 below summarizes peak velocity results after the squat intervention:

Table 5: Squat Results

Squat Training			
	Squat Peak Velocity	Bench Press Peak Velocity	Deadlift Peak Velocity
Baseline	1.382 ± .1761	1.069 ± .1555	1.491 ± .1484
24hrs	1.401 ± .1593	**0.974 ± .1780***	1.445 ± .1723
48hrs	1.362 ± .2136	**1.015 ± .1681***	1.489 ± .1558
72hrs	1.342 ± .1500	**0.970 ± .1551***	1.469 ± .1557

*Denotes a significant difference as compared to baseline values (p< .05).

Chapter 5

Discussion

The present study was the first to examine neuromuscular fatigue and recovery after maximal training in all three powerlifts while investigating the effect of maximal powerlift training on the performance of future training sessions in each lift. Many studies have attempted to assess fatigue and recovery of muscular performance after resistance training (Bigland-Ritchie, 1978; Linnamo, 1998; Ide, 2011; Walker, 2009) but few have used one or more powerlifts as the intervention (Hakkinen, 1988; McCaulley, 2009; Sanchez-Medina, 2011). The current study was the first, to the best of knowledge, to test fatigue and recovery in all three powerlifts and use each as the interventions.

A previous study (Hakkinen, 1988) examined recovery of maximum voluntary contraction of the leg extensors after a high intensity training session with the squat (20 sets x 1 rep @100% 1RM). However, subjects performed leg extensions to gauge recovery and not the specific movement that was performed during the training session. Most of the literature examining neuromuscular fatigue used isolated muscle fibers *in vitro* or *in situ* while also using electrically stimulated fibers to determine fatigue both centrally and peripherally. Although the need for these mechanisms of research is obvious in a laboratory setting to locate sites of fatigue, the procedures are not practical to use for strength training individuals in a typical training environment. The current study is the first to date, to the best of our knowledge, to use all three powerlifts as the intervention as well as using all three powerlifts performance as the mechanism to measure recovery. Such data can be used to predict future training session performance after similar interventions.

One of the major findings from the current study suggested bench press performance at submaximal intensities may decline at least 24 hours after maximal strength training of any of the three powerlifts. Specifically, bench press peak velocity was significantly lower 24, 48, and 72 hours after maximal squat training, as compared to baseline (BL: 1.069 ± .1555, 24hrs: 0.974 ± .1780, 48hrs: 1.015 ± .1681, 72hrs: 0.970 ± .1551). The squat and deadlift exercise are commonly viewed as 'lower body' movements while the bench press is commonly viewed as being an 'upper body' movement (Beachle and Earle, 2008). This classification may be because of the dynamic movement of the joints of the lower body (ankle, knee, hip) that occurs during the squat and deadlift as well as the dynamic movement of the joints of the upper body (elbow, shoulder) during the bench press. This dynamic movement of joints may result in greater activation of motor units (throughout a range of motion) controlling these localized areas and lend itself to the common classifications. Interestingly, the data from the current study suggests traditionally classified 'lower body' movements (squat, deadlift) have a fatiguing effect on traditionally 'upper body' movements (bench press). This finding may be correlated with many possibilities.

Squat training elicited the longest timeframe of fatigue in the bench press (24, 48, and 72 hours). It is possible the motor units involved in bench pressing are affected during squatting because of their relatively smaller size, although no dynamic movement is occurring in the joints of the upper body and the prime movers (pectoralis major, anterior deltoid, and triceps brachii) of the bench press during the squat exercise. If fatigue contributed to the decline in bench press peak velocity after squat training then it occurred during static, isometric contractions of upper body contractile tissue during the squat exercise that is similarly involved with the bench press.

The current study revealed bench press peak velocity performance of subjects was significantly decreased at 24 hours (BL: 1.069 ± .1555, 24 hrs: .988 ± .1659), approached significance (p=.052) at 48 hours (48hrs: 1.020 ± .1816), and was nonsignificantly lower at 72 hours (72hrs: 1.047 ± .1449) post-bench press training. This was the only lift of the three powerlifts that incurred a performance decrement in the days following training of the same lift. Similar dynamic movement and motor unit activation involved in the intervention training and during the recovery measurement at 24 hours revealed a significant performance decrease in the bench press, indicating fatigue.

