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A Comparison Of Muscular Activation During The Back Squat And Deadlift to the Countermovement Jump

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A Comparison of Muscular Activation During the Back Squat and Deadlift to the Countermovement Jump

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List of Abbreviations

1-RM: 1-Repetition Maximum

CMJ: Countermovement Jump

BS: Back Squat

DL: Deadlift

EMG: Electromyography

ES: Erector Spinae

GM: Gluteus maximus

BF: Biceps Femoris

VM: Vastus Medialis

GN: Gastrocnemius

PEMG: Peak Electromyography

sEMG: Surface Electromyography

ABSTRACT

The purpose of this study was to determine whether the back squat (BS) or deadlift (DL) is most similar to the countermovement jump (CMJ) in terms of peak muscular activation. The muscles assessed in this study were the erector spinae (ES), gluteus maximus (GM), biceps femoris (BF), vastus medialis (VM), and gastrocnemius (GN). These five muscles were chosen do to their involvement in all of these exercises. Ten college-aged males (24±1.18yrs) with a minimum of 1 year strength training experience volunteered for this study. Participants must have been strength trained and could BS and DL 1.5 x bodyweight. Results showed that only the peak muscular activation of the GN was significantly different ($p<0.05$) among all muscles between the BS (3.97mV) and CMJ (8.36mV). There were no significant differences between the DL (6.20mV) and CMJ in muscular activation. However when a Pearson Product Correlation was performed, the CMJ and DL showed a weak correlation among all muscles (ES=0.27, GM=0.42, BF=0.46, VM=0.45, GN=0.24). The CMJ and BS only showed a weak correlation among the ES, BF and GN (0.44, 0.22, and 0.32 respectively) and strong correlation for the GM and VM ($r = 0.73, 0.77$, respectively). This study suggests that in terms of peak muscular activation, the DL is more similar to the CMJ than the BS since no significant differences were found in muscular activation. However, muscle activation of the VM and GM during the BS was strongly correlated to the CMJ.

Chapter 1

INTRODUCTION

The vertical jump test is commonly used to test for lower body power, and has been found to be a valuable predictor of performance. Studies have found a correlation between vertical jump height and running back draft status(19), as well as vertical jump height among starting collegiate football players versus non-starting (11). With this type of relationship, it should be understood that the higher an athlete can jump, the better chance they have to start a game, as well as be an overall better athlete.

Several studies have shown the relationship of 1-repetition maximum squat to sprint speed. However, 1-RM squat is also related to vertical jump height. It is suggested that if an athlete can increase their 1-RM squat, their vertical jump height may improve as well (26). Even though the squat is a general lower body strengthening exercise, increasing strength during the squat can improve contractile capabilities of the muscle through training (3).

As an athlete matures, strength training may help improve athletic performance. By improving squat strength, an athlete can start to improve muscular capabilities, and start to improve performance. However, other lower body lifts, such as the deadlift, may have many similar qualities as the squat. With little research comparing the effects of the squat to the deadlift, it’s not quite certain if one weightlifting exercise is more specific to improving vertical jump height than the other.

Deciding which lifts to include in a strength program requires a certain knowledge about which lifts target specific muscle groups. The purpose of this study is to determine electromyographic (EMG) activity during a countermovement jump (CMJ) of the Erector Spinae (ES), Gluteus Maximus (GM), Biceps Femoris (BF), Vastus Medialis (VM), and Gastrocnemius

(GN), and compare the results to EMG activity of the same muscles during the back squat (BS) and deadlift (DL). EMG activity will be recorded and compared to each other to determine which lift is most similar to the CMJ. Knowing which lift is most like the CMJ may help training professionals better prepare an athlete for maximal performance gains.

Statement of the Problem

While the back squat has been the primary focus of prior studies to determine a relationship between 1-repetition max (1-RM) to maximal vertical jump height (18, 26), the deadlift has not received the same amount of attention. The deadlift is recommended by many sources as a lift that can help improve not only lower body strength, but vertical jump and sprint performance as well. Even though previous studies suggest that these lifts might have similar muscle activation (23, 28), the difference in lifting mechanics may provide evidence that one lift may exhibit a more similar muscular activation pattern to the vertical jump than the other. There is limited research in determining the deadlift's actual relationship to vertical jump performance.

Hypothesis

The following hypothesis will be tested:

Specific Aim: To determine which lift, the back squat or deadlift, shows the most similar muscular activation to that of a vertical jump.

Hypothesis: Only the back squat will show the most similar muscular activation pattern to that of a countermovement jump.

Assumptions

This study will be conducted based on the following assumptions:

Assumption 1: All subjects understand and adhere to the exercise restrictions of the study.

Assumption 2: Subjects perform the 1-RM tests, and countermovement jump with maximal effort.

Assumption 3: Randomization of whether the back squat or deadlift is performed first, after the counter movement jump, will control for any variation in muscular activation patterns that may take place over the course of the trials.

Limitations

The following limitations are present within the current study:

Limitation 1: EMG recordings will be measured using surface electrodes rather than needle EMG that requires a more invasive procedure.

Limitation 2: Assumption that these strength trained subjects will limit their training during the course of this study.

Definitions

Back-squat – A common strength training exercise that focuses on lower body strength in the thighs, gluteals, and hips. The lift starts with a weighted bar across the shoulders and upper trapezius, the individual then flexes at the hips, knees and ankles, lowering the body to a desired depth (half-squat, parallel squat, full squat), and then extends the ankles, knees and hips in order to return to the initial erect starting position.

Deadlift – A common strength training exercise that focuses on lower body strength similar to the back squat in the hips, gluteals, and thighs. The lift starts with the individual down in a squatting position with the bar in front of the feet. Arms are placed straight down with an alternated or pronated grip on the bar. The individual then extends at the hip, knee and ankle maintaining an erect posture the entire time until full extension. The individual then, under control, flexes the hips, knees and ankles returning the bar back to the initial starting position.

Vertical Jump – A commonly used performance evaluation test that requires the individual to jump as high as they can by performing a quick eccentric and concentric contraction of the hips, knees and ankles. The vertical jump tests for lower body power.

Electromyography - Electromyography (EMG) is an electrical recording of muscle activity

Biceps femoris – Commonly referred to as the “hamstrings”. It consists of two muscles, the long head and short head. It is located on the posterior part of the upper leg and its primary action is knee flexion.

Rectus femoris – One of the four quadriceps muscles, located on the anterior part of the thigh. Aids in knee flexion

Vastus medialis – One of the four quadriceps muscles, located on the anterior part of the thigh closer to the midline of the body.Aids in knee flexion.

Vastus lateralis – One of the four quadriceps muscles, located on the anterior part of the thigh closer to the lateral side of the body. Aids in knee flexion

Gastrocnemius – Located on the posterior part of the lower leg. The gastrocnemius is the most superficial calf muscle. Aids in leg flexion and ankle plantar flexion

Gluteus maximus – Located on the posterior side of the upper thigh, commonly referred to as the buttocks. Its primary function is hip extension.

Erector Spinae – Also known as the sacrospinal muscle, it is a superficial muscle located on either side of the vertebral column. Its primary function is flexion and extension of the vertebral column.

Chapter 2

REVIEW OF LITERATURE

This chapter will be broken down into different sections discussing the purpose and use of EMG, the effectiveness of the back squat, deadlift, and exercise selection for vertical jump performance, as well as the lack of comparison between the two lifting styles on the performance variable.

