The Effects of Varying Postactivation Potentiation Intensities on Vertical Jump Performance

By

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In partial fulfillment of the requirements for the degree,

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Abstract

The purpose of the study was to determine whether a submaximal loading protocol or a super maximal loading protocol was the most effective postactivation potentiation method for improving a vertical jump test with Division II football and volleyball players. If there was a significant increase in vertical jump performance following the super maximal loading or submaximal loading protocol, it may be assumed that one of the protocols causes a greater postactivation potentiation effect. The researcher hypothesized that the heavy spinal load created by the rack squat may produce a higher anaerobic output result through the vertical jump in comparison to the submaximal spinal load from the jump squat. The participants underwent a four week protocol including maximal back squat testing, baseline vertical jump testing, vertical jump testing after the submaximal loading protocol, and vertical jump testing after the super maximal loading protocol. Each intervention was completed on a separate week to ensure adequate rest from the movements. The dependent variables of the study were the vertical jump performances and the EMG peak amplitude measured after each intervention. The results were analyzed using a mixed ANOVA design since the research included two independent variables, which were the sport played and the specific intervention. All data was run through SPSS (Version 22, 2013) and the significance level was set at $p < 0.05$ for all variables. The football players observed an insignificant increase in average vertical jump performance following the jump squat intervention (27.71 inches) and rack squat intervention (27.62 inches) in comparison to the pretest performance (27.31 inches). The volleyball players observed an insignificant decrease in average vertical jump performance following the rack squat intervention (18.38 inches) and the jump squat intervention (18.45 inches) in comparison to the pretest performance (19.56 inches). There was not a significant difference within groups between the vertical jump heights after the rack squat and jump squat interventions ($p > .05$). The results show that there was a significant effect of the sport played in relation to the increase or decrease in vertical jump performance during the rack squat and jump squat interventions ($p < 0.05$). The results from the study indicate no significant difference between the super maximal and submaximal loading protocols for postactivation potentiation prior to vertical jump testing in these specific athletic groups. Therefore, the hypothesis posed by the researcher was rejected.

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Chapter 1: Introduction

Background

The ability to produce a substantial amount of power is critical for predicting performance in anaerobic sports. Strength and conditioning professionals actively seek the most advantageous training protocols to improve power output for their athletes. In order to aid in the development of explosive strength, postactivation potentiation (PAP) may be utilized during the training of power athletes. Postactivation potentiation refers to the heightened neuromuscular condition seen after a session of heavy or explosive resistance training (Lim & Kong, 2013). Postactivation potentiation is also defined as an upsurge in twitch force after maximal contractile activity (Sale, 2004). Previous research indicates that the use of a PAP movement prior to an explosive movement may increase the rate of force development (Chiu, Fry, Weiss, Schilling, Brown & Smith, 2003). The enhanced rate of force development may be attributed to neural modulation and phosphorylation during the postactivation potentiation activity (French, Kraemer, & Cooke, 2003). The aforementioned acute neurological adaptations may improve an explosive performance such as the vertical jump test (French et al., 2003).

Two major mechanisms regarding the postactivation potentiation phenomenon have been suggested. One of the major mechanisms is the increase in type Ia fibers and motoneuron excitability based on the changes in the Hoffman-reflex (H-reflex) (Smith & Fry, 2007). The H-Reflex is also considered to reveal neural excitability as a result from the postactivation potentiation intervention (Hodgson, Docherty & Zehr, 2008). A major component of the H-reflex is an increased amount of motor units used during physical exertion (Tillin & Bishop, 2009). If the athlete is able to recruit more motor units, then they may produce more power during their exercise bout. Recent research on animals shows that a tetanic isometric contraction or prior conditioning contraction increases the transmittance of excitation potentials through synaptic junctions at the spinal cord (Tillin & Bishop, 2009). The increased transmittance of excitation potentials will allow the animal to increase post-synaptic potentials for the next activity (Tillin & Bishop, 2009). Therefore, the increased amount of motor units may be associated with a postactivation potentiation effect due to the increased performance of the participant (Tillin & Bishop, 2009).

The results from the high degree of neural stimulation appear to only be acute in nature. The intensified neural state may last from five to thirty minutes after the prior conditioning contraction (Chiu et al., 2003). However, the optimal time frame for the intensified neural state depends on each individual athlete (Seitz, De Villarreal & Haff, 2014). Athletes with more heavy weight training experience might be able to recover more quickly than their recreationally trained counterparts (Seitz et al., 2014). The quicker recovery period indicates that the athlete will see a greater postactivation potentiation effect within a few minutes in comparison to an athlete with less experience (Seitz et al., 2014). The athlete with less experience might only see an enhanced training effect several minutes after the postactivation potentiation intervention (Seitz et al., 2014). Additionally, the less experienced athlete may not experience any positive effects from undergoing a postactivation potentiation intervention (Seitz et al., 2014). The initial strength level of the participant may also have an influence on the effectiveness of the postactivation potentiation intervention (Chiu et al, 2003; Seitz et al, 2014). The higher the initial strength level of the athlete, the higher chance of a positive effect (Chiu et al, 2003; Seitz et al, 2014). The initial strength level may also be tied in with the training experience of the athlete.

Another possible mechanism includes the acute rise in regulatory light chain (RLC) phosphorylation (Tillin & Bishop, 2009). The increase in regulatory light chain phosphorylation changes the actin-myosin sensitivity to calcium, one of the chief components of muscular contractions (Tillin & Bishop, 2009). Additionally, the regulatory light chain uptake causes an increased rate of cross-bridge attachment due to the heightened sensitivity of the contractile proteins to calcium (Baudry & Duchateau, 2007). The increased rate of cross-bridge attachment may produce a large twitch force and increase the overall rate of force development (Baudry & Duchateau, 2007). The structure of the myosin head may be altered and moved away from the dense filament backbone (Pearson & Hussain, 2014). Based on the altered myosin head, regulatory light chain phosphorylation may potentiate subsequent muscular contractions (Pearson & Hussain, 2014).

There are a few different loading parameters that may produce the potentially beneficial effects of postactivation potentiation. The first method used involves isometric maximal voluntary contractions (MVCs) for varying time periods. For example, a study by Pearson and Hussain (2014) compared three, five, and seven-second isometric contractions prior to a vertical jump test. The results from Pearson and Hussain's (2014) study did not yield any increases in jump power, rate of force development, or jump height after any of the interventions. A study by Lim and Kong (2013) used similar methods in addition to a dynamic squat postactivation protocol. The participants in Lim and Kong's (2013) study underwent three sets of three-second isometric contractions or one set of a 3 repetition maximum squat effort. The results from the study did not show any significant difference between the control group and any of the experimental groups. However, a few of the participants showed a performance improvement with certain interventions. Some factors that might contribute to the erratic results include the individual participant's varying strength levels and the postactivation potentiation intensity. One method of determining muscle activity during a specific movement is the use of electromyography (EMG) (Ball & Scurr, 2011). In addition to the use of vertical jump testing, EMG readings may help pinpoint the electrical activity in certain muscle groups during postactivation potentiation interventions.

A large amount of postactivation potentiation research involves the use of isometric techniques (Lim & Kong, 2013; Pearson & Hussain, 2014). However, there is some research involving plyometric, resisted sprinting or higher percentage strength work nearing 90% of the participant's one repetition maximal effort. A study by Smith et al. utilized sled resistance sprinting at 0%, 10%, 20%, and 30% of the participants' body weight (Smith, Hannon, McGladrey, Shultz, Eisenman, Lyons, 2014). The findings show improved sprint performances for all groups using additional sled resistance levels. There was not a large difference between each group, which calls for additional research to be done on submaximal loading parameters and postactivation potentiation improvements. Mitchell and Sale (2011) employed a five repetition maximal squat effort before a jump test to assess possible postactivation potentiation benefits. The results showed a positive postactivation potentiation effect on peak twitch torque and vertical jump height after the five repetition squat effort in comparison to the control group.

Statement of the Problem

Even though there was a considerable amount of research on postactivation potentiation, there was a lack of extremely heavy load training prior to an explosive test. The highest percentage training load was 130% of peak power output in a study by Sotiropoulos et al. (2013). However, most of the other research used 90% of the participant's one repetition maximal effort or less (Chiu et al, 2003; Lim & Kong, 2013; Mitchell & Sale, 2011; Smith et al., 2014). In theory, using a very heavy relative load may help recruit a larger amount of motor units (Chiu et al, 2003). The safest way to use heavy loading prior to an explosive test was to prescribe the rack squat. A rack squat involves the athlete using a super maximal load (150% of squat max) in a very small range of motion. The athlete lifts the bar from the rack, which was set for the athlete to begin in the quarter squat position. Even if the athlete fails on the repetition, the weight can be safely lower back down to the rack. The rack will serve as its own spotter, which makes it a very safe movement for athletes. Since most of the research uses loading parameters of less than 90%, there was a need for research on heavy loading parameters over 100% of the participant's one repetition maximal effort since it may cause a greater PAP effect.

Purpose of the Study

The purpose of the study was to determine whether a submaximal loading protocol or a super maximal loading protocol was the most effective postactivation potentiation method for improving a vertical jump test, a standard measure of anaerobic power. A secondary purpose was to collect and analyze muscle EMG activity during using EMG both loading protocols.

Hypothesis

The increased percentage of loading may allow the participant to recruit a higher number of motor units during the postactivation potentiation exercise (Pearson & Hussain, 2014). Therefore, it was hypothesized that a heavy spinal load (150% of one repetition maximal effort) during the postactivation potentiation movement may produce a higher anaerobic power output result through vertical jump testing than utilizing a submaximal spinal loading protocol (30% of one repetition maximal effort). The submaximal spinal loading protocol may produce high peak amplitudes during the EMG readings due to the explosive nature of the movement.

Research Questions

1. Would the use of super maximal spinal loading via the rack squat elicit a larger increase in vertical jump performance in comparison to a submaximal load during a barbell jump squat?

2. Would the athlete's initial strength level have any indication on the effectiveness of using postactivation potentiation prior to a vertical jump test?

3. Would the rack squat produce higher amplitudes for the EMG recordings in the vastus lateralis, vastus medialis, biceps femoris, and rectus femoris than the recordings from the barbell jump squat?

Delimitations

D1: Only the Adams State University football and volleyball teams were used for this study. The researcher wanted to only use athletes from power sports during their off-season phase.

D2: The method that was used to measure the effect of postactivation potentiation was the vertical jump test. Even though there are other valid methods of testing the effectiveness of PAP, the vertical jump test and EMG readings were most applicable to athletes in power sports.

D3: The researcher only used one specific time frame for rest periods after the PAP intervention and before the vertical jump test. The rest periods were kept constant in order to specifically isolate the two interventions (jump squat and rack squat).

D4: Adams State University is located at 7,544 feet above sea level. There is very little PAP research at high elevations, so the potential effect was unknown.

D5: Only Division II athlete's from Adams State University participated in the study. Due to Adams State being the only university within a large radius, athletes from other institutions and divisions were not be asked to participate.

D6: Potential participants with any recent or current lower body injuries were disqualified from joining the study. If the participants underwent any lower body surgeries over the last twelve months, they were not allowed to participate.

Limitations

L1: The method of testing the estimated one repetition maximal effort back squat might be subjective based on each participant. In theory, each participant put their best effort towards the test, but there was not an accurate way to see if they went to their true maximal effort.

L2: The researcher did not control the participant's activities outside of the testing facility. For example, one of the participants may decide to get zero hours of sleep the night before the test, which may have an effect on their performance during the experiment. However, the researcher made sure to advise the participants to maintain a normal schedule and rest as much as possible to avoid this problem.

L3: Since Adams State University is a Division II university, there were not any participants from the other NCAA divisions.

L4: Due to the timing of the study, only off-season athletes were used for the study. Football and volleyball players were the two groups used for the study based on the timing of their off-season training.

L5: Maximal Voluntary Contractions (MVC's) were not recorded for the participants since the main variable of interest for this study was the vertical jump. The EMG data was only used as secondary information.

Assumptions

The researcher assumed that the heavy spinal loading intervention would elicit a more advantageous postactivation potentiation effect compared to the submaximal spinal loading protocol. The greater effect would be caused by the larger number of motor units recruited and the high level of neural stimulation of the movement. As a result, the participants would have a better vertical jump performance after the heavy spinal loading intervention in comparison to the submaximal spinal loading protocol. Additionally, it was assumed that the EMG readings during the rack squat would produce higher amplitudes. It was assumed that the participants put forth their best effort during all aspects of the testing protocol. Also, it was assumed that the methods of PAP (rack squat and jump squat) and the performance test (vertical jump) were appropriate movements to generate a positive effect.

Definition of Terms

Active rest: light exercise such as jogging or walking during the rest periods between exercise bouts.

Anaerobic exercise: short term explosive activity or exercise such as weight lifting or sprinting.

Biceps femoris: muscle on the posterior side of the hamstring. Knee flexion is the main joint action of the biceps femoris.

Concentric contraction: the shortening of a muscle while creating force.

Contractile activity: a stimulus causing activity in the muscle.

Countermovement jump: a jumping movement starting with a slight squat and arm swing to maximize the height of the jump.

Cross-bridge or cross-bridge attachment: the head of a myosin molecule that stems from a myosin filament in the muscle attaches to the active binding site of the actin filament.

Drop jump: a plyometric movement where the athlete drops off of a box in a controlled manner. Once the athlete reaches the ground, they immediately rebound and jump as high as possible.

Eccentric contraction: the elongation of a contracting muscle due to an opposing force.

Electromyography, Surface (SEMG or EMG): a noninvasive procedure that records the summation of muscle electrical activity. Electrodes are placed on the surface of the skin in specific locations depending on the muscles used.

Force plate or platform: an instrument used to measure and record the ground reaction forces of a specific activity.

Gluteus Maximus: the largest of the three gluteal muscles located on the buttocks of the human body.

Heavy spinal loading: an exercise that loads the athlete with a very heavy perceived weight based on their strength and body weight. The loading percentage might be over 100% of the athlete's one repetition maximal effort.

Isometric contraction: a contraction where the joint angle and muscle length do not change.

Jump squat: performed with a slight knee bend (usually less than a 90 degree knee angle) and an explosive jumping movement. Very similar to a regular squat, and will be performed with a barbell. The athlete initiates the movement with a countermovement down to a 90 knee angle. Then, the athlete explodes upwards as high as possible and leaves the ground.

Knee or leg extension: seated exercise where the athlete starts with a 90 degree knee joint angle. Then, the athlete will extend their knees until their legs are completely straight.

Maximal voluntary contraction: the maximum force a participant can produce through an isometric exercise.

Motor unit: a specific motor neuron and the muscle fibers innervated by its axon.

Muscle biopsy: a procedure when a piece of muscle is removed and examined for specific properties.

Muscle twitch: a local and involuntary muscle contraction.

Neural stimulation: the activation of a motor nerve through an external source.

Phosphorylation: the addition of a phosphate group to a protein. This process can turn enzymes on and off which will alter their activity.

Plyometrics: jumping movements involved with exerting maximal force in a very short period of time. Often used as a benchmark for power output.

Postactivation potentiation: increased muscular performance as a result of a previous muscle contraction.

Power output: the force produced by a specific activity (power= force X velocity)

Rack squat: a partial range of motion squat. The bar is set on the pins so the athlete is able to set up directly underneath the bar. The pins can be set up at any height depending on the desired range of motion. The bar will be set so the athlete starts the movement with a 120 degree knee angle.

Rate of force development: a measurement in Newtons per second of the rate at which a force is developed.

Rectus femoris: one of the major quadriceps muscles located in the middle of the front of the thigh.

Repetitions (Reps): the number of times a specific exercise is performed.

Resistance training: any form of training that involves the body resisting weight and producing force.

Romanian Deadlift (RDL): the athlete starts the movement with a barbell or pair of dumbbells in their hands. The movement is initiated by pushing the hips back while keeping the shoulders pulled back and eyes towards the horizon, which will create a "flat back" for the athlete. The weight will be kept close to the shins on the way down until a stretch in the hamstrings is achieved.

Sets: the amount of cycles of repetitions that are completed. For example, three sets of five repetitions would consist of performing the movement five times in sequence before resting. This would be repeated three times.

Squat: supporting a barbell on the shoulders and performing a movement similar to sitting in a chair. The athlete will push their hips back and descend their body downwards while keeping their knees behind their toes. The athlete will achieve a 90 degree knee angle before drive upwards to the standing position.

Submaximal load: a loading protocol that uses resistance less than what the athlete is capable of performing, typically less than 80% of the athlete's one repetition maximal effort.

Super maximal loading: a loading protocol using a weight or resistance that is much heavier than their maximal effort, typically between 98-200% of the athletes one repetition maximal effort.

Training Percentage: the specific percentage of a one repetition maximal effort used to calculate a workload for an exercise.

Vastus lateralis: the largest part of the quadriceps femoris, located on the lateral portion of the thigh.