The nature of fatigue is task dependant (Enoka, 1998). One could postulate the motor units involved in the fatiguing task would theoretically be the motor units that become fatigued. Upper body motor units are generally smaller in size compared to lower body motor units and may be more easily fatigued with training as compared to lower body motor units (Zourdos, 2012). The smaller motor units may also recover at a slower rate with training that is equated in relative volume and intensity between movements. Similarly, results from Zourdos et al. (2012) suggested the bench press and other upper body exercises cause greater fatigue in the smaller muscle groups that were being used, as well as suggesting these muscle groups may need a greater time to recover than larger muscle groups. In the bench press specifically, Newton et al. (1996) found the greatest EMG activation during a bench press variation occurring in the pectoralis major, anterior deltoid, and triceps brachii (Zourdos, 2012). These muscle groups may be defined as prime movers in the bench press exercise and may need specific fatigue consideration when designing training programs using powerlifts.

It is also worth noting the central nervous system (CNS) may be more fatigued following larger, multi-joint exercises such as powerlifts. These larger movements could yield greater resistances and subsequent overall stress on the human central nervous system because they require greater neural output to perform. The effort involved in the training sessions of the present study was maximal or near maximal over multiple sets of low repetitions (1-3 repetitions). This high effort style of training may have implications in eliciting CNS fatigue, as seen by declines in EMG activity by Hakkinen et al. (1988) following an intense squat training session (Hakkinen, 1988). Training with higher volumes of repetition may be more indicative of peripheral fatigue due to the myofiber damage that occurs with the eccentric movements that are inevitably greater with higher repetition volume. Training session variables (sets, reps, intensity, rest periods) should be taken into consideration when examining this study’s data. Furthermore, bench press peak velocity also significantly decreased only 24 hours following a deadlift training session, as compared to baseline (BL: 1.069 ± .1555, 24hrs: 0.979 ± .1422). The nature of fatigue that occurs following maximal effort training in large, stressful movements, such as the squat and deadlift, may also account as to why a seemingly different lift in the bench press became significantly depressed in peak velocity performance following squat and deadlift training.

The data also suggested squat performance at submaximal intensities may decline for 24 hours after maximal strength training of the deadlift, as compared to baseline (BL: 1.362 ± .1761, 24hrs: 1.315 ± .1532). Many individuals participating in the sport of powerlifting or using powerlifting programming for strength training believe the squat and deadlift are characteristically similar and may have a “cross-over” training effect. That is, building strengths in the squat will help build strengths in the deadlift, and vice versa. Conversely, if one followed this belief one could assume training in either lift would fatigue the other if they are characteristically similar. However, Hales et al. (2009) conducted a kinematic analysis of the conventional deadlift and squat using 25 competitive powerlifters. Their results indicated biomechanical differences between the two lifts in ankle, knee, and hip angles, differences in thigh angles at average sticking points, and differences in trunk angles. Kinematic analysis indicated the two lifts are markedly different and concluded there is no cross-over effect between the conventional deadlift and squat (Hales, 2009). However, results from the current study indicated deadlift training may have a fatiguing effect on squat peak velocity 24 hours post-training. Lower body exercises may have a more generalized fatigue effect on lower body motor units (Zourdos, 2012) and thus, may lead to a cross-over fatiguing effect between the deadlift and squat. More research is needed comparing biomechanical factors with fatigue after training.

Interestingly, performance of the squat and deadlift at submaximal intensities following training of the same lift may not be affected in the days following training and may potentially increase. Deadlift peak velocity decreased nonsignificantly after deadlift training, as compared to baseline (BL: 1.491, 24hrs: 1.398, 48hrs: 1.468, 72hrs: 1.465). Squat peak velocity increased nonsignificantly after training, as compared to baseline peak velocity (BL: 1.382, 24hrs: 1.401, 48hrs: 1.362, 72hrs: 1.342). Although the increase was nonsignificant, it is interesting to see a performance increase only 24 hours after intense training. Speculatively, the squat is a more technical and precise lift as compared to the bench press and deadlift. Subjects may have taken advantage of the amount of repetitions at high intensities which may have stimulated a neuromuscular training effect that increased movement efficiency and neural coordination in the squat motor pattern. This increase in 'fitness' for the squat may have outweighed the fatigue decrement that occurred from training and may have been more beneficial to the squat movement as compared to the other two lifts. While purely speculation, fitness increases in 24 hours is interesting and may have many implications in future research.