INTRODUCTION

The back squat and deadlift are key components of well-designed strength training programs (8, 9, 16, 17). Both lifts are recognized to increase lower body strength in preparation of lower body power exercises such as a short sprint or vertical jump (18, 27). Both exercises have been shown to improve both hip and thigh strength in order to increase sprint performance (15, 23, 28). Through biomechanical analysis, studies have broken down muscular activation by analyzing electromyographic (EMG) activity of certain muscles. Doing so can help researchers see the effects of each lift on producing strength in certain muscles. Even though these analyses have been done on each specific lift and vertical jump, no comparisons have been done to see which lift has more similar EMG activity to the vertical jump.

ELECTROMYOGRAPHY

Electromyography (EMG) has been around for several decades, and has been a useful instrument for studying muscular function (24). EMG can be used to study not only gross muscular function with surface electrodes, but also deep within muscles using needle electrodes. Even though there are more limitations with surface electrodes, needle electrodes are more invasive and not always necessary. Surface electrodes are widely used for their ease of application and minimal discomfort levels to subjects, and are best used to study gross function of muscles. Surface electrodes are generally placed near the center of the muscle, and parallel to the muscle fibers. Placing electrodes in this position allows researchers to maximize the available signal from the muscle (24).

By studying gross function of muscles, motor patterns can be studied and researchers are able to see how much muscles are firing throughout a given movement. This type of research leads to a better understanding of motor unit recruitment and synchronization of muscles (24).

Studies have been performed by many researchers to look at EMG activity of different muscles during certain weight training exercises, and the different variations of those exercises. One such study by Escamilla et al. looked at the difference of EMG activity during a sumo and conventional style deadlift, both with and without a weight lifting belt. Surface electrodes were used to determine muscular activation (8). More of this study will be discussed later.

Ebben et al. also performed a study using EMG to determine activation of thigh musculature during different types of resistance training. The biceps femoris, rectus femoris and vastus lateralis were looked at during a leg extension, squat, deadlift, lunge and step up exercises. Twenty subjects, either athletes or recreationally active college students were used for this study. Surface electrodes were used to determine muscular activation. Researchers concluded that there was significant difference in muscular activation between exercises (7). It was found that the deadlift resulted in the greatest Biceps Femoris activation, the leg extension resulted in the greatest Rectus Femoris activation, and the step up resulted in the greatest Vastus Lateralis activation.

These results express the importance of understanding basic muscular activation during multiple exercises. If a particular muscle group needs to be targeted, but exercises prescribed by a professional are not targeting the muscles as much as it should, the program should be revised in order to give the athlete or individual the best chance in reaching their goals and reduce the chance of injury (7). Also, by knowing the magnitude of muscular activation, the amount of volume a given muscle receives during training can be carefully calculated and compared to other agonist or antagonist muscles to make sure muscle imbalances are not being created.

EMG studies allow professionals to understand not only the activation patterns of muscles, but also the magnitude in which a given muscle contracts. By knowing activation patterns and magnitude of activation, professionals can better prescribe exercises that will help clients reach their goals more effectively. By giving the client the best chance possible to achieve their goals, further training can then progress to make even better gains in fitness, lifestyle or performance.

BACK SQUAT AND PERFORMANCE

The back squat is commonly used in weight training routines to aid athletes in producing lower body strength (15, 17, 26). The incorporation of the back squat has become popular over the years as coaches realize the benefits it brings to improving performance (16, 17, 26, 27). Studies have found results that suggest back squat performance as an indicator of athletic performance (18, 26).

Wisloff et al. (26) performed a study examining the correlation between maximal squat strength with sprint and vertical jump performance in elite soccer players. What researchers found was that among the 17 elite international male soccer players that were tested was that maximal strength in half squats correlated strongly to sprint and vertical jump performance.

On the first day of testing, vertical jump was tested using a force plate. This was done three times with one minute rest in between trials. The best jump from each subject was recorded and used in data analysis. Half squats were also tested on the first day and each subject's 1RM was recorded. On the second day of testing, which was three days later, subjects then performed a 30 meter sprint and a 10 meter shuttle run. Results showed a strong relationship between squat strength and sprint and vertical jump performance. These results coincide with the findings of McBride et al. (17).

While McBride et al. (17), and Wisloff et al. (26) studied the squat at 70° and 90° flexion respectively, Caterisano et al. (6) studied the effect of squat depth on EMG activity of the hip and thigh musculature. EMG activity during three different depths, partial (approx. 2.36 rad at the knee joint), parallel (approx. 1.57 rad at the knee joint), and full-depth (approx. 0.79 rad at the knee joint), were studied. EMG activity was recorded of the Biceps femoris, gluteus maximus, vastusmedialis and vastus lateralis. These muscles were chosen by researchers because of their recorded involvement in previous studies (6).

Caterisano et al. found that as squat depth got deeper, the gluteus maximus becomes more active during the concentric contraction phase of the lift. Muscular contribution shifts from the biceps femoris, vastus medialis and lateralis to the gluteus maximus. This suggests that the gluteus maximus is the prime mover during the concentric phase of the squat, and the other muscles play a secondary role.

The results from these studies suggest that the back squat should be included in strength training programs that aim to increase lower body strength. The more an individual can squat as a ratio to their body weight, the better results they will show in performance tests, such as a sprint or vertical jump. Proper instruction and technique are required in order to achieve maximal results (6).

ANALYSIS OF VARIOUS DEADLIFT STYLES

The deadlift requires whole body strength in order to properly execute the lift (8). Escamilla et al. describes proper form as “The starting position requires the athlete to start in a squat position, arms straight and pointing down with an alternate or pronated grip on the bar which is placed in front of the lifters feet. The barbell is lifted upward until a completely erect posture is obtained with knees locked.” This lift requires strength throughout the body, but primarily in the back, abdominals, thighs and lower limbs. Many athletes that participate in strength sports, such as football, use the deadlift as part of their training regimens (8).

There are two different types of deadlift techniques, the sumo deadlift and the conventional deadlift (8, 9). The sumo deadlift requires lifters to have a wider stance with their feet pointing outward near a 45° angle and grip the bar in between their legs. The conventional deadlift requires a narrower stance than the sumo style, and the grip of the bar is on the outside of the legs (8). Both styles follow the same lifting technique for the concentric movements even though their starting position is different. McGuigan et al. (20) found that the sumo style deadlift places less shear forces on the L4/L5 portion of the vertebral column since the starting position of the back is more vertical than during the conventional deadlift. With fewer shear forces, researchers believe that this poses a safety advantage for general weight training. The bar was also able to be kept closer to the subject’s body which also reduced strain on the lower back (20).

Escamilla et al. (9) performed a biomechanical analysis of both the sumo and conventional style deadlifts. Researchers analyzed video of 24 lifters during a national power lifting competition. Twelve competitors performed the sumo style and 12 performed the conventional style deadlift. Total work was calculated and it was found that those competitors performing the sumo style deadlift did 25-30% less work because the center of mass was lower, and the total distance traveled was lower since their stance was so wide. Energy expenditure for the conventional style deadlift is predicted to be 25-40% more than what is predicted of the sumo style deadlift.

Researchers also concluded that the major lower extremity muscle groups involved during the sumo style deadlift include the gluteus maximus, hamstrings, quadriceps, and tibialis anterior. The conventional style deadlift requires the hamstrings, gluteus maximus, gastrocnemius, and soleus involvement to perform the lift properly. Shear forces on the L4/L5 segment of the vertebral column were also discussed within this study. It was proposed that even though the sumo style deadlift may reduce the forces on the lower back, performing the conventional style deadlift may be effective in strengthening the back (8).

Escamilla et al. (9) performed another study looking at EMG activity during both the sumo and conventional style deadlift techniques. Subjects included 13 Division 1-A collegiate football players. All subjects were familiar with these style lifts and had previously performed them in their training. EMG was used to measure muscle activity. Electrodes were placed on the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus/semimembranosus, lateral gastrocnemius, medial gastrocnemius, tibialis anterior, hip adductor longus, adductor magnus, and gracilis, gluteus maximus, L3 paraspinals, T12 paraspinals, middle trapezius, upper trappezius, rectus abdominus, and external obliques (9).