Vastus medialis: part of the quadriceps femoris muscle, located on the medial part of the thigh.

Vertical jump test: a common test for power output with athletes. The athlete begins the test with a slight eccentric movement to put the body in a powerful position. Then, the athlete will explode into the air using their lower body in addition to a powerful arm drive. The vertical jump test measures the vertical displacement of an athlete, which can be tied into overall lower body power production.

Chapter 2: Review of Literature

Postactivation potentiation refers to the intensified neuromuscular condition seen after a session of heavy or explosive resistance training (Lim & Kong, 2013). Postactivation potentiation (PAP) presents the unique opportunity to athletes for potential acute performance enhancement (Lim & Kong, 2013). Previous research indicates a possible increase in rate of force development during explosive movements after a postactivation potentiation intervention (Chiu et al., 2003). There are many different methods currently used in research to produce the advantageous effects of PAP. Isometric contractions of varying durations, heavy squats, and squat jumps are some of the most common methods for eliciting postactivation potentiation in athletes (Lim & Kong, 2013; Mitchell & Sale, 2011). Additionally, the training status of the participants may have a large effect on the timing of the enhanced performance prior to the postactivation potentiation interventions (Mola, Bruce-Low & Burnet, 2014). A comprehensive literature review was needed in order to determine the effects of different postactivation potentiation interventions, and the rest periods associated with the different training statuses of the participants.

Isometric Contractions for Postactivation Potentiation Effect

Some of the postactivation potentiation research is conducted with the use of isometric contractions. A maximal voluntary contraction (MVC) is used to elicit the postactivation potentiation effect prior to an explosive athletic movement. Based on the current research, there are many different ways to use maximal voluntary isometric contractions in hopes of achieving postactivation potentiation. A study by Pearson and Hussian (2014) employed three different durations of isometric exercise. They recruited eight males in their early 20's and participants were evaluated based on evoked twitch contractions and vertical jump performance. The twitch contractions of the quadriceps femoris was measured using an isokinetic dynamometer. The knee angle was set to 120-130 degree in order to mimic the jumping test performed later on during the experiment. The evoked twitch contractions were used as another method of testing for the postactivation potentiation effects in addition to the vertical jump test.

First, the participants finished three countermovement jumps (CMJs) and evoked twitch contractions prior to a ten-minute rest between trials. Each participant performed three trials with a three-second, five-second, or seven-second isometric contraction prior to the vertical jump test. To avoid any testing errors, the participants completed a trial using all three lengths of isometric contractions on separate days with at least 72 hours in between trials. The study was performed using a randomized test-retest design to maintain consistent and reliable measurements. Peak jump height was significantly decreased after the five and seven second isometric contraction trials by roughly six percent in comparison to the baseline numbers for the participants. The peak jump height after the three-second isometric contraction was also decreased, but only by 0.3%. Overall, there were no increases in jump height, rate of force development, or jump power following any of the isometric contractions. The results also indicate that the duration of contractions might not have any effect on postactivation potentiation (Pearson & Hussain, 2014).

Another loading method of maximal isometric contractions involves multiple repetitions per set prior to an explosive movement. The study by Pearson and Hussian (2014) used one set of three, five, or seven seconds, which is a fairly low amount of total time under tension. However, a study by French et al. (2003) used multiple repetitions of timed isometric contractions before testing. French et al. used fourteen adult track and field athletes and evaluated them through a variety of tests. Before any testing, the participants were evaluated using five-second sprint cycling, knee extension, and countermovement and drop jumps. Each participant underwent three repetitions of three seconds or three repetitions of five seconds for the preconditioning contraction. The total amount of time under tension for the participant's preconditioning contraction was between nine and fifteen seconds depending on their random group placement. A group of participants also performed no preconditioning contraction in order to act as the control group for the experiment. The participants then completed a drop jump, countermovement jump, five-second cycle sprint, or knee extension.

The participants in the study by French et al. (2003) observed a significant increase in maximal force, acceleration impulse, and jump height for the drop jump after three repetitions of three second maximal isometric contractions. Additionally, knee extension maximal torque was increased following the same maximal isometric protocol. There were no significant increases for the participants in the group using three repetitions for five seconds for the preconditioning contraction. Therefore, the study by French et al. (2003) shows that a shorter time frame for maximal isometric contractions (3 repetitions of 3 seconds) may cause favorable effects on performance.

In contrast with shorter length isometric contractions, a longer maximal contraction may be used in hope of eliciting increased performance. A study by Smith and Fry (2007) used a ten second maximal isometric contraction to observe the changes in regulatory myosin light chain phosphorylation and performance. Eleven recreationally active males underwent a one repetition maximum test in the single leg knee extension during the orientation session. Obtaining each participant's one repetition maximum data was very important since the testing was based off 70% of their maximal single leg knee extension effort. The participants underwent a muscle biopsy of the vastus lateralis upon arrival to the testing facility in order to record baseline data of their muscle fibers. The baseline data from the pre-test muscle biopsy was used to compare against the results from the experimental muscle biopsy samples. Then, the participants performed one repetition of knee extension at the previously determined intensity followed by a ten second maximal isometric contraction. The second muscle biopsy was performed five minutes after the ten-second maximal isometric contraction. Two minutes after the second muscle biopsy, the participant performed a second trial of the single leg knee extension. A total of seven minutes elapsed from the ten-second maximal isometric contraction to the second trial of the single leg knee extension. Seven of the participants had raised regulatory myosin light chain phosphorylation and the other four participants had lowered regulatory myosin light chain phosphorylation.

However, the results showed that the effects of the isometric contraction had no benefits for increased performance. The performance was measured through peak power, force, and velocity in addition to mean power, force, and velocity during the leg extension test. The lack of increased performance may be attributed to a few different factors. All of the participants were recreationally trained with at least one year of resistance training experience. Smith and Fry (2007) did not specify the type or intensity of resistance training experience of the participants, so it's difficult to determine the specific intensity they used during exercise. The participants' prior exercise intensity history may have a large impact on the effect, or lack of an effect, after a postactivation potentiation intervention. The term recreationally trained leads one to believe that the participants were inexperienced with the use of heavy resistance training at the time of the experiment. The training status of the participants in conjunction with rest periods after the postactivation potentiation intervention in the study by Smith and Fry (2007) may have caused the lack of performance increase. The participants had a total of seven minutes of rest after the ten-second maximal isometric contraction. As stated earlier, trained athletes may require a shorter recovery period before yielding the potential benefits of postactivation potentiation in comparison to recreationally trained individuals (Seitz et al., 2014). The lack of positive results from the study may indicate a longer recovery or rest period for recreationally trained individuals. Additionally, the use of long duration postactivation potentiation appears to not improve subsequent dynamic performance. The study by Pearson and Hussain (2014) showed a lack of correlation between long duration contractions and increased performance in vertical jump height. The time frame for a vertical jump or dynamic leg extension test is much shorter in studies by Seitz et al. (2014) and Mitchell and Sale (2011) than the ten or seven second isometric contractions in Pearson and Hussain (2014), and Smith and Fry's (2007) experiments. Therefore, one may hypothesize the potential positive effects of a short term and more explosive postactivation potentiation intervention.

Heavy Resisted Squats and Resisted Vertical Jump Efforts for Postactivation Potentiation Effects

In contrast with utilizing isometric contractions for postactivation potentiation, some researchers opt for a heavy resisted squat protocol. A study by Chiu et al. (2003) compared the use of different percentage load jump squats (30, 50, and 70% of one repetition maximal effort) for performance on trained and untrained participants following a squat effort of 90% of their one repetition maximal effort. The group of trained participants were involved in a sport that requires explosive strength, while the untrained group only participated in recreational activities. In an attempt to isolate specific loading percentages, the participants used 30%, 50%, and 70% of their one repetition maximal back squat. More importantly, Chiu et al. (2003) compared the differences between using heavy squats for postactivation potentiation and the use of unloaded or body weight squats.

First, the experimental and control group performed heavy resistance back squat warm-up sets. The experimental group's warm-up protocol included five sets of one repetition at the participant's 90% one repetition maximal effort in the back squat. The sets of heavy resistance back squats were performed right after two sets of five repetitions of unloaded parallel back squat and two sets of three repetitions of vertical jumps. The control group only performed the sets of unloaded parallel back squats and vertical jumps. Two series of jump squats were completed with 30%, 50%, or 70% one repetition maximum based on random placement. The first set was initiated five minutes after the warm-up session, and the second set was completed ten minutes following the first set. Therefore, the participants were performing their jump squats at five minutes and fifteen minutes postactivation. The measurements for the jump squats were analyzed with a force plate and position transducer. The force plate was used to determine the peak power, average power, and average force of each jump squat trial. The position transducer was utilized to track the displacement of the participants during the trials. Additionally, the percent potentiation was analyzed by taking the potentiated variable and dividing it by the unpotentiated variable multiplied by 100.

Based on the results collected by Chiu et al. (2003) the heavy loaded warm-up back squats did not have any significant increase peak or average power and average force during the jump squat trials for the experimental group. The percent potentiation was compared and revealed a much higher outcome for the explosive strength group. Overall, they showed a much higher power and force output than the recreationally trained group. Therefore, postactivation potentiation appears to potentially increasing explosive power performance in trained athletes.

But, the results do not show much benefit for the untrained individual. Athletes training with a focus on strength and power will develop fatigue resistance to high load and high intensity training. Recreationally trained individuals typically are not accustomed to repeated heavy resistance training, and they might experience more local fatigue following heavy training. The prior experience that the strength athletes possess will more than likely allow them to observe more advantageous effects from postactivation potentiation. The results from Chiu et al. (2003) indicate that it would be more beneficial to use a group of trained explosive strength athletes for postactivation potentiation research. Using untrained or recreationally trained participants appears to be less beneficial due to their inexperience.

A study by Seitz et al. (2014) also used two groups of athletes with varying strength levels. Instead of using trained explosive athletes and recreational trained athletes, Seitz et al. used a group of eighteen junior elite ruby players. The group of participants was divided into two separate groups, strong and weak based on their one repetition maximal squat effort. The strong group performed a squat greater than or equal to two times their body mass, whereas the weak group performed a squat that was less than two times their total body mass.

Every participant underwent a familiarization session followed by one week of time away from the testing facility. The experimental session warm-up included five minutes of submaximal cycling and six submaximal squat jumps. The squat jumps occurred every thirty seconds and required the participants to increase their overall effort on each subsequent jump. Following the warm-up jump squats, the participants observed a two-minute rest period. Next, the baseline assessment for each participant was recorded using a standard force plate for power output readings. The participants performed three sets of one unloaded squat jumps with one minute of resting in between each set. After the baseline assessments, the participants then rested for ten minutes in order to fully recover from the previous interventions. Prior to the ten-minute rest period, the participants performed three repetitions at 90% of their respective one repetition maximal squat effort in an attempt to achieve a postactivation potentiation effect. The participants then performed single repetitions of unloaded squat jumps fifteen seconds, three, six, nine, and twelve minutes after the conditioning activity. The power output from the five squat jump trials was recorded using a standard force plate.

The two groups of athletes showed very different results in their squat jump efforts following the conditioning activity. The stronger group showed a greater postactivation potentiation effect than the weaker group in the squat jump trials after the 90% squat intervention. They exhibited a larger increase in absolute and relative peak power output and jump height during the squat jumps. Both groups had a decrease in all of the measurements during the first measurement at the fifteen-second mark after the squat intervention. The decrease in the first round of measurements might have been attributed to local muscle fatigue from the squat session. The stronger group also exhibited a higher PAP response on all squat jump tests in comparison to the weaker group. Additionally, the stronger group showed postactivation potentiation effects from three to twelve minutes with the six-minute measurements showing the largest effect. The weaker group only showed postactivation potentiation effects from six to twelve minutes following the conditioning activity with the largest effect occurring during the nine-minute reading. The weaker group might have experienced fatigue after the postactivation potentiation intervention, which may explain their increased performance occurring later than the stronger group after they had a suitable amount of recovery time. Based on the results from the study, it appears that the stronger participants are able to recover at a quicker rate after experiencing a postactivation potentiation intervention. Therefore, they may see an increase performance sooner than the weaker group. The overall strength and training status of the participants needs to be taken into consideration when planning the recovery period in a practical setting.

In contrast with the study by Chiu et al. (2003), Mitchell and Sale (2011) used different loading parameters for a postactivation potentiation effect. Eleven male collegiate athletes were selected for the study. The participants underwent four separate testing days to collect data based on vertical jump performance and knee extensor twitch. The first protocol (Twitch A) involved an evoked baseline knee extensor twitch immediately before five vertical jumps. After the five vertical jumps, the participant endured an eight-minute rest before the second twitch was recorded. The second protocol (Twitch B) utilized the same first two steps as Twitch A, but the participant rested for four minutes and performed five repetitions at the predetermined five repetition maximal percentage. The five-repetition percentage is equal to roughly 87% of the participant's estimated one repetition maximal effort (Baechle & Earle, 2008). The participant follows the squat effort with four more minutes of rest and a second knee extensor twitch.

The third protocol did not utilize any knee extensor twitches, instead focusing on the vertical jump. The first jump protocol (Jump A) had the participants perform five vertical jumps, followed by an eight-minute rest. After the eight-minute rest, the participants then performed the second set of five vertical jumps. The second jump protocol (Jump B) started with five vertical jumps, followed by four minutes of rest. The four minutes of rest was immediately followed by a five repetition maximum squat effort, then four more minutes of rest. Finally, the participants performed five more vertical jumps after the rest period. The final two protocol's main purpose was to determine if the five repetition squat effort caused an increased height of the second set of vertical jumps through postactivation potentiation.

The twitch torque was significantly higher in the Twitch B protocol four minutes after the five repetition maximal squat effort. However, there was not a significant difference in twitch torque for the Twitch A protocol, which only involved a vertical jump and not five repetition maximal squat effort. The Jump B protocol observed a fairly significant increase in jump height during the second jump trial. The Jump A protocol showed a slight decrease in jump height for the second jump trial. Based on the results from the four groups, the five-repetition maximal squat effort increased peak twitch torque and vertical jump height. One may extrapolate from the data that a heavy spinal loading effort appears to be a beneficial postactivation potentiation method.

The use of varying squat jump intensities has also been used in an attempt to elicit a postactivation potentiation effect. A study by Sotiropoulos et al. utilized two different loading parameters of the squat jump, submaximal and super maximal. The submaximal load was 70% of the maximal mechanical power output, and the super maximal load was 130% of the maximal mechanical power output (Sotiropoulos, Smilios, Douda, Christou & Tokmakidis, 2013). Maximal mechanical power output was measured using an analog to digital converter connected to a computer. The converter calculated the average force, velocity, and power during the concentric portion of the movement. The higher loading parameters (130%) yielded a higher power output and more active EMG readings in the vastus lateralis, vastus medialis, rectus femoris, and biceps femoris to the control group. Additionally, the lower loading parameters (70%) showed a higher power output and more active EMG readings than the control group. Even though both interventions showed advantageous results with power output and EMG activity, neither loading protocol showed an increase of jump height at any point during the testing.

Resisted Sled Sprints for Postactivation Potentiation Effects

In contrast with the more standard exercises for postactivation potentiation (squats, jump squats), Smith et al. (2014) used resisted sled sprints in an attempt to cause the same effects. Since the study was measuring sprint performance, the use of resisted sled sprints was more specific than using jump squats or isometric contractions. First, the participants performed a forty-yard sprint directly after the standard bicycle warm-up. Four minutes of active rest followed the initial forty-yard sprint. After the four minutes of active rest was completed, the participants performed a twenty-yard sprint with no resistance. The twenty-yard sprint with no resistance served as the control trial for the experiment. The un-resisted twenty-yard sprint was followed by four minutes of active rest before the posttest 40-yard sprint trial. The participants performed twenty-yard sled resisted sprints at 10%, 20%, and 30% of their body weight with the same testing protocol as the control trial. The results showed that the sprint performance was improved by 2.14 %, 1.21%, 2.11%, 2.24% after the 0%, 10%, 20%, 30% resisted sprint load, respectively. The improved performances after the four different interventions only differed by one percent at most, which indicates an extremely small difference between the loading parameters. The different loading percentages were very gradual and the lack of variation may have resulted in the almost identical results. Although a 1-2% increase in short sprint performance may not be statistically significant in a controlled laboratory setting, it may still be related to increasing the overall performance of the athlete in their sport. Even a small increase of 1-2% is significant in terms of effectiveness of the intervention of the researchers during the study, and could result in practical meaningfulness in the athlete's performance.

EMG Analysis Using Different Muscle Groups

The use of electromyography (EMG) appears to be a very beneficial method to assess relative muscle action during athletic movements (Ball & Scurr, 2011). Additionally, electromyography measures voluntary activation of the muscle. If a coach or researcher is able to determine the most important muscle groups for a specific athletic test, then they will be able to select a postactivation potentiation intervention involving the same muscle groups. Selecting the proper intervention will increase the chances of the movement enhancing performance of the athlete.