Limitations of the present study include the intensity of the recovery measurement. For each recovery day, a 60% relative intensity was used for each lift. This intensity may not have been great enough to expose possible fatigue and greater intensities may have been able to do so. However, the intensity for the present study was chosen in an attempt to use an intensity that is great enough to expose fatigue while also trying to control the amount of fatigue incurred on recovery days. Adding excess amounts of fatigue during recovery measurements could skew data at the later time points. Another limitation of the present study included the subject's nutrition logs.

Nutrition plays an important role in recovery from training session. Subjects recorded the first week of nutrition and were instructed to keep nutrition similar to this week. However, subjects did not complete a second nutrition log to compare and ensure nutrition was kept similar. Post-training session nutrition was standardized by giving 30g of whey protein to each subject immediately upon completion of training.

Music was used in the present study during training sessions to increase the training environment intensity. Music was kept similar across training groups. Strong verbal encouragement was used during each training session to help subjects complete the highly intense workloads. Females were not allowed in the laboratory during any sessions to attempt to control environmental changes between groups, as their presence may have provided a mental stimulus for some of the male subjects.

Conclusions

Understanding fatigue and adaptation is an integral part in designing optimal strength training programs. The prevalence of powerlifts used in the training of not only powerlifting competitors, but also athletes interested in increasing strength/power and recreational weightlifters increases the need to examine ways to optimize training protocols in research. Therefore, the purpose of this study was to compare neuromuscular fatigue that is induced after training in each of the three powerlifts and observe the effect maximal effort training in one lift has on the performance of each of the three powerlifts in the days following training. Understanding the fatiguing effects of each lift may help optimize short and long term training program variables. Our findings indicated neuromuscular fatigue may have occurred in the pathways and motor units involved in the bench press exercise after observing a peak velocity decrease atleast 24 hours after training sessions in each of the three powerlifts. Maximal effort strength training with all powerlifts may lead to fatigue accumulation in upper body motor units, potentially affecting performance. Practical applications of this knowledge may lead to program alterations when attempting to train the bench press in a non-fatigued state to optimize training performance for specific strength adaptations from training or when leading into competitions. Also, depending on the training program variables, those attempting to train in a fatigued state may better understand the level of fatigue that is contributed by each lift after intense training to optimize chronic training stimuli. Additionally, our study indicated upper body motor units, specifically those involved with bench pressing, are not only fatigued by classic upper body exercise. The data challenges the traditional classification of the squat and deadlift being only ‘lower body’ exercises with evidence of upper body motor unit fatigue following training of ‘lower body’ lifts. A more appropriate labeling, in relation to training and fatigue, of the squat and deadlift may be a ‘full body’ lift. Finally, subjects experienced a significant performance decrement in squatting after deadlift training which alludes to the possibility of a fatigue cross-over effect between lifts. Once again, knowledge of this potential effect may help optimize powerlift programming. To the best of our knowledge this is the first study to examine neuromuscular fatigue using all three powerlifts in training and in measurements of fatigue in an attempt to optimize programming variables. Future research should test blood markers such as creatine kinase, testosterone, and cortisol to examine peripheral fatigue and training responses to the powerlifts after maximal effort training. Also, the current study used a performance intensity of 60% of 1RM in each lift to test fatigue and recovery in the days following training. In the future, studies should be done that use different performance variables. Specifically, research testing the effect of powerlift training sessions on maximal strength output (1RM) of each powerlift in the days following a single powerlift training session may be beneficial and meaningful.

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Appendices

Appendix A- Table A1 Testing Procedures

Week 1- Monday	**Baseline Measurements-Bar velocity (TENDO)** **Back squat, bench press, deadlift- Warm-up, 1 set of 5 reps @60% of 1RM with TENDO** **1 week nutrition log #1**
Week 2- Monday Tuesday-Thursday	**3 randomized lift conditions-1RM, 4x2 @92.5%, 4x3@87.5%** Recovery Measurements-BS, BP, DL- Warm-up, 1 set of 5reps @60% of 1RM with TENDO
Week 3- Monday Tuesday-Thursday	**3 new randomized lift conditions-1RM, 4x2 @92.5%, 4x3@87.5%** Recovery Measurements-BS, BP, DL- Warm-up, 1 set of 5 reps @60% of 1RM with TENDO
Week 4- Monday Tuesday-Thursday	**3 new randomized lift conditions-1RM, 4x2 @92.5%, 4x3@87.5%** Recovery Measurements-BS, BP, DL- Warm-up, 1 set of 5 reps @60%of 1RM with TENDO