What researchers found was that the sumo deadlift recruited more muscular activation of the vastus medialis and lateralis, as well as the tibialis anterior. The conventional deadlift recruited more activity of the medial gastrocnemius, and the use of the belt recruited more rectus abdominis activity and less external oblique activity. What Escamilla et al. concluded from this study is that both lifts have their place within a training program, however depending on what an individual's focus is during training or rehabilitation will determine which lift they employ in their training (8).

PROPER EXERCISE SELECTION

These findings suggest that proper exercise selection is necessary to target specific muscles and muscle groups that will help individuals design their strength training programs in a more effective manner. With proper exercise selection, athletes are likely to perform better in certain performance evaluation tests (12, 23, 28).

Careful consideration of an athlete's abilities and needs must take place for a program to target certain weaknesses. Power lifts are commonly used to help athletes develop power through certain movements; however, if the athlete is not adequately prepared, these lifts will only produce minimal results. Having a proper introduction to strength training and given lifts that best suit the needs of the athlete will better prepare the athlete for more complex power lifts.

Harris et al. (15) looked at the effects of different methods of resistance training on athletic performance. High power, high force, and combined weight training were looked at during this study. Forty-one subjects were included in this study. Thirteen (n=13) were in the high force group, 16 were included in the high power group, and 13 were included in the combination group. The high force group trained at 80-85% of their 1RM and the high power group trained at 30% of their peak isometric force. The combination group used a mix of these two types of training. Variables that were tested include the 1RM parallel squat, 1RM ¼ squat, 1RM mid-thigh pull, vertical jump, vertical jump power, Margaria-Kalamen power test, 30-m sprint, 10-yd shuttle run, and standing long jump. What Harris et al. found was that the combination group improved in more test variables than the high power, which improved in 5, and the high force, which improved in four (15).

What this suggests, is that even though the high force, or strength, group improved on the fewest amount of variables, strength development and neural adaptations during this 4-week study still produced favorable, significant, results. As athletes are introduced to strength training, and even those who have been a part of it for years, basic strength training can provide hypertrophic and neural adaptations that may improve performance. However, the more trained an individual is, these adaptations become less noticeable. Early emphasis on strength development and transitioning into more specific exercises may produce better results (15).

LACK OF COMPARISON

Concluding from past research, the back squat is one lift that may be needed to develop lower body strength as well as sprint speed (12, 15-17, 26, 28). The more an athlete can squat in relation to their body mass, the faster they will be (17). However, minimal research has been done specifically on the deadlift and its effect on vertical jump performance. Biomechanical analysis has been done on both the sumo and conventional style deadlifts, but no performance studies have been published. Few articles mention briefly that the deadlift may be beneficial to sprint performance, but these articles suggest this finding through interpretation and not actual results.

With the lack of actual comparison of the back squat and deadlift, it cannot be said for certain which lift may be better at developing strength for the vertical jump. Past studies have shown that both exercises should be included in a proper strength training program and that each has their own benefits (15, 23, 28). While some benefits may be reserved for each lift, they also seem to have many benefits that overlap. Quadriceps, hamstrings and gluteal muscles are all developed in each lift (12, 23, 28). However, at certain depths or stances, the manipulation of muscle activation can change the effectiveness of each lift (6).

CONCLUSION

As athletes mature, strength development needs to continue in order for maximal performances to be reached. Proper inclusion of strength training exercises that mimic specific movements and target specific muscles is the job of the coach or strength and conditioning professional (12, 23, 28). By proper selection of strength training exercises, hypertrophy and neural adaptations will take place and performance may be enhanced (23, 28).

The vertical jump requires athletes to have sufficient lower body strength in order to perform the movements efficiently and effectively. If strength is compromised or the ratio of strength to body mass is too low, performance may be affected.

With a proper comparison of EMG activity during a vertical jump, it may be concluded as to which lift, the back squat or the deadlift would be more effective after comparison of EMG activities of all three tests. With this comparison of EMG activity, better selection of strength training exercises can be made and athletes may improve even more.

Chapter 3

INTRODUCTION

Determining which exercises to use within a strength training program can have a substantial impact on athletic performance. An understanding of which exercises recruit certain musculature is necessary for strength and conditioning coaches, personal trainers and other sport performance professionals in order to train clients or athletes in the most effective way possible to reach their goals or training needs. Many studies have looked at muscular activation during the back squat (BS) strength and vertical jump height as well as back squat strength and sprint speed (15-17, 26). However, it has also been reported that the deadlift (DL) may be a valuable exercise to improve sprint speed as it involves many of the same musculature as the back squat (23, 28). Even though previous research by McBride et al. (17) and Wisloff et al. (26)have shown that the back squat 1-repetition maximum (1-RM) is a useful predictor of vertical jump height and sprint speed, there have be no previous investigations correlatingthe deadlift 1-RM to vertical jump height and/or sprint speed.

Muscular activation during the back squat and deadlift may vary since the barbell starts in different positions. The back squat, for example, requires the lifter to start the exercise holding the weight on their upper trapezius and control the weighteccentrically, where the deadlift requires the lifter to initiate movementfrom the ground. The difference in where the barbell starts and the starting position of the subject may affect selectedmuscleactivation. With no studies done on the comparison of muscular activation between the back squat and deadlift, there is agap in the literature on which exercise is better suited for achieving certain training adaptations, such as jump performance.

Young &Pryor (28) reported that the deadlift may be useful in improving 10m sprint times, due to the similarity of overcoming inertia at the start of the sprint. Under this rationale, it's plausible that the deadlift may actually be just as useful as the back squat at improving vertical jump height or sprint speed. A previous study by Wisloff et al. (26) looked at the relationship between maximal squat strength to sprint times and vertical jump height in elite soccer athletes. Wisloffet al.found that the greater the back squat strength, the faster an athlete could run and higher they could jump. It was reported that the strong correlation of both the vertical jump and 10m sprint times to 1-RM squat (r=0.78 and 0.94, respectively) were due to high needs of maximal lower body strength (26). It was suggested by researchers that these elite soccer players should focus on maximal strength training to improve sprint and jump performance. Maximal strength training, however, may also be a useful training tool among many other sports as well.

Coaches, trainers and other sport performance professionals may all benefit from incorporating maximal strength training in their programs. However, knowing which exercises produce the best results in vertical jump height is of great importance. Targeting and activating specific musculature, such as the erector spinae, gluteus maximus, biceps femoris, vastus medialis and gastrocnemius may all help improve sprint and jump performances (23, 25, 28), but knowing which exercises can activate these muscles the most, and result in the greatest strength gain, will help their athletes achieve greater performance gains (23).

While maximal back squat strength has been determined to be a valid predictor of jump performance (26), the deadlift has not received the same amount of attention even though it may work the posterior chain composed of the erector spinae, gluteus maximus, biceps femoris and gastrocnemius, in a similar way as the back squat. Measuring muscular activation during the deadlift may help determine whether this exercise could a useful training tool for football, basketball, and volleyball athletes that require lower body strength in order to improve their vertical jump performance.