The two main variables of EMG use are intrinsic and extrinsic factors that may determine the quality of the results (Ball & Scurr, 2011; Balshaw & Hunter, 2012). Intrinsic factors include the muscle fiber type, diameter, and depth, whereas the extrinsic factors include the orientation and location of the EMG electrodes (Ball & Scurr, 2011). The researcher may control both of the aforementioned factors in order to obtain the most accurate and applicable results for their experiment. For example, the researcher will choose muscles in the human body that pertain to the specific movements used in their study. If the study involves the participants performing a squat, then placing the electrodes on the rectus femoris would be a logical choice (Luera, Stock & Chappell, 2014). The extrinsic factors are more closely related to human error while setting up the EMG equipment. The researcher needs to be extremely precise and careful when placing the electrodes for surface electromyography in order to avoid obtaining misleading results (Ball & Scurr, 2011). Placing the electrodes in proper locations will also help limit the amount of crosstalk from adjacent muscles (De Luca, 1997). Signals originating from different muscles will contain less energy than the local signals due to the longer distance travelled (De Luca, 1997). The EMG signal will not necessarily reflect the total force generated by a muscle due to the disorderly force production of the muscle (De Luca, 1997). The total number of motor units identified by the electrodes will be less than the total number firing in the specific movement (De Luca, 1997). This may be caused by user error while placing the electrodes, among other possibilities (De Luca, 1997). If a motor unit is too far from the electrode, the force will increase but the EMG amplitude measurement will not change (De Luca, 1997).

Two of the main postactivation potentiation research studies using EMG activity data include measurements from the vastus medialis (French et al., 2003; Sotiropoulos et al., 2013). In addition to measuring the EMG activity in the vastus medialis, the study by Sotiropoulos et al. (2013) also recorded activity in the vastus lateralis, and biceps femoris. When dissecting the procedures from EMG studies involving squat patterns, wider ranges of muscles are used for measurement. Studies by Caterisano et al. (2002) and Isear, Erickson and Worrell (1997) include EMG activity measurements from the gluteus maximus and biceps femoris in conjunction with the three quadriceps muscles previously mentioned. The muscle activity of the gluteus maximus is largely neglected in most research involving the EMG measurements of the squat movement (Isear et al., 1997). The results from Isear et al. (1997) indicated a low level of gluteus maximus and biceps femoris activity when compared to the vastus medialis and lateralis during an unloaded squat above 90 degree of knee flexion. However, the importance of the gluteus maximus in the squat or a jump squat hinges on the range of motion and loading percentage of the movement (Caterisano et al., 2002; Isear et al., 1997). Even though the gluteus maximus is more involved with a deeper squat movement, it's still an important mover for any range of motion jumping action.

Caterisano et al. (2002) measured muscle activity in the vastus medialis, vastus lateralis, biceps femoris, and gluteus maximus during various depths during the squat movement. By comparing the partial, parallel, and full squat, the researchers were able to isolate specific percentage contributions from each muscle group while using ten experienced weight lifters as participants. When analyzing the mean data from the concentric portion of the partial squat, the vastus lateralis and medialis are the primary contributors to the movement. The gluteus maximus is much less involved during the concentric phase of the partial squat. However, as the squat depth increases to parallel and full, the gluteus maximus becomes very heavily involved. The eccentric phase of the partial squat shows similar results to the concentric phase. But, the gluteus maximus remains more consistent in terms of involvement through the different depths in the eccentric phase.

Conclusions of the Literature Review

Overall, the current research indicates a few very specific trends for effective postactivation potentiation. First, the use of heavy spinal loading appears to elicit more advantageous postactivation potentiation effects (Chiu et al., 2003; Mitchell & Sale, 2011; Seitz et al., 2014; Sotiropoulos et al., 2013). Based on the research mentioned in the literature review, the use of long duration isometrics for postactivation potentiation appears to not elicit advantageous effects. Even though there are different percentage loads used for heavy spinal loading, most of the methods produce similar results. However, most of the research uses 90% of the participant's one repetition maximal squat effort or slightly less (Chiu et al., 2003; Mitchell & Sale, 2011; Seitz et al., 2014). Since most of the research uses regular squat technique, there is a lack of information about training loads over 90% of the participants' maximum effort squat. The results from the studies involving training loads over 90% showed positive results following the postactivation potentiation intervention on trained athletes during the testing protocols (Chiu et al., 2003; Sotiropoulos et al., 2013) Therefore, using spinal loading of 150% of the participants' one repetition maximal effort squat may add considerable depth to the research area. The use of 150% of the participants' maximal effort will allow the experiment to separate itself from the majority of the research using less than 90% of the participants' one repetition maximal effort for a postactivation potentiation effect. Overall, the higher percentage load will allow the experiment to uncover new data about heavy spinal loading and its effects on postactivation potentiation.

Second, the use of heavy spinal loading to produce a greater postactivation potentiation effect has been shown to be more effective for trained strength or explosive athletes (Chiu et al., 2003; Seitz et al., 2014). Additionally, an athlete with a higher strength level may experience better results than an athlete with lower strength levels (Seitz et al., 2014) Participants that are unaccustomed to heavy or explosive training may take longer to recover after performing an activity designed to produce a postactivation potentiation effect (Chiu et al., 2003; Seitz et al., 2014). Based on the findings in the research using trained and untrained athletes, it would be more worthwhile to use trained explosive athletes for postactivation potentiation research. Athletes experienced with very heavy spinal loaded exercises may provide the best participants due to the smaller learning curve for the activity (Chiu et al., 2003; Seitz et al., 2014). Due to the time of the year for the data collection period, using off-season collegiate athletes from the fall season seemed to be the smartest choice. The two fall sports at Adams State University with the most experience utilizing heavy spinal loading techniques are the football and volleyball teams.

Once the post activation potentiation intervention and population is selected, the next step is to determine the highest quality way to measure the effects. After synthesizing the research on postactivation potentiation, the most common method is vertical jump measurement (Chiu et al., 2003; Lim & Kong, 2013; Mitchell & Sale, 2011; Mola et al., 2014; Pearson & Hussain, 2014;

Seitz et al., 2014; Smith et al., 2014; Sotiropoulos et al., 2013). The measurement of the vertical jump gives the researchers a tangible number from a valid test in order to track changes. Additionally, electromyography (EMG) appears to be a useful tool to identify the variations in amplitudes during the different postactivation potentiation interventions (Ball & Scurr, 2011; Balshaw & Hunter, 2012; Isear et al., 1997; Luera at al., 2014; Sotiropoulos et al., 2013). The primary muscles in the human body that are tracked during postactivation potentiation and squat studies are the vastus lateralis, vastus medialis, rectus femoris, gluteus maximus and biceps femoris (Balshaw & Hunter, 2012; Caterisano et al., 2002; Isear et al., 1997; Luera et al., 2014; Sotiropoulos et al., 2013). There are many other muscles used during the squat and jumping movements, but the aforementioned five were hypothesized to give the best results for tracking the differences between interventions.

One of the final primary details of the testing procedures is the amount of rest used to cause a postactivation potentiation effect. Selecting the correct rest periods during testing is extremely crucial in order to obtain the proper results (Mola et al., 2014). The majority of the research uses rest periods anywhere from three to twelve minutes (Chiu et al., 2003; Lim & Kong, 2013; Mitchell & Sale, 2011; Mola et al., 2014; Seitz et al., 2014; Sotiropoulos et al., 2013), The training level of the participants typically indicates the most effective rest periods for maximal postactivation potentiation effects (Seitz et al., 2014). The shorter rest periods (three to five minutes) appear to be more advantageous for trained athletes since they are able to recover from the explosive activity much faster than untrained individuals (Seitz et al., 2014).

Chapter 3: Procedures

Setting

All testing and measurements were completed in the Adams State University weight room in Plachy Hall. Adams State University is a small, rural Division II University located in southern Colorado in the town of Alamosa. Alamosa is located in the San Luis Valley and has an elevation of 7,544 feet above sea level.

Population

Eleven female collegiate volleyball players and eight male collegiate football players participated in the study. Due to the high number of football players on the team, the first eight to volunteer were selected for the study. All eleven members of the volleyball team agreed to participate. An equal number of male and female participants was not as important as the total number of participants. Participants were required to provide written consent (Appendix A), which was approved through the ASU Institutional Review Board. All of the participants were in the off-season of their respective sports, and used similar training methods. The weight training programs were designed by the head strength and conditioning coach at Adams State University. The similar training methods included comparable exercises (squat, bench, deadlift) and almost identical training percentages (Appendix B). The workouts were focused on the athletes gaining strength during their off-season phase. Additionally, the participants had at least one year of heavy weight lifting experience. Due to the advanced nature of the heavy spinal loading lifting techniques, the participants were adequately prepared to safely perform the exercises.

Instrumentation

The vertical jump measurements were taken using the "Just Jump!" mat. The "Just Jump!" mat is manufactured by Probiotics INC, which is located in Hunstville, Alabama. The barbells used for the jump squats and the rack squats were standard weight room equipment from Samson Equipment, INC located in Las Cruces, New Mexico.

The electromyography of the muscle activity during the postactivation potentiation interventions was recorded using the BTS FREEEMG 100 RT system from the BTS Bioengineering Corporation. The disposable electrodes used were from the BTS FREEMG 100 RT system. The BTS FREEEMG 100 RT system was connected to a PC computer for data collection and analysis.

Research Design

The participants participated in a four-week protocol described below. The first week involved measurements of basic subject characteristics, explanation of the study, completion of a short participant questionnaire about prior weight training experience, and the informed consent document. The short participant questionnaire (Appendix C) helped the researcher determine if the potential participants were physically ready to undergo the study. Any current or recent lower body injuries or surgeries disqualified the individuals from participation. If the participants underwent any lower body surgery over the last twelve months, then they were not allowed to participate in the study.

Then, the participants performed a one repetition maximal squat effort test. The participants performed four warm-up sets at certain training percentages to prepare their body for the test. The warm-up and experimental sets were formatted from the testing protocol featured by Baechle & Earle (2008):

- Warm-up with a light resistance that allowed for five to ten repetitions
- Rested for one minute
- Add thirty to forty pounds to the initial warm-up set and complete three to five repetitions for the male participants. The female participants added twenty to thirty pounds and followed the same protocol.
- Rested for two minutes
- Next, the athlete added thirty to forty pounds to the last attempted weight and completed two to three repetitions for the male participants. The female participants added twenty to thirty pounds and followed the same protocol
- Rested for three minutes
- Increased the load by thirty to forty pounds and the athlete started their first attempt at their one repetition maximal effort for the male participants. The female participants added twenty to thirty pounds and followed the same protocol.
- After each attempt, the athlete rested for three minutes before completing their next attempt
- If the athlete failed their attempt, then fifteen to twenty pounds were subtracted for the next attempt. The athlete had three opportunities to achieve a successful attempt at their one repetition maximal effort squat.

One week after the first session, the participants returned to the weight room for vertical jump testing. All of the testing occured on the *Just Jump!* Mat from Probiotics INC (Huntsville, AL). The participants performed a warm-up protocol with three repetitions of squats at 30%, 40%, and 50% of their one repetition maximum squat effort from the previous week's one repetition maximal effort test. After the warm-up, each participant had three attempts to achieve their maximal vertical jump height. Between each attempt, the participants rested for three minutes. The participants used a countermovement and descended to a knee angle of roughly 120 degrees for the vertical jump test. The average vertical jump height for each participant was used as their baseline number.

For the third week of testing, the participants were randomly split up into Group A and Group B. Group A consisted of six volleyball players and four football players. They underwent the submaximal loading intervention during week three. The submaximal loading intervention was barbell squat jumps with 30% of the participant's one repetition maximum effort squat. The barbell jumps were performed with a knee angle of 120 degrees. The 120 degree knee angle was determined by the use of a goniometer before the participant performs any of the barbell jumps. Once the participant understood the proper knee angle, then the jumps were performed. Group B underwent the maximal spinal loading intervention. The maximal spinal loading intervention involved the participants using 150% of the one repetition maximum effort squat during rack squats. The safety pins were set based on the participants' height so they started with a 120 degree knee angle using the goniometer for accurate measurements. The 120 degree knee angle was selected to stay consistent with the range of motion used during the barbell jump squats (Pearson & Hussian, 2014). The rack squat was performed by setting the body under the bar in a squat position, and lifting the bar as quickly as possible to the standing position.

Prior to the postactivation potentiation interventions, bipolar electrodes were placed on the participants to measure muscular activity. The electrodes were placed on the vastus lateralis, vastus medialis, biceps femoris, gluteus maximus, and rectus femoris of each participant during the rack squat and jump squat trials. All of the electrode placements were completed by the main researcher in order to maintain consistent measurements. Before the electrodes were placed on the proper sites, the participants went through a preparation process. The selected areas underwent a skin abrasion process with emery paper in addition to wiping the area with an alcohol pad. If needed, the participant was instructed to shave the areas if their body hair was likely to cause interference with the signal. The electrode was placed on the muscle belly of the quadriceps on the lateral side for the vastus lateralis. The electrode was placed on the muscle belly of the quadriceps on the medial side for the vastus medialis. The placement for the rectus femoris was in the center of the quadriceps on the muscle belly. The electrode was placed on the muscle belly of the hamstring and slightly towards the lateral side for the biceps femoris. The placement for the gluteus maximus was in the center of the muscle belly. A diagram illustrating the proper electrode placements was placed in Appendix D.

Participants in both groups underwent the same active warm-up prior to starting the separate testing interventions. The active warm-up was performed as follows:

- High Knees (2x10 yards)
- Forward Skips with Arm Circles (2x10 yards)
- Reverse Lunge with Twist (2x10 yards)
- Single Leg Romanian Deadlift (RDL) (2x10 yards)

After the active warm-up was completed, the participants rested for three minutes before continuing the testing protocol to allow for a full recovery from the warm-up. Group A performed 3 repetitions of barbell jump squats at their predetermined intensity. Group B performed 3 repetitions of rack squats at 150% of their one repetition squat maximum effort. After the exercises were completed, the participants rested for three minutes. Three minutes was chosen for the rest period based on the training status of the participants. They were all trained explosive athletes; therefore they required a short recovery period for the desired postactivation potentiation effect (Seitz et al., 2014). After the three minutes of rest was completed, the participants completed three vertical jump tests. Each participant rested for one minute in between the three vertical jump tests. Therefore, they performed vertical jump tests at three, four, and five minutes following the PAP intervention. The average and peak vertical jump measurements for each participant were used for the data collection.

The fourth week of testing was exactly the same as week three, but the participant switched groups and performed the other postactivation potentiation intervention. The rest period protocol and the other aspects of the testing procedure mirrored the week three testing protocol. All of the aspects were kept the same in order to eliminate any errors during the testing protocol and improve reliability.

All of the testing sessions involved the assistance of two strength coaches in addition to the primary researcher. The two assistants were both in the Exercise Science graduate program at Adams State University and were currently employed as strength coaches in the athletic department. Both assistants had experience with exercise testing and the procedures used in the study.

Reliability

Based on the procedures for the experiment, there should have been a high level of reliability. Other researchers will be able to duplicate the study if they have the same models of the EMG equipment and the jump mat. Additionally, the use of comparable Division II athletes should yield similar results if the same testing protocols and equipment was used by other researchers. However, the most important aspect that needed to be kept consistent was the loading protocols for the jump squats and rack squats. The loading protocol of the two interventions needed to be kept the same in order to allow the data to be consistent.

Validity

The data collected from the experiment should have been valid, based on the type of participants and exercises that were selected. Utilizing postactivation potentiation techniques appeared to be applicable for power athletes such as football and volleyball players (Seitz et al., 2014). Including only trained athletes from power sports allowed the researcher to maintain consistent rest periods, which eliminated extraneous variables that may have influenced the outcome of the study. Additionally, the rack squat and jump squat were movements that the participants had prior experience with as Adams State University athletes. Heavy spinal loading via the rack squat and barbell jump squats are a valid measure of postactivation potentiation and power output for trained athletes (Chiu et al., 2003; Lim & Kong, 2013; Sotiropoulos et al., 2013). The participants' familiarity with the movements helped maintain consistency between the trials. There should have been a high level of validity for measuring anaerobic power output through vertical jump testing (French et al., 2003; Mitchell & Sale, 2011; Sotiropoulos et al., 2013). The EMG sites also should have shown a high level of validity based on their involvement with the squat and vertical jump movements (Caterisano at al., 2002; French et al., 2003; Luera et al., 2014).