Appendix B

Personal Information Sheet

Personal Information

Name:

Address:

City: ______________ State: _____ Zip Code_________

Home Phone: (___) _____________ Work Phone: (___) ______________

Cellular (___) _________________ Fax: (___) _________________

Email address: _______________________

Birth date:___ /___ /____ Age: ____ Height: _____ Weight: ______

Exercise History/Activity Questionnaire

1. Describe your typical recreational activities.

2. Describe any exercise training that you routinely participate.

3. How many days per week do you exercise/participate in these activities?

4. How many hours per week do you train?

5. How long (years/months) have you been consistently training?

6. Supplement question?

Appendix C

Pre-Activity Screening Questionnaire (PASQ)

Section 1-Diagnosed Medical Conditions

Please mark either Y (Yes) or N (No) *for* each of the items below that you have had diagnosed by a physician.

Cardiovascular (Heart) Disease
Y❑ N❑ Heart attack
Y❑ N❑ Heart surgery
Y❑ N❑ Coronary angioplasty (PTCA)
Y❑ N❑ Heart valve disease
Y❑ N❑ Heart failure
Y❑ N❑ Heart transplantation
Y❑ N❑ Congenital heart disease
Y❑ N❑ Abnormal heart rhythm
Y❑ N❑ Pacemaker/implantable cardiac defibrillator
Y❑ N❑ Peripheral vascular disease (PVD or PAD): disease affecting blood vessels in arms, hands, legs, and feet
Y❑ N❑ Cerebrovascular disease (stroke or transient ischemic attack): disease affecting blood vessels in the brain

Pulmonary (Lung) Disease
Y❑ N❑ Emphysema
Y❑ N❑ Chronic bronchitis
Y❑ N❑ Interstitial lung disease
Y❑ N❑ Cystic fibrosis
Y❑ N❑ Asthma
↪If Yes to asthma, is this a current condition **Y❑ N❑**

Metabolic Disease
Y❑ N❑ Liver disease
Y❑ N❑ Diabetes
Y❑ N❑ Thyroid disorders
Y❑ N❑ Kidney disease

Y❑ N❑ Do you have any other medical conditions diagnosed by a physician (such as musculoskeletal problems, recent surgery, seizures, pregnancy, cancer, etc.) that may limit your physical activity?
Y❑ N❑ Do you take any prescription medications?

Section 2- Signs or Symptoms

Please mark either Y (Yes) or N (No) for each item below that you have recently experienced.

Y❑ N❑ Pain, discomfort in the chest, neck, jaw or arms at rest or upon exertion
Y❑ N❑ Shortness of breath at rest or with mild exertion
Y❑ N❑ Dizziness or loss of consciousness during or shortly after exercise
Y❑ N❑ Shortness of breath occurring at rest or 2-5 hours after the onset of sleep
Y❑ N❑ Edema (swelling) in both ankles that is most evident at night or swelling in a limb
Y❑ N❑ An unpleasant awareness of forceful or rapid beating of the heart
Y❑ N❑ Pain in the legs or elsewhere while walking; often more severe when walking upstairs/uphill
Y❑ N❑ Known heart murmur
↪If Yes to known heart murmur, is this a current condition **Y❑ N❑**
Y❑ N❑ Unusual fatigue or shortness of breath with usual activities

Section 3- CVD Risk Factors

Please mark Y (Yes) or N (No) for each the following:

Positive Risk Factors
Y❑ N❑ I am a man who is 45 years or older or a woman who is 55 years or older.
Y❑ N❑ I have a father or brother who had a heart attack, coronary (heart) by-pass surgery, or who died suddenly before age 55 or I have a mother or sister who had a heart attack, coronary (heart) by-pass surgery, or who died suddenly before age 65.
Y❑ N❑ I am a smoker or I have quit smoking in the last 6 months or am exposed to environmental tobacco smoke.
Y❑ N❑ In the last 3 months, I have **not** been physically active - meaning I have **not** participated in 30 min of moderate intensity physical activity at least 3 days/week.
Y❑ N❑ I have a BMI greater than or equal to 30 (see BMI chart on page 2 to determine your BMI).