Electromyography (EMG) has been used in many studies before to determine muscular activation levels among different strength training exercises (6, 7,8, 10, 14, 21, 24, 27). Escamilla et al. (8) have performed studies looking at muscular activation during different deadlift techniques using surface EMG (sEMG). The conventional deadlift was compared to the sumo deadlift to determine which techniquerecruits musculature more in the lower body and lower back. Surface EMG electrodeswere used to collect data, and proved to be a useful form of measurement. Caterisano et al. (6) also used surface electrodes to investigatethe muscular activity of the vastus medialis, vastus lateralis, biceps femoris and gluteus maximus in different back squat depths. The use of sEMG electrodes allowed researchers to determine that as the back squat depth increases, the greater the gluteus maximus is activated during the concentric phase (6). With previous studies using sEMG as a viable option to collect data in place of a more invasive fine-wire EMG, this present study utilized sEMG as the primary data collection tool.

The purpose of this study was to determine whether muscle activation patterns of the erector spinae, gluteus maximus, biceps femoris, vastus medialis and gastrocnemius during the back squat or deadlift were most similar to a common measure of human performance, the countermovement jump (CMJ). Surface EMG analysis was used to determine muscular activation for the selected muscles activated during the three exercises. It is hypothesized that the back squat would providemore similar peak muscular activations to the countermovement jump than the deadlift in the muscles selected. This hypothesis is based upon the similarity of movement patterns between the BS and CMJ.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

This study was designed to assess the differences in peak muscle activation between the CMJ and the BS and DL.The muscles assessed during this study were the Erector spinae (ES), Gluteus maximus (GM), Biceps femoris (BF), Vastus medialis (VM), and Gastrocnemius (GN). These muscles were chosen due to their involvement in all three exercisesas reported previously (6, 8, 9). Additionally, it is believed that these muscles play an important role in athletic performance (28).

This study required participation during three separate sessions. The first day was a familiarization day, the second, a strength testing day, and the third, an experimental day (Figure 1). Each session was attempted to be held at roughly the same time of day to limit fatigue or any outside factors.Each day is separated by 72 hours to allow for recovery from the previous session (4, 5).

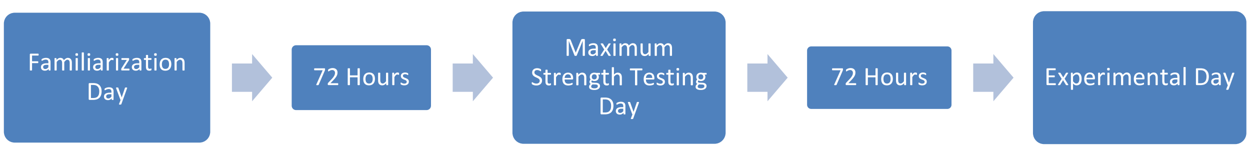


Figure 1: Time-line of events. Three days of meeting (Familiarization Day, Strength Testing Day, Experimental Day). Each day is separated by 72 hours to allow for recovery from the previous session.

SUBJECTS

Tencollege aged males(Table 1) were recruited for this study. Subjects had at least one year of strength training experiencewith both the back squat and deadlift, and were required to be able to lift 1.5 times their bodyweight to be considered strength trained.Subjects also signedan informed consent form approved by the Institutional Review Board (IRB) at Sacred Heart University.

Table 1: Subject Data

Subject Data	
Age (years)	24 ±1.18
Height (m)	1.77 ±0.05
Weight (kg)	82.19 ±10.21
1RM BS (kg)	140±37.05
1RM DL (kg)	143 ±32.28

PROCEDURES

FAMILIARIZATION DAY

Following the review of the study, and signing of the consent forms, a review of eachtechnique in all three exercises took place. Subjects performed up to 3 sets of 6-10 repetitions of both the BS and DL to ensure subjects understood proper technique. Up to 5 repetitions of the CMJ were performed as well. A Certified Strength and Conditioning Specialist (CSCS) provided technical feedback and presented what was expected of the subjects during testing. Proper mechanics of the countermovement jump, back squat and deadlift were based upon the National Strength and Conditioning Association (NSCA) guidelines (2) to limit the influence of differing techniques on EMG activity.Depth of the back squat was be determined by NSCA guidelines and was considered as the femur parallel to the ground.Proper workout clothing, shorts, t-shirt and running or cross training shoes were required for all subjects. Weightlifting belts were not used during this testing.

MAXIMUM STRENGTH TESTING DAY

Seventy-two hours after the familiarization day, subjects attendedthe maximal strength testing day at Sacred Heart University's Pitt Center. On the strength testing day, the subject's1-

RM in both the back squat and deadlift wereachieved. Subjects performed a dynamic warm up prior to 1-RM testing (Table 2).The 1-RM protocol followed that of McBride et al. (17) wherein subjects performed multiple repetitions at 30% (8-10 repetitions), 50% (4-6 repetitions), 70% (2-4 repetitions), and 90% (1 repetition) of estimated 1-RM. After the warm-upsetswere performed, subjects had up to 4 attempts to reach their 1-RM. Three minutes were given between sets to allow for full recovery. Subjects had 15 minutes between testing the back squat and deadlift with the back squat being performed first.

Table 2: Dynamic Warm-up Exercises

Warm-up Exercises (10yds down and back)
3-minute jog on Treadmill @ 6mph
Walking Lunge
Zombie Kicks
Knee Hugs
Inch Worms
High Knees
Butt Kicks
Side Lunges

EXPERIMENTAL DAY

Seventy two hours following the maximum strength testing day, muscle activity was assessed during the participants' performance of the CMJ, BS and DLat the Sacred Heart University Motion Analysis Lab. Before the muscular activation trials, subjects performed the same warm-up routine (Table 2) as performed during 1-RM testing. The EMG electrodes (20mm rectangular shaped bipolar electrodes) were then placed on the participants and connected to the Therapeutics Unlimited 8-Channel EMG 544 (Therapeutics Unlimited, Inc. Iowa City, IA). EMG settings were constant among all subjects with a gain of 20K, and root mean square (RMS) of 11.75 milliseconds. A ten minute interval between the warm-up and EMG recording was given. During this time, electrodes and electrode sites were prepped and placed on the subjects.

Subjects wererequired to either shave their legs prior to testing, or opt for the electrode sites to be shaved in the lab for them. The electrode sites were cleaned with alcohol swabs to ensure a clean surface for electrodes. Electrodes were placed on the cleaned sites with a double sided adhesive washer, athletic tape and pre-wrap. Once the electrodes were placed on the skin, athletic tape was used to keep it in place, pre-wrap was used to provide more consistent contact, and a single piece of athletic tape was used to keep the pre-wrap from unraveling (Pictures 1-7). Electrodes were placed on the Erector Spinae (ES), Gluteus Maximus (GM), Biceps Femoris (BF), Vastus Medialis (VM), and Gastrocnemius (GN). Electrodes were placed on these muscles according to sites detailed by www.seniam.org (Table 3).Signa Crème Electrode Cream (Parker, Fairfield, NJ) was placed on the electrodes to improve conductivity.