EMG Signal Processing

Bipolar surface electrodes were used to detect the EMG signal during the four weeks of testing in this study. At the site of EMG placement, all subjects were wiped down with an alcohol prep pad and shaved if excess body hair was a concern to decrease impedance levels. Electrode placement was determined via the chart in Appendix D. Maximum voluntary contractions (MVC) were not performed as a part of this study, therefore the results are not reported as a percentage of the MVC, and the researcher will just speculate on the data to look for any apparent trends. EMG data were collected at a sampling rate of 1000 Hz using a differential amplifier with variable gain. The raw EMG signals were processed using the EMG analyzer software (BTS Bioengineering, Italy) via full wave rectification; then peak amplitude (μV) of each muscle was determined for both the rack squat and jump squat exercises.

Statistical Analysis

An Excel spreadsheet was used to record and compile all relevant data. The dependent variables for the study were the results from the vertical jump testing and the EMG activity measurements. The EMG measurements were from the vastus lateralis, vastus medialis, biceps femoris, rectus femoris, and gluteus maximus. All of the EMG signals were recorded in microvolts and the frequency was measured in Hertz (Hz) during the postactivation potentiation interventions of the rack squat and barbell jump squat with the EMG analysis software. The EMG peak amplitude of each site was used for data collection and comparison. The signal was bandpass between 20-150 Hz in order to filter the signal from outside interference (Ball & Scurr, 2011). The six dependent variables should be directly impacted by the intervention variables, which were the jump squat and rack squat interventions used to produce PAP. Each participant underwent both interventions in a randomized crossover design in order to determine any differences caused by the interventions to each to the EMG activity measurements and vertical jump test. To properly analyze the data, means and standard deviations for all variables were compared using a mixed ANOVA. The researcher used the 2SPSS Statistics Version 22 program from 2013 to compute all of the data generated from the specific variables during testing. Statistical significance was accepted at $p < .05$.

Chapter 4: Results

A total of 19 power athletes (N=8 male football players, N=11 female volleyball players) completed the four weeks of the study. One volleyball player quit the team after week one, so she did not complete the study. The drop out participant only completed the baseline back squat max testing session, so the data was not included in the study. A mixed ANOVA was run through SPSS (Version 22, 2013). A mixed ANOVA was chosen since the research included two independent variables, which were the sport played and the specific intervention. The independent variables included unrelated data as the participants were from two different sports. The independent variables also included related data as all of the participants completed both interventions. For all variables, the significance level was set at $p < 0.05$. If Mauchly's Test of Sphericity was not significant, then sphericity was assumed by the researcher. Individual subject data for the study can be found in Appendix E.

Descriptive Statistics

Due to the differences in anaerobic output between the male and female participants, based on male average vertical jump of 27.31 inches and female average vertical jump of 19.56 inches ($p < 0.05$), the two groups were separated for the analysis of descriptive statistics (Appendix F). The average age and standard deviation of the volleyball and football participants was 19.7 +/- 0.9 and 21.5 +/- 1.3 years. The average height of the volleyball and football participants was 67.45 +/- 4.93 and 72.50 +/- 3.02 inches, respectively. The average weight of the volleyball and football participants was 67.78 +/- 9.24 and 107.25 +/- 17.42 kg, respectively.

The average of the volleyball participants' vertical jump during the week two pretest was 19.56 inches with a standard deviation of 3.57 inches. During the vertical jump trials after the rack squat intervention, the average vertical jump decreased (non-significant, $p > 0.05$) to 18.38 inches with a standard deviation of 3.74. Similarly, the average vertical jump also insignificantly decreased in comparison to the pretest after the jump squat intervention ($p > 0.05$). The average vertical jump was 18.45 inches with a standard deviation of 4.02 inches after the jump squat intervention. Overall, the vertical jump measurements from the pretest were insignificantly higher than the measurements from after both the rack squat and jump squat interventions.

The average of the football participants' vertical jump during the week two pretest was 27.31 inches with a standard deviation of 4.46 inches. The average vertical jump insignificantly increased following the rack squat and jump squat interventions ($p > 0.05$). After the rack squat intervention, the average vertical jump was 27.62 inches with a standard deviation of 5.27 inches. Likewise, the average vertical jump was 27.71 inches with a standard deviation of 5.35 inches following the jump squat intervention. Overall, the vertical jump measurements from the pretest, post rack squat, and post squat jump were roughly the same and the data was insignificant ($p > 0.05$).

Mauchly's Test showed that the assumption of Sphericity was not violated, $p > 0.05$. These results show that there was a significant effect of the sport played in relation to the increase or decrease in vertical jump performance during the rack squat and jump squat interventions ($F(2, 3.348) = p < 0.05$). There was not a significant difference between the vertical jump heights after the rack squat and jump squat interventions in either group ($F(2, .991) = p > .05$).

EMG Data

Electromyography data is shown in Appendix G. All of the data shown is from participant 1, who was one of the football players. No statistical analysis was done on the EMG data since it was a secondary purpose to the effect of two different PAP interventions on vertical jump measurements. Also, no normalization was done to the data, therefore it would not make sense to compare them. Football and volleyball are abbreviated as FB and VB, respectively. Jump squat and rack squat are abbreviated as JS and RS, respectively. The peak amplitude of the gluteus maximus (VB RS=9, VB JS=7, FB RS=6, FB JS=6), vastus lateralis (VB RS=11, VB JS=7, FB RS=8, FB JS=8), vastus medialis (VB RS=11, VB JS=7, FB RS=7, FB JS=6), biceps femoris (VB RS=11, VB JS=6, FB RS=8, FB JS=8), and rectus femoris (VB RS=11, VB JS=6, FB RS=7, FB JS=8) were recorded during the rack squat and jump squat trials. Due to technical errors with the equipment, some of the muscles were not recorded for a few participants. All of the EMG data was collected and analyzed together to determine the outcome of the interventions.

The average peak amplitude for each muscle was higher during the jump squat in comparison to the rack squat (Appendix G).The biceps femoris (Figure 1, 2) and rectus femoris (Figure 3, 4) during the jump squat both had average peak amplitude readings higher than during the rack squat. Similarly, the vastus medialis (Figure 5, 6) during the jump squat had an average peak amplitude higher than the rack squat. The gluteus maximus (Figure 7, 8) during the jump squat had an average peak amplitude higher than the rack squat. The vastus lateralis (Figure 9, 10) during the jump squat had an average peak amplitude higher than the rack squat. Overall, there was a large standard deviation due to analyzing the data for both groups together.

Chapter 5: Discussion

Discussion of Hypothesis and Research Questions

This study was designed to answer three research questions in addition to test the hypotheses formulated by the researcher. The hypotheses and each research question were evaluated and discussed based on the results of the study.

Hypothesis and Research Question 1

The hypothesis predicted that the heavy spinal load created by the rack squat may produce a higher anaerobic output result through the vertical jump in comparison to the submaximal spinal load from the jump squat. Research question one (Q1) posed the same question as the hypothesis. The vertical jump average for the volleyball players following the rack squat (18.38 inches) was slightly lower than the average vertical jump after the jump squat intervention (18.45 inches). Similarly, the vertical jump average for the football players following the rack squat (27.62 inches) was slightly lower than the average vertical jump after the squat jump intervention (27.71 inches). Since the squat jump produced a slightly higher subsequent vertical jump effort, the data did not support the hypothesis or Q1. However, the increase in vertical jump following the jump squat was insignificant in both groups (p=.391). Overall, the specific intervention did not appear to have any significant impact on vertical jump performance.

A study by Sotiropoulos et al. used submaximal and maximal loading protocols to create a postactivation potentiation effect in male volleyball players (Sotiropoulos et al., 2013). The mechanical power output and EMG activity was increased in the maximal loading protocol when compared to the submaximal protocol. However, there was not a significant difference in the vertical jump performance when comparing the two interventions. Therefore, the researchers concluded that the type of loading protocol does not make an impact on the subsequent vertical jump performance (Sotiropoulos et al., 2013).

Research Question 2

Research question two (Q2) asked if the athlete's initial strength level would have any influence on the effectiveness of using postactivation potentiation prior to a vertical jump test. Overall, the volleyball players produced a lower vertical jump measurement than the football players by roughly nine inches. The volleyball players were weaker than the football players in the study based on their squat max testing and vertical jump performances. The football players had an average squat max a roughly 490 lbs, whereas the volleyball players' squat max was around 188 lbs. Furthermore, the football players had an average pretest vertical jump of 27.31 inches, whereas the volleyball players recorded an average of 19.56 inches. The volleyball players had a slight decrease in average vertical jump when comparing the pretest trial to both the post rack squat and jump squat trials. The volleyball players had an average vertical jump of 19.56 inches during the pretest, whereas they recorded 18.38 and 18.45 inches after the rack squat and jump squat interventions, respectively. The football players had a slightly increased vertical jump performance following the postactivation potentiation interventions. After recording an average vertical jump of 27.31 inches during the pretest trial, the football players increased their vertical to 27.62 and 27.71 inches after the rack squat and jump squat interventions, respectively. However, the increase and decrease in vertical jump performance for each group following the postactivation potentiation interventions was insignificant ($p=.391$).

A study by Chiu et al. used a heavy back squat at 90% of the participant's maximal effort for a possible postactivation potentiation effect. The population included trained explosive athletes and recreationally trained athletes to identity the PAP effect on the two groups (Chiu et al., 2003). While the entire sample size did not see a significant increase in power output measured by vertical jump testing, the results indicated a difference between the two groups of participants. When the data from the two groups was analyzed separately, the particpants with the explosive power training background observed an increase in force and power output; whereas the recreationally trained group did not show any differences after the heavy back squat intervention (Chiu et al., 2003). The volleyball group in the current study has some similar characteristics as the recreationally trained group, and the football group has very similar characteristics to the power trained group. The volleyball players and Chiu's recreationally trained subjects had lower initial strength compared to the football players and Chiu's power trained subjects. Therefore, the results from Chiu's study are similar to the results from the current study.

The study by Seitz et al. further solidified the possibility of initial strength level and training experience in relation to the outcome of anaerobic power output following postactivation potentiation (Seitz et al., 2014). The study used heavy back squat loading at 90% of the participant's one repetition maximal effort. Participants were broken up into two groups based on their initial strength levels before testing. The strong group consisted of the participants with the ability to perform a maximal effort back squat greater than double their body weight. On the other hand, the weak group consisted of athletes with a maximal back squat effort of less than two times their body weight. The strong group recovered much quicker than the weak group and also produced significantly higher PAP responses to the heavy back squat intervention (Seitz et al., 2014). The strong group closely lines up with the football players, and the weak group is similar to the volleyball players in the current study. Overall, the strong group (football players) seemed to benefit more from the PAP activity than the weak group (volleyball players).

When comparing the results of Chiu et al.'s (2003) and Seitz et al.'s (2014) with the current study, there are some similarities. The football players were on average much more advanced in terms of resistance training experience and athletic ability as measured through the vertical jump test. Therefore, the football players could be considered trained explosive athletes, whereas the volleyball players were comprised of a mixture of trained explosive and recreationally trained. These categories indicate the slight insignificant increase in vertical jump performance during the PAP interventions in comparison to the pretest for the football players. Additionally, it might explain the decrease in vertical jump performance from the pretest to the PAP interventions in volleyball players.

One factor that may have caused the decrease in vertical jump performance with the volleyball players was the lack of control outside of the testing setting. The type and timing of the volleyball practices outside of the weight room were unknown during the duration of the study. There was a chance of the participants having an intense practice before one of the testing sessions, which may have caused fluctuation in the vertical jump performances. The volleyball players might have been participating in more activity outside of the weight room than the football players. However, the weight room sessions for all of the participants were controlled and monitored during the study.

Research Question 3 and Secondary Hypothesis

Research question three (Q3) asked if the rack squat would produce higher peak amplitudes for the EMG recordings in the selected muscle groups in comparison to the jump squat. Contrary to this, the average peak amplitude was much higher during the jump squat intervention compared to the rack squat intervention, as shown in Appendix G. The secondary hypothesis predicted a higher rate of firing during the rack squat, and higher peak amplitude during the jump squat. The biceps femoris (Figure 1, 2) and rectus femoris (Figure 3, 4) during the jump squat both had average peak amplitude readings higher than the rack squat. Similarly, the vastus medialis (Figure 5, 6) during the jump squat had an average peak amplitude higher than the rack squat. The gluteus maximus (Figure 7, 8) during the jump squat had an average peak amplitude higher than the rack squat. The vastus lateralis (Figure 9, 10) during the jump squat had an average peak amplitude higher than the rack squat. However, the rate of firing was much higher during the rack squat intervention (Figures 1-10). Due to the heavy spinal load during the rack squat, the body produced more dense EMG readings as there might have been more muscle activation. The EMG electrodes were placed on all participants by the researcher in order to create consistency with the data collection process. Maintaining consistent placement of the EMG electrodes should eliminate the chance of large variations in the data.

The study by Sotiropoulos et al. (2013) had similar results to the current study in terms of a higher level of mechanical power output or rate of firing based on EMG data discussed in RQ3 during the maximal loading protocol. The maximal loading protocol in Sotiropoulos et al.'s study involved a jump squat motion in comparison to the current study which used a rack squat for the maximal loading protocol. Therefore, the jumping motion of the maximal loading protocol for Sotiropoulos et al.'s study produced higher relative peak EMG amplitude measurements than the maximal loading protocol from this study. The maximal loading produced higher EMG activity during the early stages of data collection at the first and third minute in comparison to the submaximal loading protocol. Additionally, the EMG activity for the submaximal loading protocol was higher than the maximal loading protocol during the seven and ten minute stage (Sotiropoulos et al., 2013). The timeframe for the data collection in the current study was three, four and five minutes, whereas the study by Sotiropoulos et al. included a timeframe up to ten minutes for data collection.

Conclusion

When examining the results from this study, the researcher concluded that the heavy spinal load and submaximal load protocols provided no significant increase or decrease on the vertical jump performances of the participants. However, the data was analyzed as a group and no individual data was reported. If the data was analyzed on an individual basis, there might have been a few cases of either postactivation potentiation intervention causing a significant increase in vertical jump performance. For example, one of the football players had a very large increase in vertical jump following the rack squat (33.9 inches) in comparison to the jump squat (31.4 inches), suggesting support for the hypothesis that the super maximal loading protocol would cause more of a PAP effect than the submaximal loading protocol. The majority of the participants showed a very minimal difference between vertical jump performances after the rack squat and jump squat inteventions.

Chapter 6: Conclusion

Summary of Major Findings

The purpose of the study was to determine whether a submaximal loading protocol or a super maximal loading protocol was the most effective postactivation potentiation method for improving a vertical jump test, a standard measure of anaerobic power. The anaerobic power output was measured by vertical jump testing during the pretest, and after the postactivation potentiation interventions. Vertical jump testing was chosen by the researcher since it's a universal measurement of anaerobic power output (French et al., 2003). Additionally, peak EMG amplitude was also measured by the researcher to determine muscle activity during the heavy spinal loading and submaximal spinal loading protocols.

The researcher hypothesized that the heavy spinal load created by the rack squat may produce a higher anaerobic output result through the vertical jump in comparison to the submaximal spinal load from the jump squat. Based on the results from the study, neither intervention created a more advantageous postactivation potentiation before performing the vertical jump test. There was a noticeable but insignificant decrease for the volleyball group from their pretest vertical jump performance (19.56 inches) to the postactivation potentiation trial results ($p=.391$). There were very slight and insignificant differences between the vertical jump performances when comparing the trials after the rack squat (18.38 inches) and the jump squat (18.45 inches). A possible reason for the insignificant ($p > 0.05$) decrease was the uncontrolled practice sessions outside of the weight room. There was a slight and insignificant increase of vertical jump performance following the rack squat (27.62 inches) and jump squat

(27.71 inches) interventions in comparison to the pretest performance (27.31 inches) (p=.391) in the football players.

The researcher also hypothesized that the rack squat would cause a higher rate of firing on the EMG readings, and higher peak amplitude for the jump squat movement. The biceps femoris (Figure 1, 2) and rectus femoris (Figure 3, 4) during the jump squat both had average peak amplitude readings higher than the rack squat. Similarly, the vastus medialis (Figure 5, 6) during the jump squat had an average peak amplitude readings higher than the rack squat. The gluteus maximus (Figure 7, 8) during the jump squat had an average peak amplitude higher than the rack squat. The vastus lateralis (Figure 9, 10) during the jump squat had an average peak amplitude readings higher than the rack squat. A possible reason for the increased peak amplitude during the jump squat intervention is the explosive nature of the jump squat when compared to the rack squat.

Recommendations

There are a few aspects of the study that can be improved upon to possibly achieve statistically significant results. The major issue with this study was the lack of control of the participants' practice sessions outside of the weight room. Even though the researcher was able to control the weight room workouts for each participant, their sport practice was not controlled by the researcher. The volleyball team may have been doing more activity outside of the weight room compared to the football team. The ability to control every aspect of their physical output during the duration of the study would drastically increase the likelihood of obtaining consistent and accurate results.