Please mark Y (Yes), N (No), or DK (Don't Know) for each the following:

Y❑ N❑ DK❑ My blood pressure is greater than or equal to 140/90 mm Hg.
Y❑ N❑ DK❑ My blood cholesterol level is greater than or equal to 200 mg/dL.
Y❑ N❑ DK❑ My fasting blood glucose is greater than or equal to 100 mg/dL.

Negative Risk Factor
Y❑ N❑ DK❑ My high-density lipoprotein (HDL) cholesterol level is greater than or equal to 60 mg/dL.

Section 4- Acknowledgment, Follow-up, and Signature

I acknowledge that I have read this questionnaire in its entirety and have responded accurately, completely, and to the best of my knowledge. Any questions regarding the items on this questionnaire were answered to my satisfaction. Also, if my health status changes at any time, I understand that I am responsible to inform this health/fitness facility of any such changes.

(Participant's Name-Please Print) (Participant's Signature) (Date)

Appendix D

UNIVERSITY OF SOUTH FLORIDA

Informed Consent to Participate in Research

Information to Consider Before Taking Part in This Research Study

IRB Study # 9641

You are being asked to take part in a research study. Research studies include only people who choose to take part. This document is called an informed consent form. Please read this information carefully and take your time making your decision. Ask the researcher or study staff to discuss this consent form with you, please ask him/her to explain any words or information you do not clearly understand. We encourage you to talk with your family and friends before you decide to take part in this research study. The nature of the study, risks, inconveniences, discomforts, and other important information about the study are listed below.

We are asking you to take part in a research study called: *Comparisons of acute neuromuscular fatigue in maximal effort strength training using powerlifts*

The person who is in charge of this research study is Nick Theilen. This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge. He is being guided in this research by Dr. Bill Campbell.

The research will be conducted at The University of South Florida in Tampa. It will be specifically located in the Performance and Nutrition Laboratory on the ground floor of the USF Recreation Center.

Purpose of the study

Many people involved in strength training use the squat, bench press, and deadlift (commonly referred to as powerlifts) as the basis of their training program. The purpose of the present study is to understand the extent of fatigue that occurs after an intense training session using each of the three powerlifts in strength trained males. This information can be very useful when planning a strength training program. Power lifters, strongmen, strength coaches, strength and power athletes, recreational weight trainers, and more may benefit from such knowledge. There is no study to date that specifically targets powerlifts and the fatigue relationship between and among each lift. Nick Theilen, who is an exercise science graduate student, will be conducting this study.

Should you take part in this study?

- This form tells you about this research study. After reading through this form and having the research explained to you by someone conducting this research, you can decide if you want to take part in it.
- You may have questions this form does not answer. If you do have questions, feel free to ask the study doctor or the person explaining the study, as you go along.
- Take your time to think about the information that is being provided to you.
- Talk it over with your regular doctor.

This form explains:

- Why this study is being done.
- What will happen during this study and what you will need to do.
- Whether there is any chance of benefits from being in this study.
- The risks involved in this study.
- How the information collected about you during this study will be used and with whom it may be shared.

Providing informed consent to participate in this research study is up to you. If you choose to be in the study, then you should sign the form. If you do not want to take part in this study, you should not sign this form.

Why are you being asked to take part?

We are asking you to take part in this research study because you are a part of a specific demographic that regularly strength trains using these exercises. We want to obtain information that may help people who weight train in this manner.

What will happen during this study?

You will be asked to be one of 12 participants in this study. All of the testing will be done in the Exercise and Performance Nutrition Laboratory located on the ground floor of the University of South Florida Recreation Center. There will be a total of 17 possible lab visits over 5 weeks. This study is a randomized crossover design. All subjects will be assigned to all trials (or arms) of the study before it is completed. 1/3 of subjects will be randomly assigned to the Squat group, 1/3 to the bench press group, and 1/3 to the deadlift group at the beginning of the study. Randomization will occur using a random number generator (http://andrew.hedges.name/experiments/random/). After the first trial is completed each subject will be randomly assigned to one of the two remaining arms of the study for the second trial. The third and final trial will be obvious for each subject at the end of the second trial because it will be the only trial remaining for that specific subject. If an injury occurs at any time, subjects will be asked to visit their primary care physician for guidance and will be excluded from the study if unable to continue.

The schedule and description of lab visits are listed below.