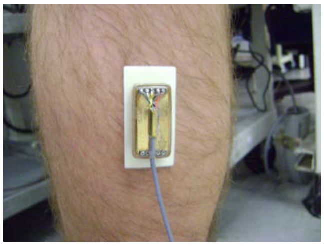
Table 3: Guide to sEMG electrode placement on subjects from www.seniam.org

Muscle	Electrode Location	Electrode Orientation
ES	Electrodes need to be placed on and aligned with a line from caudal tip posterior spinailiaca superior to the interspace between L1 and L2 interspace at the level of L5 spinous process (i.e. about 2 - 3 cm from the midline).	In the direction of the line described
GM	The electrodes need to be placed at 50% on the line between the sacral vertebrae and the greater trochanter. This position corresponds with the greatest prominence of the middle of the buttocks well above the visible bulge of the greater trochanter.	In the direction of the line from the posterior superior iliac spine to the middle of the posterior aspect of the thigh
BF	The electrodes need to be placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia.	In the direction of the line between the ischial tuberosity and the lateral epicondyle of the tibia.
VM	Electrodes need to be placed at 80% on the line between the anterior spinailiaca superior and the joint space in front of the anterior border of the medial ligament.	Almost perpendicular to the line between the anterior spinailiaca superior and the joint space in front of the anterior border of the medial ligament.
GN	Electrodes need to be placed on the most prominent bulge of the muscle.	In the direction of the leg

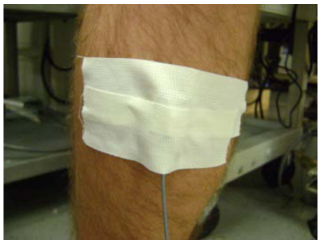
Picture 1:sEMG electrode

Picture 2: Electrode with double sided adhesive sticker

Picture 3: Back side of electrode

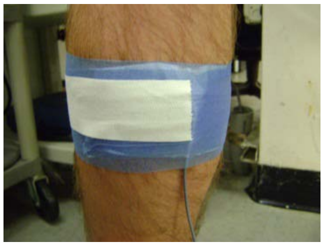


Picture 4: Electrode attached to prepped site (GN)



Picture 5: Athletic tape over electrode

Picture 6: Pre-wrap over tape and electrode for extra adherence



Picture 7: Athletic tape to hold pre-wrap in place

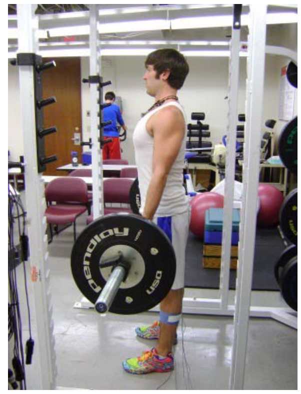
Once electrodes were placed on and secured to the body, subjects then performeda warm-up set of 3-5 repetitions prior to testing each exercise. After the CMJ warm-up set, three repetitions of theCMJ were performed to collect data. Subjects were not allowed to use their arms to aid there movement and were required to keep their hands on their hips the entire time (Picture 8-9). After the CMJ, the subjects were allowed a warm-up set for the back squat, given three minutes for recovery, and then performed three repetitions of the back squat (Picture 10-

11). The back squat was followed by a warm-up set for the deadlift, followed by three minutes of recovery, and then three repetitions of the deadlift (Picture 12-13). The A load of 85% of subjects 1-RM was used for both the BS and DL three repetition trials. This 85% load was chosen to mimic what would be used in a typical strength training routine in order to improve strength (22).A rest period of 3 minutes was given to the subjects between exercises to allow for full recovery (1).


Picture 8: Start/End for the CMJ**Picture 9:**CMJ


Picture 10: Start/End for the BS **Picture 11:**Proper depth for the BS

Picture 12: Start/End position for DL



Picture 13: Fully erect DL

The countermovement jumpwas always performed first, while the order of the back squat and deadlift was determined by an integer originator. A metronome was used to set the cadence for the back squat and deadlift. The back squat followed a 3/1/x cadence, a 3 second eccentric contraction downward, a 1 second isometric hold at the bottom of the lift (when the thigh is parallel to the ground), and a fast, explosive concentric contraction back to the starting position. The deadlift followed an x/1/3 cadence, a fast, explosive concentric contraction upward, a 1 second pause in the fully erect position, and a 3 second eccentric contraction downward to the starting position. Subjects were required to set the barbell back on the ground to stop movement before completing another repetition.

STATISTICAL ANALYSIS

After EMG data of each muscle was collected using LabView software, at a 1000Hz sampling frequency, peak EMG (PEMG) was determined by using Microsoft Excel 2010. For each muscle, of each three repetition trial, the “Maximum” function was used within Microsoft Excel to find the three greatest peaks (one for each repetition of the CMJ, BS and DL). The threePEMG values of each muscle were averaged together to create one mean peak EMG (MPEMG) value for each separate exercise for every subject (10 APEMG values for the ES, GM, BF, VM and GN). Using PASW Statistics 18 software (SPSS Inc., Chicago, IL), five one way repeatedmeasures ANOVAs (one for each muscle group) were used to analyze MPEMG between exercises for each muscle analyzed. Any significant omnibus tests were analyzed using post hoc paired t-tests with a Bonferroni corrected alpha level set at 0.01.

A Pearson product correlation was also calculated using Microsoft Excel 2010 to determine whether or not there was any type of relationship among individual muscles between the CMJ and BS, as well as the CMJ and DL.

RESULTS

PEMG activity during the CMJ, BS and DL among the five muscles analyzed is shown in Figure 2.A significant difference was only found between the CMJ and BS with the CMJ resulting in significantly greater GN activity($p<0.001$). The GN was the only muscle group that achieved the desired power and effect size (0.93, and 0.60 respectively) as well.

Weak correlations were observed between PEMG values of the selected muscles analyzed (ES, GM, BF, VM and GN) during the CMJ and DL. The comparison of CMJ to BS reported that the ES, BF and GN showed weak correlation, but the GM and VM showed a strong correlation (Table 4).

Table 4: Pearson Product Moment Correlation

	CMJ vs BS	**CMJ vs DL**
ES	0.44	0.27
GM	0.73	0.42
BF	0.22	0.46
VM	0.77	0.45
GN	0.39	0.24

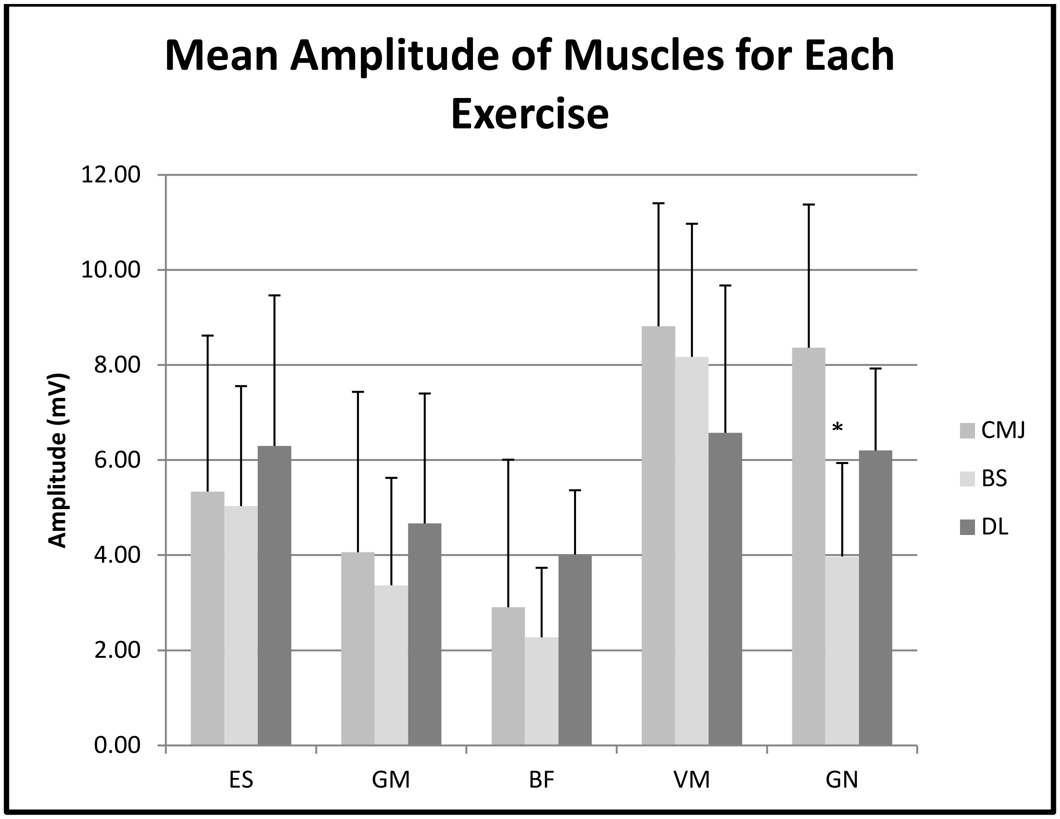


Figure 2: Peak EMG Bars represent the mean PEMG values for the Erector Spinae (ES), Gluteus Maximus (GM), Biceps Femoris (BF), Vastus Medialus (VM), and Gastrocnemius (GN) during the CMJ, BS and DL. *p<0.05, significantly different from CMJ