There were only 19 participants used for the duration of the study. While the total number was a decent sample size, a larger sample size would give more consistent and comprehensive results. The more participants used for the study, the better chance of acquiring results that contain a true average of data. Football and volleyball are both adequate power sports, but adding sports such as Olympic weight lifting, track and field, and bobsled would give more depth to the data. All of the aforementioned sports require varying types of power production and movement patterns to achieve successful results. Therefore, adding more participants from other power sports would also be beneficial to create more comprehensive data.

All of the participants in the study were NCAA Division II caliber student-athletes. Even though all of the participants were trained power sport athletes, there was still a fairly wide range of abilities seen from the student-athletes. A future recommendation may include the use of only elite level (Olympic, international, high level national) athletes for postactivation potentiation research. There will likely be less of a difference between the most talented and least talented participants in a group of high level elite athletes.

Future Research

If resources and time were not an issue, there are some very different aspects that could be added to the protocol. First, the ability to control every aspect of the participants' day including amount of sleep, type of nutrition, and physical training plans may help eliminate all possible human errors of the study. Second, recruiting participants from a wide array of power based sports would help create more depth and potential generalizability to the data collected. In additional to recruiting participants from more sports, it would be ideal to include as many participants as possible. There are many different possible routes to explore to improve upon this study, but it ultimately depends on the research goals of the research team.

Practical Applications

Strength and conditioning professionals may be able to apply the procedures from the study to determine the most advantageous postactivation potentiation method. If an athlete reaps the positive benefits of the PAP intervention, they can use the protocol to improve their performance at a combine or other testing event for their sport. For example, if a football player acutely increased his vertical jump on a consistent basis following the maximal loading protocol, then it could be used before his vertical jump test at the NFL combine. Another example would be using postactivation potentiation methods before a track and field meet. A shot putter that see increased throwing distances following a plyometric push-up PAP protocol could use the technique before competition. The athlete could also utilize PAP movements to elicit a higher training stimulus, increased physiological adaptations, and potential improved performance. However, the athletes need to be physically prepared to endure intense training before attempting to utilize postactivation potentiation. Additionally, the athletes will need to become familiar with the rack squat and jump squat movements before using them for postactivation potentiation purposes.

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Appendix A: Consent and IRB Forms

RESEARCH PARTICIPATION CONSENT FORM

The Effects of Varying Postactivation Potentiation Intensities on Vertical Jump Performance

Eric Birch
Adams State University
Department of Human Performance and Physical Education

INFORMED CONSENT FOR PARTICIPATION IN RESEARCH

Postactivation potentiation refers to the heightened neuromuscular condition seen after a session of heavy or explosive resistance training (Lim & Kong, 2013). In theory, using a very heavy relative load may help recruit a larger amount of motor units (Chiu et al, 2003). The safest way to use heavy loading prior to an explosive test will be to prescribe the rack squat. A rack squat involves the athlete using a super maximal load (150% of squat max) in a very small range of motion. The rack squat will be compared with the results of a submaximal barbell squat jump. Additionally, the use of electromyography (EMG) will identify the variations in amplitudes during the different postactivation potentiation interventions.

The purpose of the study is to determine whether a submaximal loading protocol or a super maximal loading protocol is the most effective postactivation potentiation method for improving a vertical jump test, a standard measure of anaerobic power. The variables being measured will initially include baseline data for vertical jump height and one repetition maximal squat. After the baseline data is collected, the researchers will then test the PAP effect of the rack squat and barbell squat jump on vertical jump measurements. The PAP effect will be measured using the vertical jump measurement in addition to EMG recordings. The muscles that will be tracked during the postactivation potentiation interventions are the vastus lateralis, vastus medialis, rectus femoris, gluteus maximus and biceps femoris (Balshaw & Hunter, 2012; Caterisano et al., 2002; Isear et al., 1997; Luera et al., 2014; Sotiropoulos et al., 2013).

PROCEDURES

This study will take place over a course of four (4) weeks, in the Plachy Hall weight room at Adams State University. The athletes will be split into two groups, and undergo the two PAP interventions in consecutive weeks. The four-week experimental protocol is explained in the following section.

Pre-testing (week one):

1. You will be asked to fill out a short questionnaire about demographics and injury history prior to participating in the study.
2. You will be asked to perform a specific warm up, and then a one repetition max test, as according to the protocol by Baechle & Earle (2008).

Vertical jump testing (week 2):

1. You will be asked to perform a specific warm-up.
2. After the warm-up, each participant will have three attempts to achieve their maximal vertical jump height. Between each attempt, the participants will rest for three minutes.

Participant's Signature : ______________________________

PAP testing (week 3 & 4):

1. You will be prepped for electrode placement by a skin abrasion process with emery paper in addition to wiping the area with an alcohol pad in each area, as designated by the researcher.
2. The submaximal loading intervention will be barbell squat jumps with 30% of the participant's estimated one repetition maximum effort squat.
3. The maximal spinal loading intervention will involve the participants using 150% of the estimated one repetition maximum effort squat during rack squats.
4. Group A will perform 3 repetitions of barbell jump squats at their predetermined intensity.
5. Group B will perform 3 repetitions of rack squats at 150% of their one repetition squat maximum effort.
6. The participants will rest for three minutes before completing three vertical jump tests.
7. Each participant will rest for one minute in between the three vertical jump tests. Therefore, they will be performing vertical jump tests at three, four, and five minutes following the PAP intervention.
8. The fourth week of testing will be exactly the same as week three, but the participant will switch groups and perform the other postactivation potentiation intervention.

DURATION OF PARTICIPATION

The duration of participation for this study will be approximately four weeks. The four weeks of participation will include the three sections listed above (pre-testing, vertical jump testing, and PAP testing). The participants should expect to spend one hour for pre-testing, thirty minutes for vertical jump testing, and forty-five minutes to one hour for each PAP testing sessions.

RISKS AND DISCOMFORTS OR EXCLUSION FROM TESTING

Inherent risks associated with resistance exercise or any new exercise program includes: muscle and joint soreness as well as joint and muscle pain and injury. Injuries most often occur with improper progression, improper loads, or poor technique; however, the risks associated with a resistance training program are less than that of playing an actual sport. Based on the nature of the movements and experience of the participants, excessive soreness is unlikely. Every effort will be made to minimize the risk of injury throughout this study by performing the program under the supervision of certified professionals, teaching and encouraging proper form, and also by having the training programs written by individuals with years of experience. As a participant, to minimize your individual potential for injury, you will be asked to perform exercises to the best of your ability while you are being supervised by certified professionals.

BENEFITS

There are many benefits included with performing this study, as a participant of this study; participants will have the opportunity to learn about the most advantageous postactivation potentiation method to acutely increase their anaerobic performance. The gained knowledge will be especially important for athletes wanting to increase their vertical jump performance for a combine type test. Participant's individual results will be provided and explained to you, which may result in basic physiologically knowledge about anaerobic power output. The data collected from the study may

Participant's Signature : ______________________________

contribute to the field by adding insight about the most effective postactivation potentiation methods for power based athletes.

CONFIDENTIALITY

Participation is voluntary and will be held confidential. You may choose not to answer any question you do not want to answer and/ or you may withdraw from participation at any time without penalty. Names will not be used in the study, participants will be assigned a number and group data will be reported. Data will be locked under a password protected computer for seven years in which the researcher only has the password. Adams State University reserves the right to use the results of this study for future research and/or presentation of results. In such cases, participants will be asked to sign a release form freeing all collected information prior to its use by the institution or researcher. If research is used in a public forum, data will be reported as a group without individual or school identification.

INQUIRIES

Any questions or concerns regarding this study are welcomed at any time. If questions arise, please contact the researcher of the study, graduate student Eric Birch, via email at birchew@grizzlies.adams.edu Or by phone at 763-229-4061 or Dr. Tracey Robinson, chair of thesis committee, at tlrobins@adams.edu, or by phone at (719) 587-7663. If there are any additional questions, please contact Dr. Robert Demski, chair of the IRB committee, at rmdemski@adams.edu, or by phone at (719) 587-7216.

PLEASE READ THE FOLLOWING STATEMENTS, AND SIGN IN THE SPACES PROVIDED TO INDICATE YOUR CONSENT:

AUTHORIZATION: I have read the above and understand the discomforts and inconvenience of this study as well as the benefits and risks. I, ________________________________ (printed name of participant) agree to participate in this research. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

______________________________ ______________________

Participant's Signature Date

______________________________ ______________________

Researcher's Signature Date

ADAMS STATE COLLEGE
INSTITUTIONAL REVIEW BOARD
Approved on: 2-1-15
Expires on: 2-1-16

Participant's Signature : ______________________________

IRB Form

Adams State College

Request to obtain approval for the use of human participants

Date: December 1, 2014

Name: Eric Birch

Email: birchew@grizzlies.adams.edu

Mailing Address: 230 Calle Buena Alamosa CO, 81101

Phone: 763-229-4061

Chair of Thesis Committee: Tracey Robinson, Ph.D.
Email: tlrobins@adams.edu
Phone: 719-587-7663

Subject: The Effects of Varying Postactivation Potentiation Intensities on Vertical Jump Performance

The title of the research: The Effects of Varying Postactivation Potentiation Intensities on Vertical Jump Performance (Master's thesis research)

Objectives of the research: Postactivation potentiation refers to the heightened neuromuscular condition seen after a session of heavy or explosive resistance training (Lim & Kong, 2013). Even though there is a considerable amount of research on postactivation potentiation, there is a lack of extremely heavy load training prior to an explosive test. The highest percentage training load is 130% of peak power output in a study by Sotiropoulos et al. (2013). However, most of the other research used 90% of the participant's one repetition maximal effort or less (Chiu et al, 2003; Lim & Kong, 2013; Mitchell & Sale, 2011; Smith et al., 2014). In theory, using a very heavy relative load may help recruit a larger amount of motor units (Chiu et al, 2003). The safest way to use heavy loading prior to an explosive test will be to prescribe the rack squat. A rack squat involves the athlete using a super maximal load (150% of squat max) in a very small range of motion. The athlete lifts the bar from the rack, which is usually set for the athlete to begin in the quarter squat position. Even if the athlete fails on the repetition, the weight can be safely lower back down to the rack. The rack will serve as its own spotter, which makes it a very safe movement for athletes. Since most of the research uses loading parameters of less than 90%, there is a need for research on heavy loading parameters over 100% of the participant's one repetition maximal effort since it may cause a greater PAP effect. Additionally, the use of electromyography will identify the variations in amplitudes during the different postactivation potentiation interventions. The muscles that will be tracked during the postactivation potentiation interventions are the vastus lateralis, vastus medialis, rectus femoris, gluteus maximus and biceps femoris (Balshaw

& Hunter, 2012; Caterisano et al., 2002; Isear et al., 1997; Luera et al., 2014; Sotiropoulos et al., 2013).

Methods of Procedure:

The Setting: All testing and measurements will be completed in the Adams State University weight room in Plachy Hall. Each testing session will be completed when the weight room is completely open and no other teams will be training at the same time. Adams State University is a small, rural Division II University located in southern Colorado in the town of Alamosa. Alamosa is located in the San Luis Valley and has an elevation of 7,544 feet above sea level.

The Participants: Twelve female collegiate volleyball players and eighteen male collegiate football players will be asked to volunteer to participate in the study. Due to the high number of football players on the team, the first eighteen to volunteer will be selected for the study. There will be less volleyball players involved with the study based on their smaller roster size. An equal number of male and female participants is not as important as the total number of participants. Participants will be required to provide written consent. Due to the nature of the study, there will be no deception used for the experimental protocol. Additionally, participants will not receive compensation for volunteering in this study. All of the participants will be in the off-season of their respective sports, and will be using similar training methods. The weight training programs will be designed by Matt Gersick, the head strength and conditioning coach at Adams State University. The similar training methods include comparable exercises (squat, bench, deadlift) and almost identical training percentages. Training percentages for weight lifting refers to the percentage of the individual's one repetition maximal effort used during the specific movements. Since both sports have their season in the fall, the athletes from each team will follow the same general outline in preparation for their season. The workouts will be focused on the athletes gaining strength during their off-season phase. Additionally, the participants will have at least one year of heavy weight lifting experience. Due to the advanced nature of the heavy spinal loading lifting techniques, the participants need to be adequately prepared to safely perform the exercises.

Research Design:

Pre-test: The participants will participate in a four-week protocol described below. The participants will first fill out the informed consent document upon arrival to the facility The first week will involve measurements of basic subject characteristics, which includes name, date of birth, gender, and age. An explanation of the study will occur during the first week, along with a short participant questionnaire about prior weight training experience. The short participant questionnaire will help the researcher determine if the potential participants are physically ready to undergo the study. Any current or recent lower body injuries or surgeries will disqualify the participants from joining the study. If the participants underwent any lower body surgery over the last twelve months, they will not be allowed to participate in the study.

After demographic information has been collected, the participants will perform a one-repetition maximal squat effort test after an adequate warm up. The participants will perform four warm-up sets at certain training percentages to prepare their body for the test. The warm-up and experimental sets will be formatted from the testing protocol featured by Baechle & Earle (2008):

- Warm-up with a light resistance that allows for five to ten repetitions.
- Rest for one minute.
- Add thirty to forty pounds to the initial warm-up set and complete three to five repetitions for the male participants. The female participants will add twenty to thirty pounds and follow the same protocol.
- Rest for two minutes.
- Next, the athlete will add thirty to forty pounds to the last attempted weight and complete two to three repetitions for the male participants. The female participants will add twenty to thirty pounds and follow the same protocol.
- Rest for three minutes.
- Increase the load by thirty to forty pounds and the athlete will start their first attempt at their one repetition maximal effort for the male participants. The female participants will add twenty to thirty pounds and follow the same protocol.
- After each attempt, the athlete will rest for three minutes before completing their next attempt.
- If the athlete fails their attempt, then fifteen to twenty pounds will be subtracted for the next attempt. The athlete will have three opportunities to achieve a successful attempt at their one repetition maximal effort squat.

One week after the first session (week two of the study), the participants will return to the weight room for vertical jump testing. All of the testing will occur on the Just Jump! mat from Probiotics INC (Huntsville, AL). The protocol for the vertical jump tests is as follows:

- The participants will perform a warm-up protocol with three repetitions of squats at 30%, 40%, and 50% of their estimated one repetition maximum squat effort from the previous week's one repetition maximal effort test.
- After the warm-up, each participant will have three attempts to achieve their maximal vertical jump height. Between each attempt, the participants will rest for three minutes. The participants will use a countermovement and descend to a knee angle of roughly 120 degrees for the vertical jump testing.
- The highest vertical jump height for each participant will be used as their baseline number.

Protocol: For the third week of testing, the participants will be randomly split up into Group A and Group B. Group A will consist of six volleyball players and nine football players.

EMG Prep: Prior to the postactivation potentiation interventions, EMG electrodes will be placed on the participants to measure muscular activity.

- The electrodes will be placed on the vastus lateralis, vastus medialis, gluteus maximus, biceps femoris, and rectus femoris of each participant during the rack squat and jump squat trials. All of the electrode placements will be completed by the main researcher in order to maintain consistent measurements.
- Before the electrodes are placed on the proper sites, the participants will go through a preparation process.
- The selected areas will undergo a skin abrasion process with emery paper in addition to wiping the area with an alcohol pad.
- If needed, the participant will be instructed to shave the areas if their body hair is likely to become an issue.
- The electrode will be placed on the muscle belly of the quadriceps on the lateral side for the vastus lateralis.
- The electrode will be placed on the muscle belly of the quadriceps on the medial side for the vastus medialis.
- The placement for the gluteus maximus will be in the center of the muscle belly.
- The placement for the rectus femoris will be in the center of the quadriceps on the muscle belly.
- The electrode will be placed on the muscle belly of the hamstring and slightly towards the lateral side for the biceps femoris.
- A diagram illustrating the proper electrode placements is located in Appendix D.
- The surface EMG set-up will be measuring peak amplitude.

Warm-Up: Participants in both groups will undergo the same active warm-up prior to starting the separate testing interventions. The active warm-up is listed below:

- High Knees (2x10 yards)
- Forward Skips with Arm Circles (2x10 yards)
- Reverse Lunge with Twist (2x10 yards)
- Single Leg Romanian Deadlift (RDL) (2x10 yards)

Postactivation Potentiation Intervention Pre Test:

- After the active warm-up is completed, the participants will rest for six minutes before continuing the testing protocol to allow for a full recovery from the warm-up.
- The participants will break up into their respective groups in order to become prepared for their postactivation potentiation intervention.