See the chart below for an outline of the scheduled days. See below for the descriptions.

Terms:
1RM (1 repetition maximum) - The maximal load that can be lifted within a given exercise. The protocol is explained below.
Bar Velocity (TENDO) - Using a linear velocity transducer (name brand is a TENDO Power and Speed Analyzer), each subject will perform repetitions in the exercises and the TENDO unit will analyze the velocity of the movement. The protocol is explained below.
BS, BP, DL – Back squat, bench press, and deadlift. These are the three exercises that will be used in this study.
Please review the study outline in the chart. Explanations of each day are below the chart.

Week 1-Monday	**Baseline Measurement-Bar velocity (TENDO)** **Back squat, bench press, deadlift- Warm-up, 1 set of 5 reps @60% of 1RM with TENDO** **1 week nutrition log #1**
Week 2-Monday Tuesday-Friday	**3 randomized lift groups-1RM, 4x2 @92.5%, 4x3@87.5%** Recovery Measurements-BS, BP, DL- Warm-up, 1 set of 5reps @60% of 1RM with TENDO

Week 3-Monday Tuesday-Friday	**3 new randomized lift groups-1RM, 4x2 @92.5%, 4x3@87.5%** Recovery Measurements-BS, BP, DL- Warm-up, 1 set of 5 reps @60% of 1RM with TENDO
Week 4- Monday Tuesday-Friday	**3 new randomized lift groups-1RM, 4x2 @92.5%, 4x3@87.5%** Recovery Measurements- BS, BP, DL- Warm-up, 1 set of 5 reps @60%of 1RM with TENDO

Week 1, Monday: Baseline measurements

Each participant will have baseline measures of bar velocity taken one week prior to the first exercise protocol. Subjects will begin the day by addressing how they feel on a perceived recovery status scale of 1-10. Then measures of peak velocity will be recorded using the TENDO Power and Speed Analyzer for each lift starting with the back squat, bench press, and finally the deadlift. The TENDO unit is a device that attaches to the barbell used in the exercise which takes measurements of the bar velocity. Each participant will complete a warmup using bodyweight squats and arm circles. Subjects will then be assigned a load of 60% of 1RM to complete at least 3 repetitions to achieve the highest peak velocity possible. If the third repetition velocity is higher than the first and second repetition, additional repetitions will be given until there is a drop in peak velocity. No more than 5 repetitions will be allowed for each lift during each measurement day.

Weeks 2,3,4: Monday Training Protocol

Participants will be randomly assigned to a squat, bench press, or deadlift group. Each group will begin each training session with a warm-up lasting three-five minutes, followed by a light, dynamic warm-up of bodyweight squats and arm circles. Subjects will then work up to a 1 RM following the same protocol used during 1RM testing. After a single maximal effort repetition is completed, subjects will then complete 4 sets of 2 repetitions at 95% of the tested 1 RM. This will be followed by 4 sets of 3 repetitions at 90% of the tested 1 RM. Repetitions are meant to be maximal or near maximal but without failure. Weights will be adjusted as needed to ensure these constructs are met. If there is failure on a repetition, a 5% reduction in weight will occur to accommodate the next repetition if it is still in the same intensity range. This protocol was chosen arbitrarily, partly based on practical strength training methods used with powerlifts and partly based on the need to elicit appropriate amounts of fatigue in each subject. It would not be uncommon to see similar repetition ranges being done at these percentages in a practical power lifting training session. However training with this volume, or multiple sets, of these high effort repetitions is typically perceived as being sub-optimal due to the amount of fatigue that occurs. Therefore, this protocol was selected to intentionally induce fatigue to ensure appropriate stress for testing while attempting to adhere to a practical design. Verbal encouragement and training music will be used to help each participant meet the demands of the training protocol and elicit maximal efforts. Subjects will be instructed to stay under control during the downward phase and to lift upward as fast as possible. A Certified Strength and Conditioning professional and spotters will be used to ensure each lift requirement is properly met. There will be three minute rest intervals between each working set. Spotters will be present to assist the subjects during the lift, if needed, and ensure safety. 30g of Whey protein will be provided to each subject at the end of the training protocols. Subjects with an allergy to whey protein will not be included in this study.