DISCUSSION

The results of this study suggest that the DL may be more similar to the CMJ than the BS in terms of muscle activation. Similarity can be determined by the lack of significant differences between the DL and CMJ among all muscles analyzed.Results showed that the GN was significantly different between the CMJ and BS.While the results suggest a difference in activation of the GN, there is no statistical difference among any of the other muscles tested (ES, GM, BF, VM). The data does not support our hypothesis that the back squat would have the most similar peak muscular activation to the countermovementthan the deadlift. However, when calculating the Pearson product correlation, the BS had two strong correlations of the GM and VM while all the muscles for the DL were considered a weak correlation.

When reviewing the data and trying to figure out why the GN was activated more during the DL than BS, a possible explanation could be where the starting position of the barbell is in relationship to the body. During the BS, the barbell is loaded on the subject's posterior side. With proper form, heels are kept firmly on the ground, and unless balance is an issue, the GN may not need to be highly activated to aid in the lift. The DL, however, starts with the barbell on the anterior side of the body on the ground. With the weight placed anterior to the body, subjects may have been more likely to initiate the lift by pushing through the forefoot before shifting the weight through their entire foot. This slight moment of imbalance and shifting weight may cause the GN to be activated greater in the DL than BS.

The explanation of where the load is placed and how it affects the use of the GN is supported by the findings of Escamilla et al. who state that during the conventional deadlift, GN activity is high when knee angles are low, and GN activity is lower when knee angles are high (8). Meaning, that when the knee is in a greater flexed position (the starting stance for the DL), GN activity will be higher than when the subject's body is close to being erect. Even though subjects are decreasing their knee angles while squatting, the depth may not be the same as the DL and the load of the bar is placed on the posterior side of their body. The GN may become activated to maintain proper balance by plantar flexion in the DL, and produce force in order to lift the weight. However, experienced lifters may not need the concentric contraction of the GN to complete the lift, but rather the activation recorded may be more of the eccentric stretch the GN experiences.

With the DL requiring greater knee and ankle flexion, the GN would be in a position of greater stretch than during the BS. With origin of the GN being the medial and lateral condyles of the femur, and the insertion point at the Achilles to the Calcaneus, the GN is placed in a stretched position in both the BS and DL. However, the DL requires a greater degree of ankle dorsiflexion. With the ankle being dorsiflexed, the GN is stretched and may be put in a position to contract more forcefully during the DL. With experienced lifters, however, especially with the BS, may not require as much GN activation to maintain balance and the decreased activation found in this study may be a result of a lack of activation needed to complete the lift.

One last explanation as to why the GN was higher in the DL is a possible moment of instability at the top of the lift (when subjects were fully erect). The one second pause at the top of the lift, which was part of the tempo followed, could have had the subjects sway just slightly enough to require a contraction to maintain balance before the eccentric part of the lift. Since timing of max EMG data was not looked at during this study, this is only a hypothesis.

Besides decreased muscle activation in the GN during the BS, there is no difference between the BS and DL when compared to the CMJ. Thelack of significant data suggests that whether the BS or DL is implemented into a regular training program, muscular activation is similar. However, the timing of activation and the length of muscular activation may be differentfor the CMJ, BS and DL. Whether the muscles were activated during the eccentric or concentric motion, and also the length of activation may have an effect on performance benefits. These factors were not measured during this study.

Even though Hales et al (13) reported that the BS and conventional DL are significantly different in terms of hip, knee and ankle kinematics, results from this study are showing that muscular activation is remaining similar even with these different joint patterns. The CMJ, BS and DL all require lower back strength for correct posture and control of movement, strong gluteal and quadriceps and hamstring muscles to control eccentric actions as well as propel the body during the concentric phase. What seem to change the magnitude of muscular activation are the depth, load, and placement of the load in relation to the body. Varying degrees of flexion at the knee, ankle and hip may require greater activation to complete the movement. This assumption is supported by Caterisano et al. (6) and Escamilla et al. (8).

The CMJ showed to be just as similar in muscular activation to the BS and DL as the BS and DL were to each other. Results from this study are supported by previous studies (1, 26)linking maximal BS strength to vertical jump height. Promoting exercises that can target muscles in a similar way as the movements athletes may perform may lead to an increase in not only general athletic ability but also improved execution of sport skill.The additional muscular activation in the deadlift compared to the BS and CMJ in the ES, GM, and BF, though not significant, may suggest greater muscular development, however this hypothesis warrants further research.

When reviewing the Pearson Product correlations, the BS showed more strong correlation to the CMJ than the DL. The GM and VM were the only two muscles during the BS and DL to have a strong relationship to the CMJ. Even though there was no difference in muscular activation in the GM and VM during the BS and DL, the correlation analysis shows that the BS may be a valuable exercise. Therefore, a well-balanced program that utilizes both the BS and DL could be effective in improving CMJ performance. Even though the relationship of the DL and CMJ was shown to be weak among all muscles selected, this is only between muscular activation, and not 1-RM to vertical jump height. While muscular activation relationships may be weak, performance relationships may be stronger. This thought may warrant further research as well.

While the GN was found to have a high statistical power and large effect size, all other muscles failed to have both the desired power and effect size necessary to be considered relevant. The BF and VM were shown to have a moderate effect size, but a low power. If the number of subjects needed to increase both the power and effect sizes to significant levels is so large, it may suggest that the BS and DL may not be that different at all. The data may also suggest that if an individual needs to improve their GN activation, and needs to choose between the BS and DL, the DL would be a better choice.

Limitations of this study include not using a goniometer to determine proper knee angle for BS depth, not calculating the impulse of each muscle during each trial, or looking at the timing of peak muscular activation during each trial to see if the muscular activation patterns were similar rather than just the peaks.

PRACTICAL APPLICATION

The results show that the only statistical difference between the back squat and deadlift, in regards to muscle activation, is found in the GN between the BS and CMJ. As mentioned earlier, unless an athlete needs to incorporate more lifts that target the GN, incorporating the back squat or deadlift are both effective weight training exercises that may improve CMJ performance. If the GN needs to be targeted in a multi-joint lift such as the back squat or deadlift, the deadlift would be the better choice.

Coaches, trainers, and other sport performance professionals can use these results to help decide which lift may better fit their training to improve CMJ performance. With only onestatistical difference found among the muscle groups studied, the back squat or deadlift these exercises could fit into a training program interchangeably.

With multiple studies comparing 1-RM back squat to vertical jump height, more studies should be done looking at the relationship between a 1-RM deadlift to vertical jump height. Additional studies may also need to be done to determine the timing of muscular activation during these movements and how it may affect training. This study reports no statistical difference of the ES, GM, and VM between any of the exercises.

APPENDIX A:

SACRED HEART UNIVERSITY

SACRED HEARTUNIVERSITY
Institutional Review Board (IRB)

for Research Involving Human Subjects

DATE: March 1, 2011

TO: **Name** David Robbins

Address Exercise Science

Telephone 508-272-1730

FR: **Name/Title** Dr.Stephen Lilley

Address Sociology Department

Telephone 203-371-7761

RE: **Proposal** A Comparison of Muscular Activation during the Back Squat and Deadlift to the Countermovement Jump

__X The IRB has reviewed and approved the above-referenced proposed project. Please honor the following requirements when conducting your study:

- At all times, minimize risks to subjects.
- Any significant change in procedure that may impact subjects must first be approved by the IRB.