- The submaximal loading intervention will be barbell squat jumps with 30% of the participant's estimated one repetition maximum effort squat. The barbell jumps will be performed with a knee angle of 120 degrees.
- The 120-degree knee angle will be determined by the use of a goniometer before the participant performs any of the barbell jumps.
- Once the participant understands the proper knee angle, then the jumps will be performed.
- Group B will undergo the maximal spinal loading intervention.
- The maximal spinal loading intervention will involve the participants using 150% of the estimated one repetition maximum effort squat during rack squats.
- The safety pins will be set based on the participants' height so they start with a 120-degree knee angle using the goniometer for accurate measurements. The 120-degree knee angle will be selected to stay consistent with the range of motion used during the barbell jump squats (Pearson & Hussian, 2014).
- The rack squat is performed by setting the body under the bar in a squat position, and lifting the bar as quickly as possible to the standing position.

Postactivation Potentiation Intervention Testing

- Group A will perform 3 repetitions of barbell jump squats at their predetermined intensity.
- Group B will perform 3 repetitions of rack squats at 150% of their one repetition squat maximum effort.
- After the exercises are completed, the participants will rest for three minutes. Three minutes was chosen for the rest period based on the training status of the participants. They will all be trained explosive athletes; therefore they require a short recovery period for the desired postactivation potentiation effect (Seitz et al., 2014).
- After the three minutes of rest is done, the participants will complete three vertical jump tests.
- Each participant will rest for one minute in between the three vertical jump tests. Therefore, they will be performing vertical jump tests at three, four, and five minutes following the PAP intervention.
- The highest vertical jump measurement for each participant will be used for the data collection.
- The fourth week of testing will be exactly the same as week three, but the participant will switch groups and perform the other postactivation potentiation intervention.
- The rest period protocol and the other aspects of the testing procedure will mirror the week three testing protocol.
- All of the aspects will be kept the same in order to eliminate any errors during the testing protocol and improve reliability.

Duration of Participation

The duration of participation for this study will be approximately four weeks. The four weeks of participation will include the three sections listed above (pre-testing, vertical jump testing, and PAP testing). The participants should expect to spend one hour for pre-testing, thirty minutes for vertical jump testing, and forty-five minutes to one hour for each PAP testing sessions. The EMG prep and warm-up will both take approximately ten minutes to complete.

Statistical Analysis: An Excel spreadsheet will be used to record and compile all relevant data. The dependent variables for the study are the results from the vertical jump testing and the EMG activity measurements. The EMG measurements will be from the vastus lateralis, vastus medialis, biceps femoris, rectus femoris, and gluteus maximus. All of the EMG signals will be recorded and in millivolts (mV) and the frequency will be measured in Hertz (Hz) during the postactivation potentiation interventions of the rack squat and barbell jump squat with the EMG analysis software. The EMG peak amplitude of each site will be used for data collection and comparison. The signal will be bandpass between 20-150 Hz in order to filter the signal from outside interference (Ball & Scurr, 2011). The two dependent variables will be directly impacted by the intervention variables, which are the jump squat and rack squat interventions used to produce PAP. Each participant will take both interventions in a randomized crossover design in order to determine any differences caused by each to the EMG activity measurements and vertical jump test. To properly analyze the data, means and standard deviations for all variables will be compared using a repeated measures two-way ANOVA. The researcher will use the SPSS Statistics Version 22 program from 2013 to compute all of the data generated from the specific variables during testing. Statistical significance will be accepted at $p < .05$.

Protection Measures: All participants will be fully informed of all study procedures, and may withdraw at any time. All of the testing sessions will involve the assistance of two strength coaches in addition to the primary researcher. The two assistants are both in the Exercise Science graduate program at Adams State University and are currently employed as strength coaches in the athletic department. Both assistants have experience with exercise testing and the procedures used in the study. Participants will also be asked to fill out a questionnaire regarding their health status prior to any testing, and if necessary, have a physician's clearance before participating in the study. Results of the study will be reported as group data, without any individual subject identifying information. Any presentation of the results will be in aggregate form that does not identify individual participants. The results will be locked away in a cabinet where only the leading researcher will have a key.

Benefits: There are many benefits included with performing this study, as a participant of this study; participants will have the opportunity to learn about the most advantageous postactivation potentiation method to acutely increase their anaerobic performance. The gained knowledge will be especially important for athletes wanting to increase their vertical jump performance for a combine type test. Participant's individual results will be provided and explained to you, which may result in basic physiologically knowledge about anaerobic power output. The data collected from the study may contribute to the field by adding insight about the most effective postactivation potentiation methods power based athletes.

Risks: Inherent risks associated with resistance exercise or any new exercise program includes: muscle and joint soreness as well as joint and muscle pain and injury. Injuries most often occur with improper progression, improper loads, or poor technique; however, the risks associated with a resistance training program are less than that of playing an actual sport. Based on the nature of the movements and experience of the participants, excessive soreness is unlikely. Every effort will be made to minimize the risk of injury throughout this study by performing the program under the supervision of certified professionals, teaching and encouraging proper form, and also by having the training programs written by individuals with years of experience. As a participant, to minimize your individual potential for injury, you will be asked to perform exercises to the best of your ability while you are being supervised by certified professionals.

Consent: Participants will be asked to read over and sign the consent form before any testing commences. The informed consent is attached separately.

Changes: If any changes are made to the research I will contact the IRB immediately and fill out the needed paperwork.

Tracey L Robinson 2-4-2015

Name and Signature of Department Chair or Appropriate Person Date

Robert Demski 2-1-15

Name and Signature of IRB Chair Date

Appendix B: Weight Training Program Example

Football/Volleyball Off-Season Training Program Example

Lower Body (Monday and Thursday)

	Sets/Reps	Rest
• Deadlift	4x10	90 seconds
• Back Squat	4x10	90 seconds
• Step-Up	3x10	90 seconds
• Leg Curl	3x10	60 seconds
• Calf Raise	3x10	60 seconds

Upper Body (Tuesday and Friday)

	Sets/Reps	Rest
• Bench Press	4x10	90 seconds
• Bent-Over Row	3x10	60 seconds
• Shoulder Press	4x10	90 seconds
• Barbell Biceps Curl	3x10	60 seconds
• Shoulder Shrug	3x10	60 seconds
• Lying Triceps Extension	3x10	60 seconds
• Abdominal Crunch	3x20	20 seconds

(Baechle & Earle, 2008)

Appendix C: Participant Questionnaire

Questionnaire for Potential Research Participants

1. Full name, date of birth, gender, and age

___

2. Years of heavy weight lifting experience? Only include years as a collegiate athlete and indicate the sport

___

3. Any current injuries or health concerns? Include all past treatments received from physical therapists or athletic trainers.

___

4. Any major surgeries or injuries in the past 12 months?

___

5. Height and Weight measured by the research team (in centimeters and kilograms)

___

6. What medications or supplements are you currently using?

___

Appendix D: EMG Electrode Placement Example

Frontal View

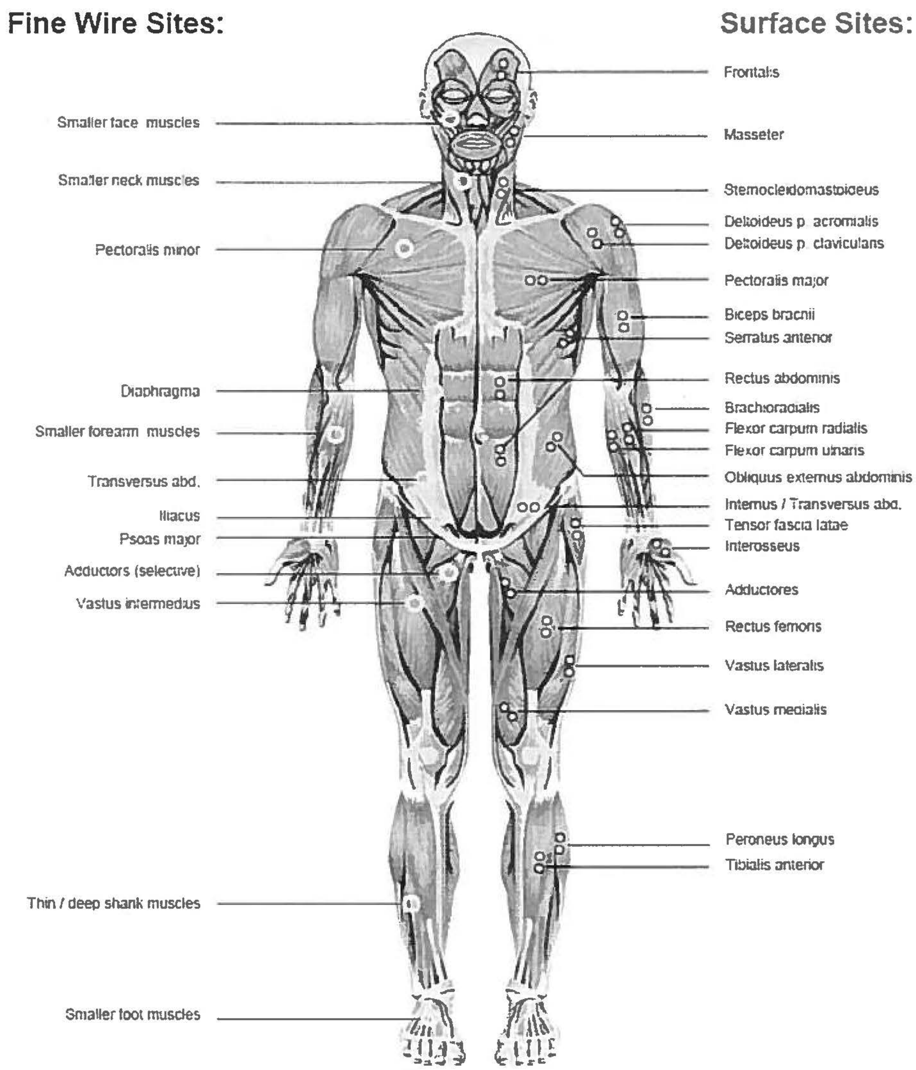

*Fig. 26a: Anatomical positions of selected electrode sites, frontal view. The left side indicates **deep** muscles and positions for fine wire electrodes, while the right side is for **surface** muscles and electrodes*

(Konrad, 2006)

Dorsal View

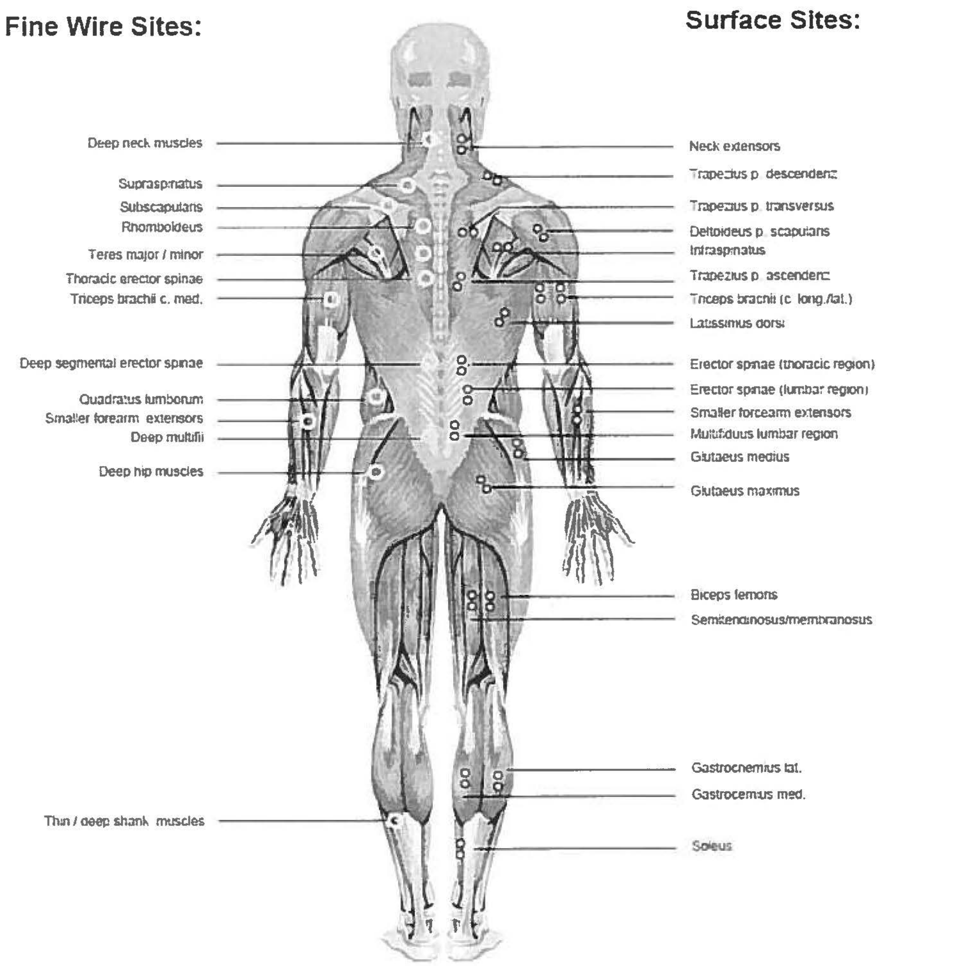

*Fig. 26b: Anatomical positions of selected electrode sites, dorsal view. The left side indicates **deep** muscles and positions for fine wire electrodes, while the right side is for **surface** muscles and electrodes*

(Konrad, 2006)

Appendix E: Participant Data From Weeks 1-4

Volleyball Descriptive Data and Vertical Jump Averages

ID	Gender	Height (in)	Weight (lbs)	Age (years)	Sport	AVE PT VJ (in)	AVG RS VJ (in)	AVE JS VJ (in)
990	F	63	135.6	18	VB	18.3	16.7	17.3
991	F	66	170.4	19	VB	15.7	13.8	13.0
17	F	63	130.3	19	VB	16.1	16.1	15.5
18	F	62	115.3	19	VB	20.2	19.1	19.4
10	F	66	150.3	20	VB	23.0	21.8	22.1
9	F	70	176.4	20	VB	24.5	23.3	23.5
19	F	61	130.3	21	VB	15.1	14.9	15.8
15	F	75	165.3	20	VB	19.0	19.2	18.8
13	F	73	145.2	20	VB	21.8	18.7	19.3
12	F	71	150.3	21	VB	24.9	24.8	25.2
11	F	72	174.4	20	VB	16.6	13.8	13.1

PT: Pretest

RS: Rack Squat

JS: Jump Squat

VJ: Vertical Jump

Volleyball Rack Squat EMG Data

ID	RS EMG GM	RS EMG BF	RS EMG RF	RS EMG VMO	RS EMG VL
990	N/A	185	521	944	1303
991	N/A	109	472	634	929
17	67	290	450	550	679
18	261	180	571	723	1186
10	176	252	470	560	895
9	80	287	558	1323	528
19	99	603	252	557	757
15	535	248	623	1300	1198
13	135	492	597	951	1183
12	70	385	291	867	498
11	44	615	305	227	349

Note: Measured in microvolts

RS: Rack Squat

GM: Gluteus Maximus

BF: Biceps Femoris

RF: Rectus Femoris

VMO: Vastus Medialis

VL: Vastus Lateralis

Volleyball Jump Squat EMG Data

ID	JS EMG GM	JS EMG BF	JS EMG RF	JS EMG VMO	JS EMG VL
990	1277	1223	1205	1300	1303
991	207	351	1050	657	771
17	432	723	756	806	1038
18	622	N/A	N/A	1060	932
10	N/A	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A	N/A
19	1256	672	1251	1311	1309
15	1259	1281	1396	1386	1334
13	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A
11	619	1012	592	1106	729

Note: Measured in microvolts

JS: Jump Squat

GM: Gluteus Maximus

BF: Biceps Femoris

RF: Rectus Femoris

VMO: Vastus Medialis

VL: Vastus Lateralis

Football Descriptive Data and Vertical Jump Averages

ID	Gender	Height (in)	Weight (lbs)	Age (years)	AVG PT VJ (in)	AVG RS VJ (in)	AVG JS VJ (in)
1	M	74	201.5	22	32.5	31.1	33.9
993	M	68	200.5	22	27.5	27.2	29.2
3	M	73	235.4	21	30.5	28.9	29.0
4	M	78	320.8	22	18.6	16.5	16.6
5	M	72	215.4	21	30.7	33.9	31.4
6	M	71	212.5	20	28.5	29.0	28.2
7	M	74	260.6	20	23.7	24.4	23.6
992	M	70	224.9	24	26.5	30.0	29.8

PT: Pretest

RS: Rack Squat

JS: Jump Squat

VJ: Vertical Jump

Football Rack Squat EMG Data

ID	RS EMG GM	RS EMG BF	RS EMG RF	RS EMG VMO	RS EMG VL
1	226	896	1368	688	1446
993	208	1058	N/A	1330	1342
3	523	446	1325	1180	1271
4	71	894	226	592	449
5	394	1207	770	1177	1291
6	902	743	1147	1147	1157
7	355	634	842	1189	922
992	N/A	1341	1292	1160	1404