Weeks 2,3,4: Tuesday-Friday -Baseline and Recovery Measurements

Each participant will have baseline measures taken one week prior to the first exercise protocol. During this time, subjects will begin by choosing a number of 1-10 off the perceived recovery status scale to assess their subjective feeling of fatigue. Then measures of peak velocity will be recorded using the TENDO Power and Speed Analyzer for each lift starting with the back squat, bench press, and finally the deadlift.

The baseline and recovery measurement will begin with 3-5 minutes of light, dynamic warm-ups using bodyweight squats and arm circles. The warm-up will be followed by three sets of five repetitions at 40-50% of 1RM. Subjects will then be assigned a load of 60% of 1RM to complete at least 3 repetitions to achieve the highest peak velocity possible. If the third repetition velocity is higher than the first and second repetition, additional repetitions will be given until there is a drop in peak velocity. No more than 5 repetitions will be allowed for each lift during each measurement day.

Spotters will be present during every exercise to ensure the safety of the repetitions being completed.

Weeks 2- Dietary Logs

Each subject will be asked to keep a nutrition diary for Monday-Wednesday and Saturday of weeks 2. This will be done to help ensure nutrition was constant throughout the study.

Total Number of Participants

12 individuals will take part in this study at USF.

Alternatives

You do not have to participate in this research study.

Benefits

We are unsure if you will receive any benefits by taking part in this research study.

Risks or Discomfort

The following risks may occur:

There may be possible risks associated with the exercises involved in this study (bench press, squat, and deadlift) and with physical activity in general. According to the American College of Sports Medicine, "vigorous physical exertion increases the risk of sudden cardiac death and acute myocardial infarction. However, exercise only provokes cardiovascular events in individuals with pre-existing heart disease. Exercise does not provoke cardiac events in individuals with normal cardiovascular systems." In addition, the exercise tests may also cause short-term muscle soreness and fatigue for several days following the tests. Likewise, you may also experience muscle strains during testing. These risks, however, are similar to the risks of participating in other typical physical activity programs, but in order to participate in this study, you must be considered "low-risk" and are therefore at a reduced risk of injury.

This particular study will choose participants who regularly use these exercises and train with this intensity. Therefore, this study will not increase the risk of the participants beyond what they normally incur during their own training.

Compensation

You will receive no payment or other compensation for taking part in this study.

Cost

There will be no additional costs to you as a result of being in this study.

Privacy and Confidentiality

We will keep your study records private and confidential. Certain people may need to see your study records. By law, anyone who looks at your records must keep them completely confidential. The only people who will be allowed to see these records are:

- The research team, including the Principal Investigator, study coordinator, and all other research staff.
- Certain government and university people who need to know more about the study. For example, individuals who provide oversight on this study may

need to look at your records. This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.

- Any agency of the federal, state, or local government that regulates this research. This includes the Food and Drug Administration (FDA), Florida Department of Health, and the Department of Health and Human Services (DHHS) and the Office for Human Research Protection (OHRP).
- The USF Institutional Review Board (IRB) and its related staff who have oversight responsibilities for this study, staff in the USF Office of Research and Innovation, USF Division of Research Integrity and Compliance, and other USF offices who oversee this research.

We may publish what we learn from this study. If we do, we will not include your name. We will not publish anything that would let people know who you are.

Voluntary Participation / Withdrawal

You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study. You are free to participate in this research or withdraw at any time. There will be no penalty or loss of benefits you are entitled to receive if you stop taking part in this study.

New information about the study

During the course of this study, we may find more information that could be important to you. This includes information that, once learned, might cause you to change your mind about being in the study. We will notify you as soon as possible if such information becomes available.

What if you get sick or hurt while you are in the study?

If you need emergency care:

- Go to your nearest hospital or emergency room right away or call 911 for help. It is important that you tell the doctors at the hospital or emergency room that you are participating in a research study. If possible, take a copy of this informed consent form with you when you go. USF does not have an emergency room or provide emergency care.

If you do NOT need emergency care:

- Go to your regular doctor. It is important that you tell your regular doctor that you are participating in a research study. If possible, take a copy of this informed consent form with you when you go.
- The USF Medical Clinics may not be able to give the kind of help your needs.

Will I be compensated for research related injuries?