- Insure adequate safeguarding of sensitive data during the study, and destroy sensitive material when the study is completed.

- If the study continues beyond one year, an annual review form must be filed with the IRB.
- If results are disclosed to subjects, agencies, etc., make sure that the findings are disclosed in such a manner that confidentiality is protected.

cc: Virginia Harris, IRB Secretary

Dr. Jason Miller

APPENDIX B:

SACRED HEART UNIVERSITY

Consent Document

BACKGROUND

You are being asked to participant in a research study looking at muscular activation during a back squat (BS), deadlift (DL) and countermovement jump (CMJ) using surface electromyography. Electromyography (EMG) is a tool that can be used to determine muscular activation of a given muscle. Surface EMG is when electrodes are placed on the surface of the skin. These electrodes detect electrical activity within the muscle and transmit it to the computer. As a muscle contracts, an electrical signal is sent throughout the muscle in order for it to fully contract. Muscular activation will be displayed as hertz (Hz) when it gets recorded. The purpose of this study is to determine which lift, the back squat or deadlift, displays the most similar muscular activation to the countermovement jump.

STUDY PROCEDURE

In order to participate in this study you must be a college aged individual (18-28 years of age) and have a minimum of at least one year of strength training experience in the back squat and deadlift. You must be free from any acute (less than 4 weeks) or chronic (6 months or more) injuries that may hinder your performance in weight lifting or jumping.

Today, we will perform the warm-up (shown below), as well as review proper technique for the CMJ, BS and DL. You will perform 5 repetitions of the CMJ, and up to 3 sets of 6-10 repetitions for the BS and DL, until proper technique is met. Exercise technique will follow the National Strength and Conditioning Association (NSCA) guidelines. A Certified Strength and Conditioning Specialist (CSCS) will approve proper technique.

You will also be advised that on the experimental day, electrodes sites (erector spinae, gluteus maximus, vastus medialis, biceps femoris, and gastrocnemius), will have to be shaved in order to get the best reading possible. Only the electrode site will be shaved, not the entire muscle area. Shaving will take place in the lab if necessary. You will also be asked to wear clothes that will allow researchers to reach each electrode site without obstruction.

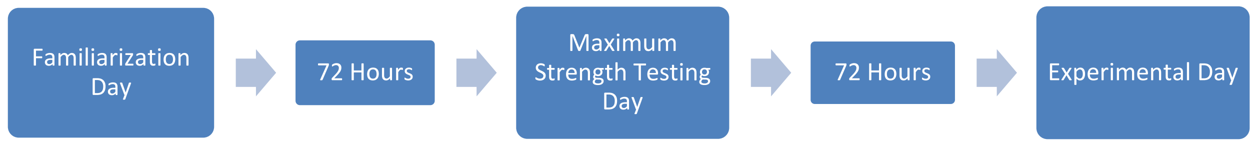
In order to determine which lift is most similar to the CMJ, you will perform 3 sets of the countermovement jump, back squat, and deadlift. The BS and DL will be performed at 85% of your 1-repetition maximum (1-RM).

To determine your 1-RM BS, a testing day will be necessary 72 hours after our familiarization day. First, the same warm-up as the familiarization day will be performed. You will then perform multiple repetitions at 30% (8-10 repetitions), 50% (4-6 repetitions), 70% (2-4 repetitions), and 90% (1 repetition) of estimated 1-RM. You will then have up to 4 attempts to reach your 1-RM. You will have 15 minutes to recover, and then the same protocol will be followed to test your 1-RM DL.

Seventy-two hours later, the experimental day will occur where you will be hooked up to surface EMG electrodes. First, though, you will perform the same warm-up as the previous two days. After the warm-up you will have 10 minutes to recover, and during this time, you will be prepped and hooked up to the electrodes. Skin prep will include any shaving that may need to be done, as well as cleaning of each electrode site with an alcohol swab. The purpose of this shaving and cleaning of electrode sites is to limit the amount of interference between the muscle and the electrode itself. Having a clean shaved area will allow more optimal readings. Electrodes will be placed on your erector spinae, gluteus maximus, vastus medialis, biceps femoris, and gastrocnemius. After the 10 minute break, 3 repetitions of the CMJ will be performed. After the CMJ, a 3 minute break will be given between each exercise to prevent any carryover fatigue. Then, either the BS or DL will be performed. The order of the BS or DL will be determined by a random number generator. The BS will follow a 3/1/x cadence (3 seconds eccentric, 1 second isometric, and rapid contraction). A metronome will be used to make sure proper cadence is followed. The DL will follow an x/1/3 cadence (rapid contraction, 1 second isometric, and 3 second eccentric).

During the 72 hour wash-out periods, no outside exercise is permitted. If additional exercise is performed during these periods, results may be skewed and result in poor data readings.

Time line of Events:



Dynamic Warm-up:

Warm-up (10yds down and back)
3-minute job on Treadmill @ 6mph
Walking Lunge
Zombie Kicks
Knee Hugs
Inch Worms
High Knees
Butt Kicks
Side Lunges

3-minute jog
Walking Lunge: (Glute, quad)
Zombie kicks: (hamstring)
Knee hug: (glute and calf): While walking, flex your hip and knee as high as you can and hug that flexed leg when you take a step.
Inch Worms: (Calf, hamstrings) Start in a push up position, keeping legs straight, slowly inch feet forward by taking tiny steps until feet are as close to hands as possible.
High knees: Run while pumping the knees as high as possible
Butt Kicks: Run while pulling the heals straight up and kicking the but each stride when the leg is recovered.
Side Lunges: (groin): Walking groin stretch, like a shuffle but includes dragging the trail leg to stretch the groin.

The familiarization day and experimental day will take place in the Motion Analysis Lab at Sacred Heart University's Oakview Building. The strength testing day will take place at Sacred Heart University's Pitt Center. Each session will take roughly one hour to complete.

RISKS

As with any physical activity or performance testing and activity there is a chance that you may incur an injury such as a muscle strain or joint sprain. Additionally, because of the 1-RM testing, muscle soreness may also occur. All exercises are designed to take place in a safe and controlled environment but the opportunity for injury does exist with the same likelihood of injury during sporting activity.

BENEFITS

There is no benefit for you to participate in this study other than helping researchers determine muscular activation patterns in the CMJ, BS and DL.

CONFIDENTIALITY

Your data will be kept confidential. Data and records will be stored in a locked filing cabinet or on a password protected computer located in the researcher's work space. Only David Robbins and Jason Miller will have access to this information. All access to data will be stored and handled following HIPPA guidelines. All data used for publication purposes will be de-identified and reported as averages for the whole sample.

PERSON TO CONTACT

If you have questions, complaints or concerns about this study, you can contact David Robbins at 508-272-1730. If you feel you have been harmed as a result of participation, please call David Robbins at 508-272-1730, who may be reached during normal business hours, Monday through Friday.

VOLUNTARY PARTICIPATION

It is up to you to decide whether to take part in this study. Refusal to participate or the decision to withdraw from this research will involve no penalty or loss of benefits to which you are otherwise entitled. This will not affect your relationship with the investigator.

COSTS AND COMPENSATION TO PARTICIPANTS

There is neither a cost or compensation for participating in this study. However, you may request a copy of your results and if desired a copy of the study can be given to you at the study's conclusion.

CONSENT

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE, HAVING READ THE INFORMATION PROVIDED ABOVE. YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM TO KEEP.