Note: Measured in microvolts

RS: Rack Squat

GM: Gluteus Maximus

BF: Biceps Femoris

RF: Rectus Femoris

VMO: Vastus Medialis

VL: Vastus Laterali

Football Jump Squat EMG Data

ID	JS EMG GM	JS EMG BF	RS EMG RF	RS EMG VMO	RS EMG VL
1	902	1354	1423	1405	1437
993	1200	1503	1427	1469	1329
3	N/A	1072	1370	N/A	1386
4	1220	1357	1232	N/A	1378
5	N/A	1144	1296	1443	1378
6	981	1387	1337	1689	1444
7	N/A	1216	1224	N/A	1283
992	1317	1438	1472	1610	1507

Note: Measured in microvolts

JS: Jump Squat

GM: Gluteus Maximus

BF: Biceps Femoris

RF: Rectus Femoris

VMO: Vastus Medialis

VL: Vastus Lateralis

Appendix F: Descriptive Statistics Tables

Descriptive Statistics

	Sport played	Mean	Std. Deviation	N
Average vertical jump of three trials before the start of the study in inches	volleyball	19.5636	3.57219	11
	football	27.3125	4.46588	8
	Total	22.8263	5.50412	19
Average vertical jump of three trials after rack squatting in inches	volleyball	18.3818	3.74828	11
	football	27.6250	5.27738	8
	Total	22.2737	6.37337	19
Average vertical jump of three trials after squat jumps in inches	volleyball	18.4545	4.01880	11
	football	27.7125	5.35522	8
	Total	22.3526	6.49456	19

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
ex_treatment_VJ	Sphericity Assumed	1.983	2	.991	.965	.391	.054
	Greenhouse-Geisser	1.983	1.772	1.119	.965	.383	.054
	Huynh-Feldt	1.983	2.000	.991	.965	.391	.054
	Lower-bound	1.983	1.000	1.983	.965	.340	.054
ex_treatment_VJ * Sport	Sphericity Assumed	6.964	2	3.482	3.390	.045	.166
	Greenhouse-Geisser	6.964	1.772	3.930	3.390	.052	.166
	Huynh-Feldt	6.964	2.000	3.482	3.390	.045	.166
	Lower-bound	6.964	1.000	6.964	3.390	.083	.166
Error(ex_treatment_VJ)	Sphericity Assumed	34.922	34	1.027			
	Greenhouse-Geisser	34.922	30.124	1.159			
	Huynh-Feldt	34.922	34.000	1.027			
	Lower-bound	34.922	17.000	2.054			

Appendix G: Peak Amplitude Differences Between Rack Squat and Jump Squat Interventions

EMG Peak Amplitude Information

		Avg peak activation (microV) of the glute max during the three rack squat trials	Avg peak activation (microV) of the biceps femoris during the three rack squat trials	Avg peak activation (microV) of the rectus femoris during the three rack squat trials	Avg peak activation (microV) of the vastus medialis during the three rack squat trials	Avg peak activation (microV) of the vastus lateralis during the three rack squat trials	Avg peak activation (microV) of the glute max during the three jump squat trials	Avg peak activation (microV) of the biceps femoris during the three jump squat trials	Avg peak activation (microV) of the rectus femoris during the three jump squat trials	Avg peak activation (microV) of the vastus medialis during the three jump squat trials	Avg peak activatin (microV) of the vastus lateralis during the three jump squat trials
N	Valid	16	19	18	19	19	12	14	14	12	15
	Missing	3	0	1	0	0	7	5	5	7	4
Mean		259.1250	571.842	671.1111	899.9474	988.789	941.000	1123.78	1216.50	1270.166	1237.20
Median		192.0000	492.000	564.5000	944.0000	1157.00	1090.50	1219.50	1273.50	1348.500	1329.00
Std. Deviation		234.4519	366.553	375.6263	328.9110	353.160	382.093	332.795	257.242	309.9873	247.138
Range		858.00	1232.00	1142.00	1103.00	1097.00	1110.00	1152.00	880.00	1032.00	778.00
Minimum		44.00	109.00	226.00	227.00	349.00	207.00	351.00	592.00	657.00	729.00
Maximum		902.00	1341.00	1368.00	1330.00	1446.00	1317.00	1503.00	1472.00	1689.00	1507.00

Note: Measured in microvolts

JS: Jump Squat

RS: Jump Squat

GM: Gluteus Maximus

BF: Biceps Femoris

RF: Rectus Femoris

VMO: Vastus Medialis

VL: Vastus Lateralis

Figures 1-10

Note: All data is from participant #1 (as a typical example)

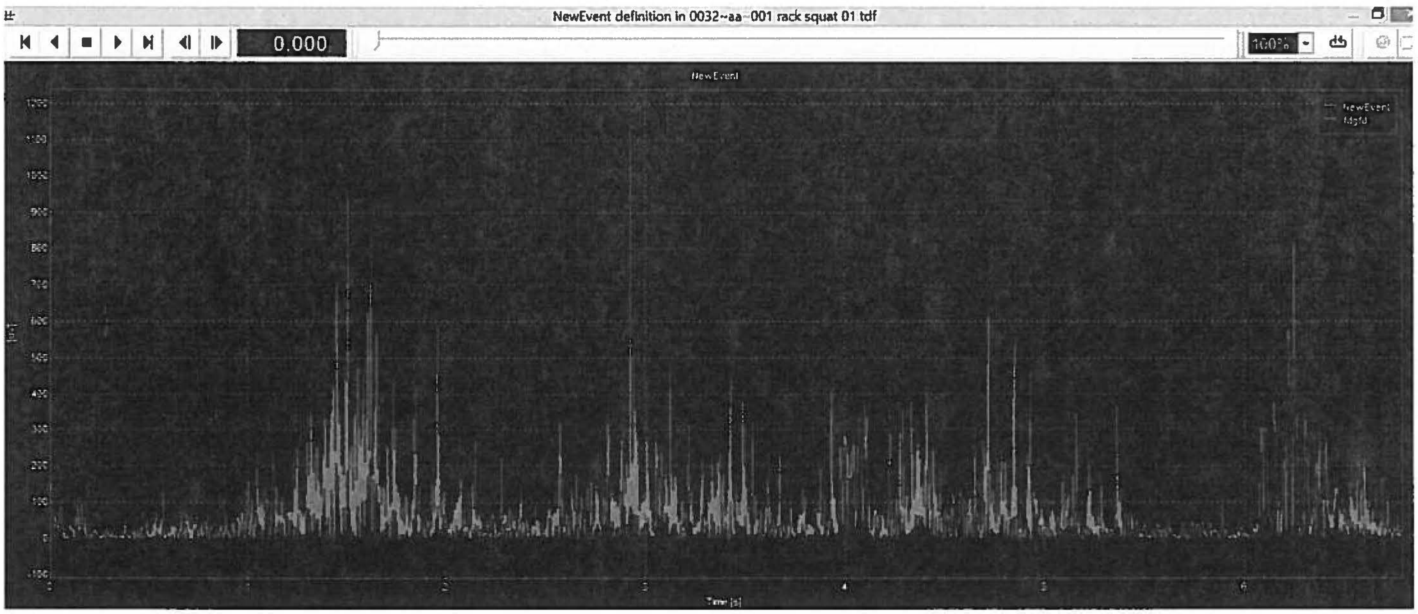

Figure 1. Rack Squat EMG Recoding for Biceps Femoris (measured in microvolts)

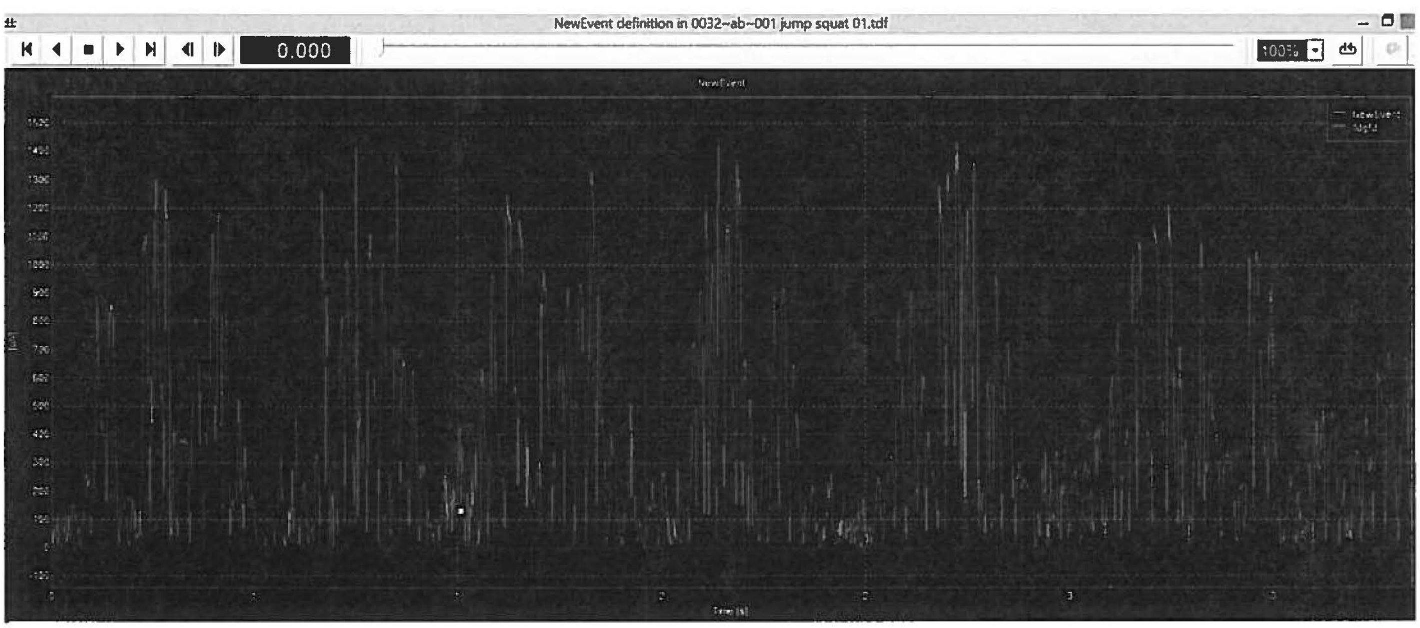

Figure 2. Jump Squat EMG Recoding for Biceps Femoris (measured in microvolts)

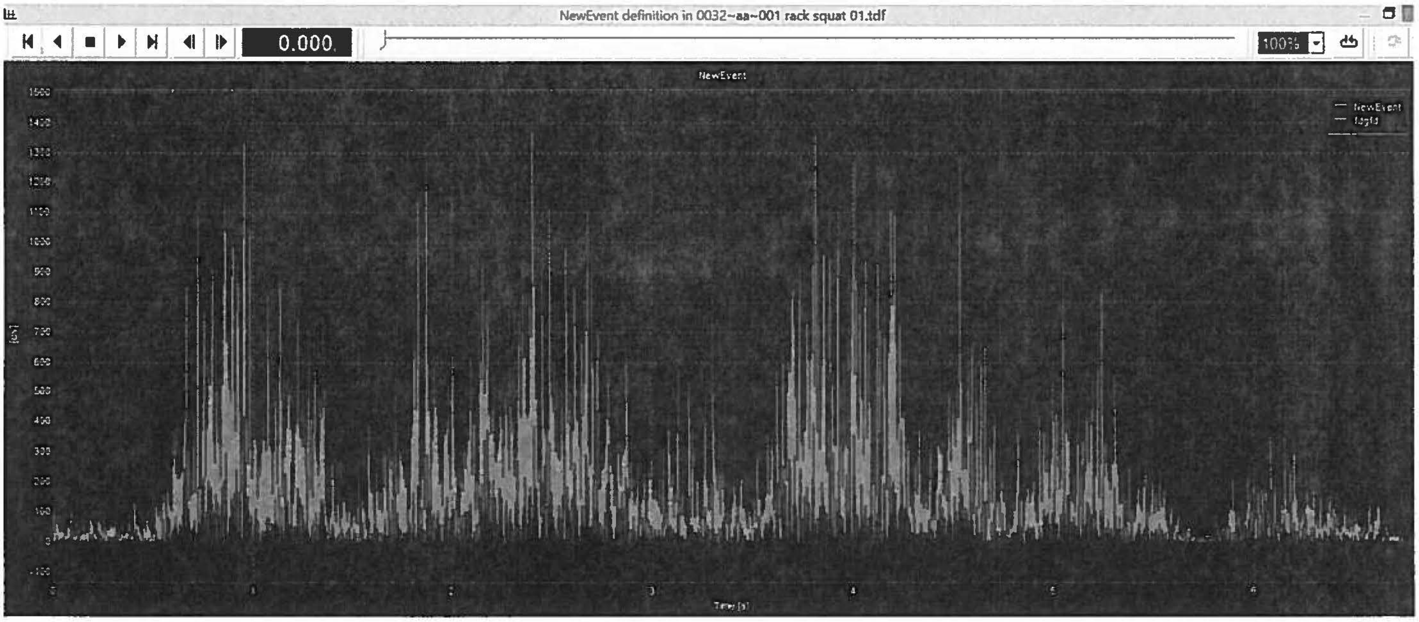

Figure 3. Rack Squat EMG Recoding for Rectus Femoris (measured in microvolts)

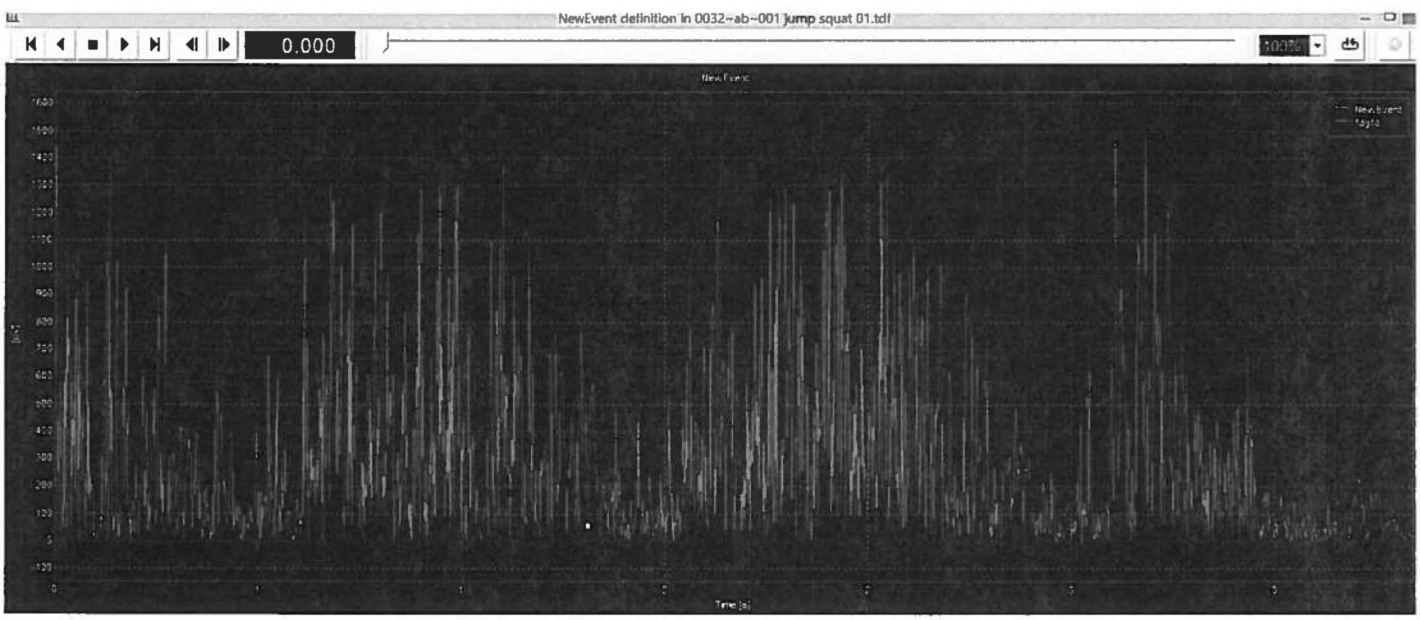

Figure 4. Jump Squat EMG Recoding for Rectus Femoris (measured in microvolts)