If you believe you have been harmed because of something that is done during the study, you should call Nick Theilen at 502-314-9661 immediately. The University of South Florida will not pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. The cost of such care or treatment will be your responsibility. In addition, the University of South Florida will not pay for any wages you may lose if harmed by this study. The University of South Florida is considered a state agency and therefore cannot usually be sued. However, if it can be shown that the researcher, or other USF employee, is negligent in doing his or her job in a way that harms you during the study, you may be able to sue. The money that you might recover from the State of Florida is limited in amount.

You can also call the USF Self Insurance Programs (SIP) at 1-813-974-8008 if you think:

- You were harmed because he/she took part in this study.
- Someone from the study did something wrong that caused you to be harmed, or did not do something they should have done.
- Ask the SIP to look into what happened.

What happens if you decide not to take part in this study?

You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study to please the study doctor or the research staff. If you decide not to take part in the study you will not be in trouble or lose any rights you normally have. You will still have the same health care benefits and get your regular treatments from your regular doctor.

You can decide after signing this informed consent document that you no longer want to take part in this study for any reason at any time. If you decide you want to stop taking part in the study, tell the study staff as soon as you can.

- We will tell you how to stop safely. We will tell you if there are any dangers if you stop suddenly.
- If you decide to stop, you can continue getting care from your regular doctor.
- Please contact Nick Theilen at 502-314-9661 as soon as possible if you decide to stop.
- Even if you want you to stay in the study, there may be reasons we will need to withdraw you from the study. You may be taken out of this study if we find out it is not safe for you to stay in the study or if you are not coming for the study visits when scheduled. We will let you know the reason for withdrawing you from this study.

You can get the answers to your questions, concerns, or complaints.

If you have any questions, concerns or complaints about this study, call Nick Theilen at 502-314-9661.

If you have questions about your rights, general questions, complaints, or issues as a person taking part in this study, call the USF IRB at (813) 974-5638.

Consent to Take Part in Research

And Authorization for the Collection, Use and Disclosure of Health Information

It is up to you to decide whether you want to take part in this study. If you want to take part, please read the statements below and sign the form if the statements are true. I freely give my consent to take part in this study and authorize that my health information as agreed above, be collected/disclosed in this study. I understand that by signing this form I am agreeing to take part in research. I have received a copy of this form to take with me.

_______________________________________ ____________
Signature of Person Taking Part in Study Date

____
Printed Name of Person Taking Part in Study

Statement of Person Obtaining Informed Consent and Research Authorization

I have carefully explained to the person taking part in the study what he or she can expect from their participation. I hereby certify that when this person signs this form, to the best of my knowledge, he/ she understands:

- What the study is about;
- What procedures/interventions/investigational drugs or devices will be used;
- What the potential benefits might be; and
- What the known risks might be.

I can confirm that this research subject speaks the language that was used to explain this research and is receiving an informed consent form in the appropriate language. Additionally, this subject reads well enough to understand this document or, if not, this person is able to hear and understand when the form is read to him or her. This subject does not have a medical/psychological problem that would compromise comprehension and therefore makes it hard to understand what is being explained and can, therefore, give legally effective informed consent. This subject is not under any type of anesthesia or analgesic that may cloud their judgment or make it hard to understand what is being explained and, therefore, can be considered competent to give informed consent.

Signature of Person Obtaining Informed Consent / Research Authorization Date

Printed Name of Person Obtaining Informed Consent / Research Authorization

Appendix E

USF
UNIVERSITY OF SOUTH FLORIDA

DIVISION OF RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-5618

October 18, 2012

Mr. Nicholas Theilen
University of South Florida
School of Physical Education & Exercise
Science 15501 Bruce B. Downs Blvd, Apt. 2702
Tampa, Florida 33647

RE: **Full Board Approval** for
IRB#: Pro00009461
Title: Comparisons of acute neuromuscular fatigue in maximal effort strength training using power lifts.
Study Approval Period: 10/17/2012 to 9/27/2013

Dear Mr. Theilen: On 10/17/2012 the Institutional Review Board (IRB) reviewed and **APPROVED** the above application and all documents outlined below.

Approved Items:
Protocol Document(s):
Data collection forms
Neuromuscular fatigue using power lifts
PASQ
personal information sheet
Risk Stratification

Consent/Assent
Document(s): Revised IC.pdf

Please note, if applicable, the **informed consent/assent documents are valid during the period indicated by the official, IRB-Approval stamp located on the form.** Valid consent must be documented on a copy of the most recently IRB-approved consent form. As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

Jose Montero M.D., Chairperson

USF Institutional Review Board