____

Printed Name of Participant

______________________________ ____________________

Signature of Participant Date

____

Printed Name of Researcher or Staff

______________________________ ____________________

Signature of Researcher or Staff Date

APPENDIX C:

Health History Form

Please indicate whether any of the following apply to you. If so, please place a check in the blank beside the appropriate item. Thank you.

______ Hypertension or high blood pressure

______ A personal OR family history of heart problems or heart disease

______ Diabetes

______ Orthopedic problems/Surgery. If so, when/for what reason

______ Cigarette smoking or other regular use of tobacco products

______ Asthma or other chronic respiratory problems

______ Recent illness, fever or Gastrointestinal Disturbances (diarrhea, nausea, vomiting)

______ Allergies

______ Any other medical or health problems not listed above (provide details below):

____

____

List any *prescription medications*, *vitamin/nutritional supplements* or *over-the-counter medicines* you routinely take or have taken in the last five days (including dietary/nutritional supplements, herbal remedies, cold or allergy medications, antibiotics, migraine/headache medicines, aspirin, ibuprofen, etc.)

____

____

I certify that my responses to the foregoing questionnaire are true, accurate, and complete.

Signature:__________________ Name (printed): ___________________

Date: _________

APENDIX D:

RESULTS TABLES

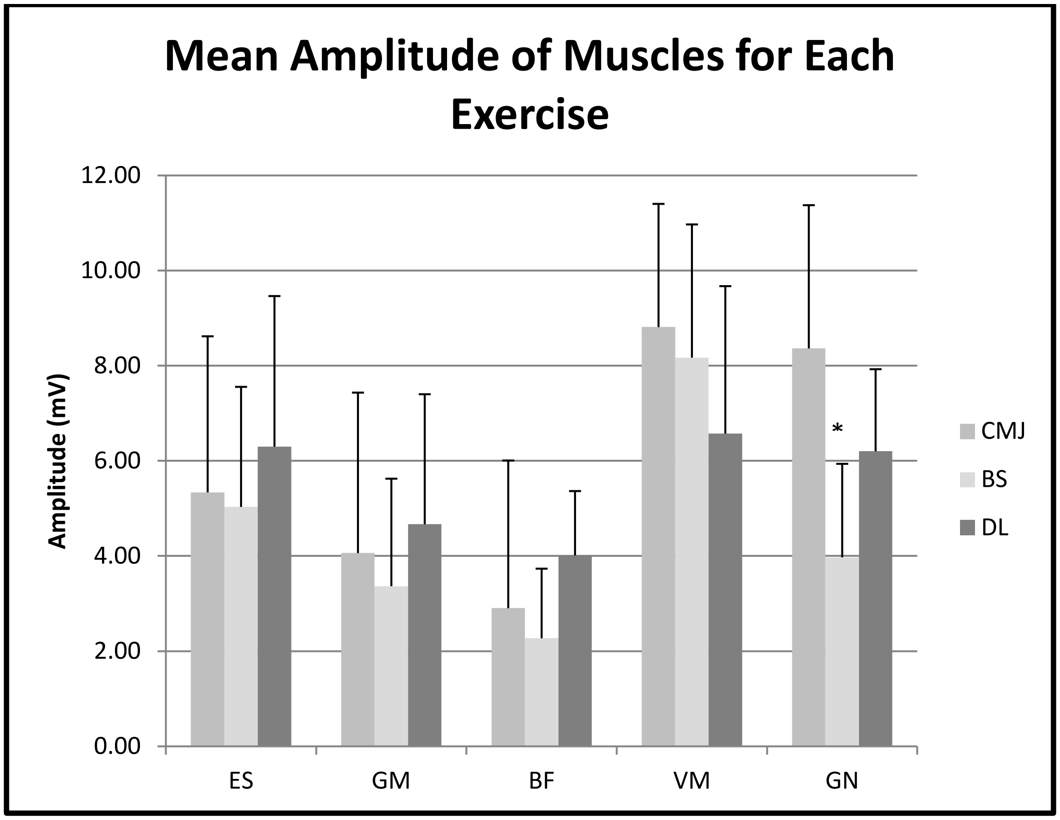


Figure 2: Peak EMG Bars represent the mean PEMG values for the Erector Spinae (ES), Gluteus Maximus (GM), Biceps Femoris (BF), Vastus Medialus (VM), and Gastrocnemius (GN) during the CMJ, BS and DL. *p<0.05, significantly different from CMJ

APENDIX E:

STATISTICAL TABLES

Table 1: Subject Data

Subject Data	
Age (years)	24 ±1.18
Height (m)	1.77 ±0.05
Weight (kg)	82.19 ±10.21
1RM BS (kg)	140±37.05
1RM DL (kg)	143 ±32.28

Table 4: Pearson Product Moment Correlation

	CMJ vs BS	**CMJ vs DL**
ES	0.44	0.27
GM	0.73	0.42
BF	0.22	0.46
VM	0.77	0.45
GN	0.39	0.24

APPENDIX F:

RAW DATA

Data Table 1: Individual Avg. PEMG (mV) of each muscle for each exercise (CMJ, BS, DL)

	Muscle Group EMG (mV)				
	ES	GM	BF	VM	GN
Subject 1					
CMJ	3.36	1.10	1.46	8.08	0.82
BS	6.85	1.40	0.20	5.35	0.09
DL	11.41	7.60	5.20	9.21	3.90
Subject 2					
CMJ	8.66	7.34	2.24	7.80	8.18
BS	3.99	5.66	2.15	7.30	3.91
DL	4.75	5.66	4.74	5.12	7.68
Subject 3					
CMJ	3.27	1.53	3.51	9.48	9.24
BS	5.49	0.95	3.89	9.77	3.74
DL	6.83	0.90	5.34	10.41	3.56
Subject 4					
CMJ	5.00	2.19	1.37	11.52	7.08
BS	7.68	4.00	2.09	12.54	7.66
DL	6.60	4.23	3.75	10.36	7.31
Subject 5					
CMJ	0.52	0.40	0.53	4.79	7.48
BS	0.70	0.55	0.69	7.04	4.48
DL	0.79	0.70	1.65	4.48	6.08
Subject 6					
CMJ	11.66	11.10	11.43	11.05	11.62
BS	5.47	4.45	2.29	11.80	3.32
DL	5.53	4.67	5.24	10.45	4.77
Subject 7					
CMJ	2.46	2.01	2.21	4.19	10.25
BS	2.29	1.79	3.30	3.36	4.53
DL	2.88	2.36	4.74	3.26	6.65
Subject 8					
CMJ	7.79	6.45	1.47	10.10	8.46
BS	9.28	7.70	1.32	9.49	4.72
DL	10.46	9.10	3.02	4.20	9.13
Subject 9					
CMJ	5.26	4.23	2.09	11.18	9.96
BS	4.02	3.32	1.75	7.62	5.09
DL	6.26	5.27	2.03	3.76	6.29
Subject 10					
CMJ	5.39	4.27	2.74	9.94	10.54
BS	4.56	3.84	5.02	7.43	2.17
DL	7.47	6.16	4.42	4.48	6.65

Data Table 2: Mean PEMG of each muscle, among all subjects, for each exercise

	ES	GM	BF	VM	GN
Mean CMJ	5.34 ±3.28	4.06 ±3.37	2.90 ±3.10	8.81 ± 2.59	8.36 ±3.01
Mean BS	5.03 ±2.52	3.37 ±2.26	2.27 ±1.46	8.17 ±2.80	3.97 ±1.97
Mean DL	6.30 ±3.17	4.67 ±2.73	4.01 ±1.35	6.57 ±3.10	6.20 ±1.72

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