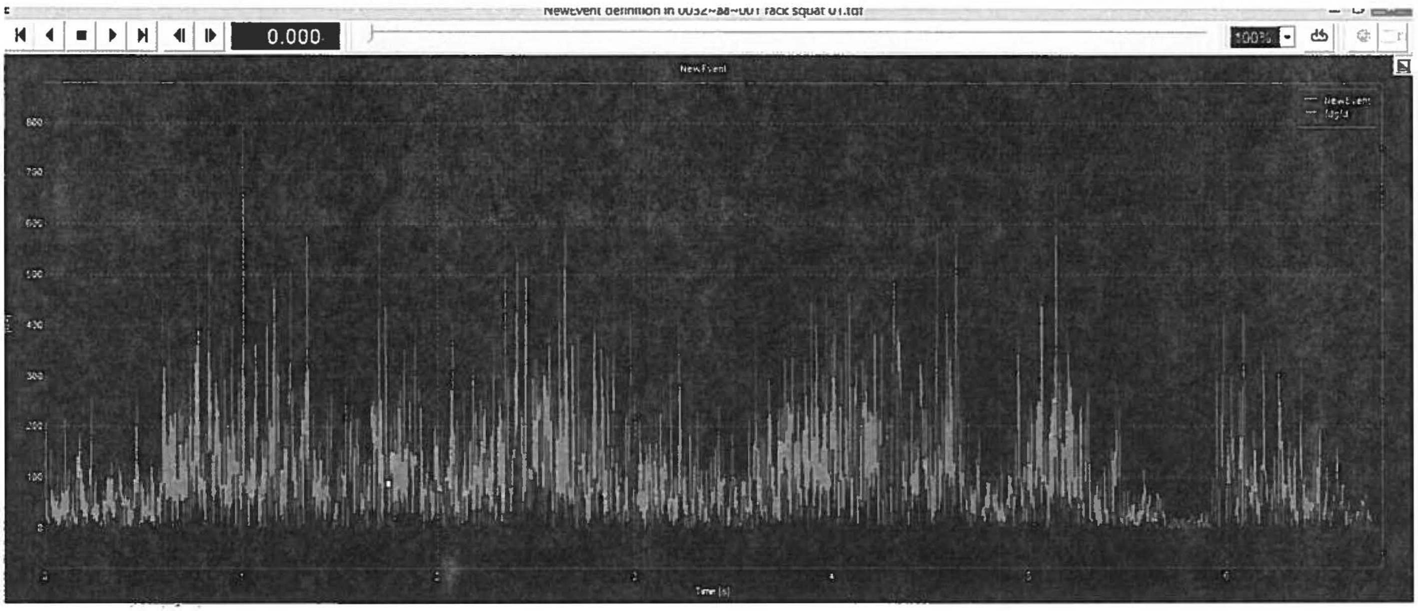

Figure 5. Rack Squat EMG Recoding for Vastus Medialis (measured in microvolts)

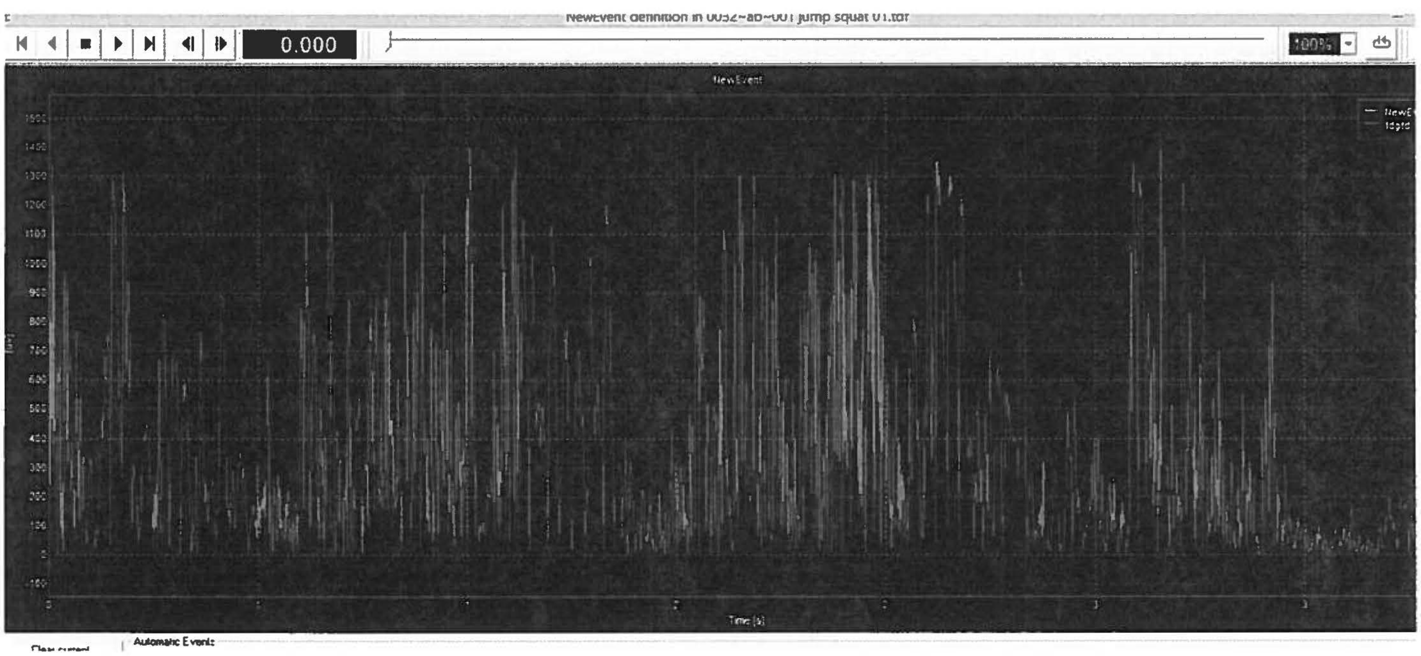

Figure 6. Jump Squat EMG Recoding for Vastus Medialis (measured in microvolts)

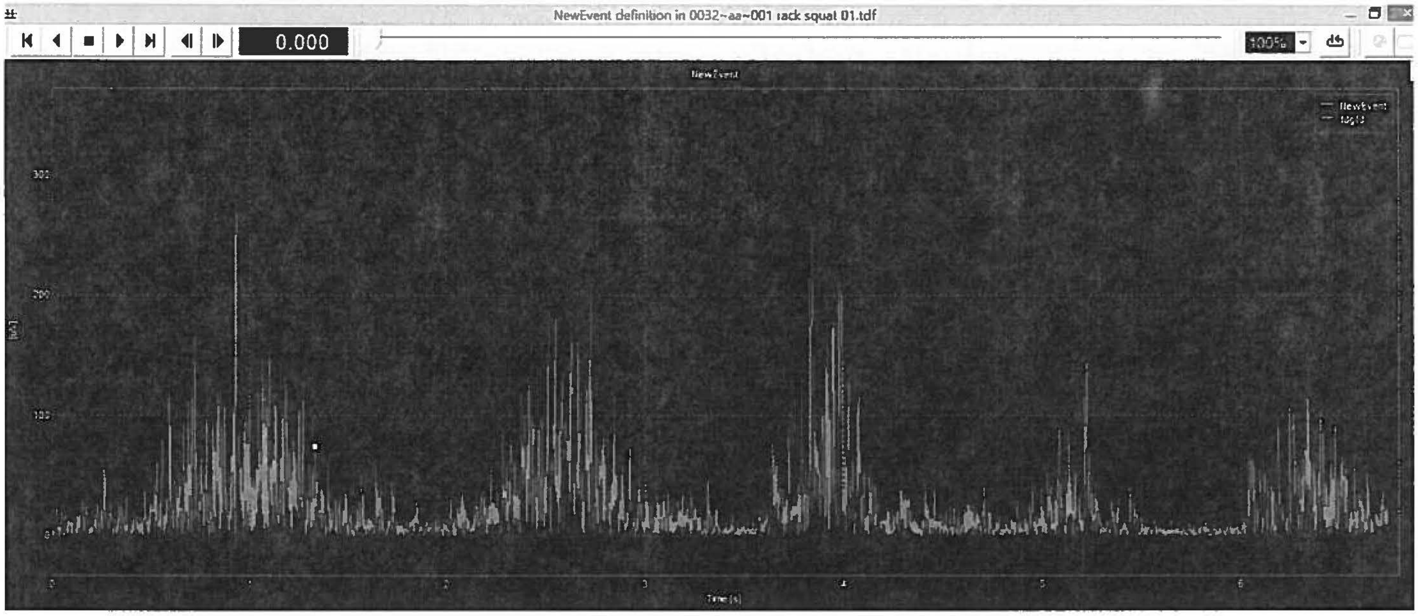

Figure 7. Rack Squat EMG Recoding for Gluteus Maximus (measured in microvolts)

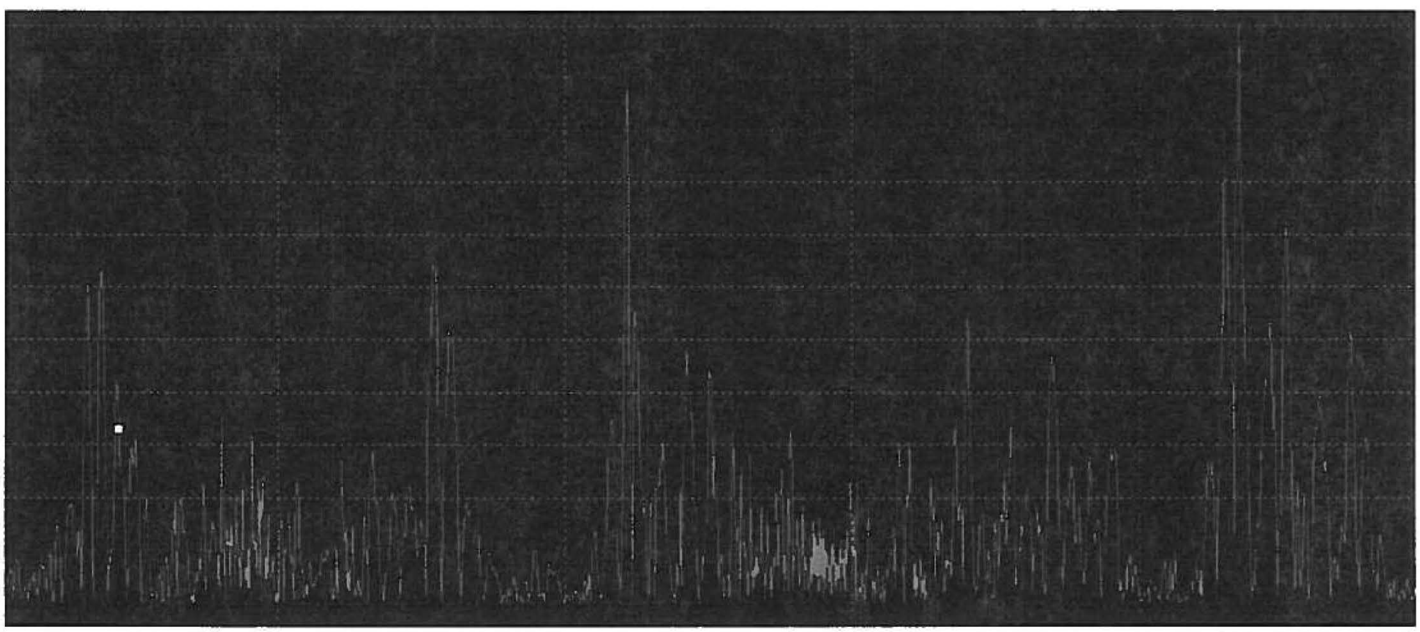

Figure 8. Jump Squat EMG Recoding for Gluteus Maximus (measured in microvolts)

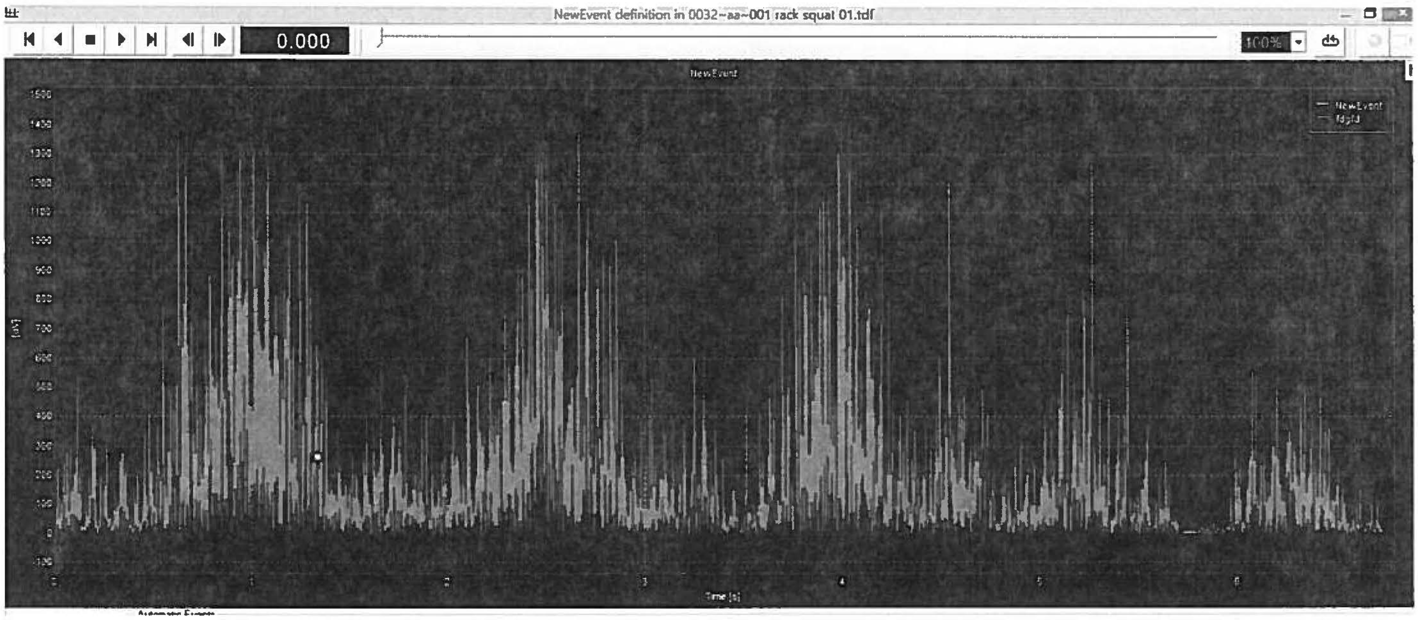

Figure 9. Rack Squat EMG Recoding for Vastus Lateralis (measured in microvolts)

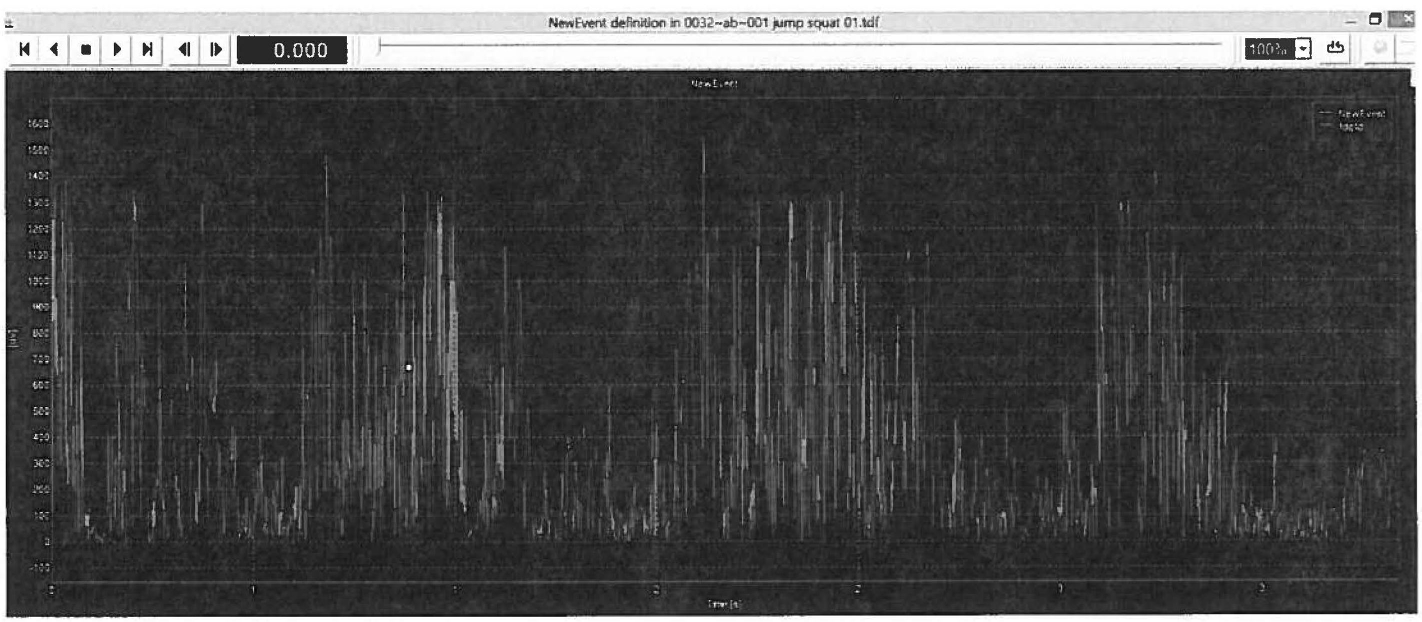

Figure 10. Jump Squat EMG Recoding for Vastus Lateralis (measured in microvolts)