# COMPARISONS OF MUSCLE ACTIVATION AND VOLUME DURING TRADITIONAL AND ALTERNATIVE LOWER BODY RESISTANCE EXERCISES IN TRAINED WOMEN


By

John Adam Korak


A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy
in Health and Human Performance


Middle Tennessee State University



August 2017


Dissertation Committee:

Dr. John M. Coons, Chair

Dr. Jennifer L. Caputo

Dr. Dana K. Fuller

Dr. Max R. Paquette

I would like to dedicate this work to my fiancé, Isadora, and my parents, John and Michelle'e Korak. Thank you for your continued love and support throughout this journey. I truly am a lucky man to have such a strong family and partner to aid me in pursuing my Ph.D. Without this, none of my work would have been possible. Thank you for your patience, love, support, and being my biggest fan until the very end.

I love you all always,

Adam

ACKNOWLEDGEMENTS

I would like to acknowledge my dissertation committee, Dr. John Coons, Dr. Jenn Caputo, Dr. Dana Fuller, and Dr. Max Paquette for all of their support and guidance. Thank you Dr. Coons for your advice and mentoring in my four years at MTSU, along with chairing my Dissertation. Thank you Dr. Caputo, Dr. Fuller, and Dr. Paquette for your help and guidance from a professional and personal level. Dr. Paquette, thank you for agreeing to be part of this committee at the University of Memphis. Having the chance to earn my Ph.D. at MTSU has allowed me to achieve my personal and professional goals that will last my lifetime.

I would also like to acknowledge the other doctoral exercise science graduate teaching assistants at MTSU throughout my four years here. Thank you for proofreading and allowing me to vent during the stressful times we all go through. I could not have picked better co-workers/friends to share my time with while pursuing my degree.

Lastly, a special thank you to my parents John and Michelle'e Korak and fiancé Isadora. Thank you for supporting me throughout my time at MTSU and your continued love and support. I am so excited to experience what the future holds.

ABSTRACT

Lower body resistance exercises have positive outcomes on health and knowledge of how muscles activate during resistance training is important to understand for rehabilitative and training purposes. Therefore, the purpose of the first study was to measure muscle activation patterns among the vastus medialis, vastus lateralis, gluteus maximus, rectus femoris, and biceps femoris muscles during the back squat, front squat, and deadlift exercises in resistance trained women ($N$ = 13). The purpose of the second study was to examine volume alterations and muscle activation patters among the vastus medialis, vastus lateralis, gluteus maximus, and rectus femoris muscles between a traditional and rest-pause Smith machine squat while performing four sets to movement failure ($N$ = 13).

When comparing muscle activity among the back squat, front squat, and deadlift exercises, the gluteus maximus muscle was found to have significantly higher muscle activity during the front squat exercise in comparison to the deadlift exercise ($p$ = .04) when performing 3 repetitions at 75% 1 repetition maximum load. No other significance was found among the remaining four muscles ($p$ > .05). The results of this study can aid strength and conditioning specialist and trainers to address issues of synergistic dominance that can likely result in arthrokinetic dysfunction and injury.

Study two examined muscle activity and total volume lifted between a traditional and rest-pause (4 second unloaded rest between repetitions) Smith machine squat at 80% 1 repetition maximum load to movement failure during four sets. Total volume lifted was significantly higher for the rest pause protocol in comparison to the traditional protocol ($p$ < .01, $d$ = .50). Furthermore, percent change muscle activity from the first three

repetitions of set one to the last three repetitions of set 4 was significantly higher in the traditional protocol in comparison rest-pause protocol ($p$ = .03, $d$ = .36). No other significance was observed for the remaining three muscles ($p$ > .05). The findings indicate if volume is the goal, the rest-pause protocol may be a superior training method.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

# CHAPTER I

# INTRODUCTION

Coaches, athletes, athletic trainers, and recreational weightlifters use strength training to improve performance, physique, and reduce the likelihood of injuries. For the general population, it is recommended that individuals perform resistance training to increase muscular fitness, lower cardiometabolic risk factors, lower risk of mortality, and decrease risk of nonfatal diseases (American College of Sports Medicine [ACSM], 2014). In studying the effectiveness of strength and resistance training interventions, it is helpful to record and measure muscular activity. Surface electromyography (EMG) is the preferred tool used to measure muscle activity during isotonic movements due to safety and practicality. Previous research is limited examining muscle activation patterns among traditional free weight multi-joint lower body exercises.

The squat, deadlift, and leg press are the most common exercises selected to improve lower body muscular fitness due to the use of multiple joints and activation of large muscle groups. However, previous research has produced equivocal results measuring lower body muscle activation patterns during dynamic leg exercises. Gullet, Tillman, Guitierrez, and Chow (2009) found no significant difference in muscle activation of the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus, and erector spinae between the front and back squat exercises in 9 male and 6 female participants. Schwanbeck, Chilibeck, and Binsted (2009) found 43% greater muscle activity of the tibialis anterior, gastrocnemius, vastus lateralis, vastus medialis, biceps femoris, lumbar erector spinae, and the rectus abdominus during the free bar squat vs the Smith machine squat. Furthermore, Anderson and Behm (2005) found greater activation of the soleus, vastus lateralis, biceps femoris, abdominal stabilizers, upper lumbar erector spinae, and lumbo-sacral erector spinae during the back squat vs Smith machine squat with 14 male participants. Previous research has also indicated that the back squat produces greater muscle activation of the vastus medialis, vastus lateralis, rectus femoris, biceps femoris, semitendinosus, semimembranosus, and gastrocnemius in comparison to the leg press and leg extension exercise (Wilk et al., 1996). Similar findings were observed by Signorile et al. (1994) with significantly greater muscle activation of the vastus medialis and lateralis during the back squat exercise in comparison to the leg extension exercise. Comparison of muscle activation in the lower body has not been examined during the traditional back squat vs. deadlift exercise. However, Hales, Johnson, and Johnson (2009) found bar velocities (m/s) were significantly faster during the squat vs. deadlift exercise. Furthermore, because significant differences in hip, knee, and ankle angular positions existed between lifts, the authors concluded there was no direct or specific cross-over effect of bar velocity, angular position, and kinematic analysis between the squat and deadlift exercises.

Lifting volume can be defined as the product of sets, repetitions, and total load lifted during an exercise session (Baechle & Earle, 2008). Increases in volume are needed to increase muscular strength and hypertrophy. Rest-pause is a training method described as a brief rest period between repetitions that can range from 2-100 seconds (Keogh, Wilson, & Weatherby, 1999; Korak, Paquette, Fuller, Brooks, & Coons 2016; & Marshall, Robbins, Wrightson, & Siegler 2012). Previous research indicates the rest-pause method produces greater volume lifted, prolonged power output, and increases in 1 repetition maximum (RM) with equivocal results for muscle activation in comparison to traditional training methods (Keogh et al., 1999; Korak et al., 2016; Lawton, Cronin, & Lindsell, 2006; & Marshall et al., 2012). Keogh et al. (1999) found participants completed an average of 1.3 more repetitions with a 2 second pause using a 6RM load during bench press with significantly lower muscle activation in comparison to the traditional bench press exercise. Conversely, Marshall et al. (2012) found greater muscle activation when performing repetitions to failure (80% 1RM), followed by a 20 second rest interval until 20 repetitions were completed, in comparison to a traditional squat protocol with matched volume. Lastly, Korak et al. (2016) found participants who utilized a 4 second unloaded rest between each repetition, produced significantly greater volume over a 4-week training protocol with no differences in muscle activation in comparison to a traditional bench press protocol.

It must be noted that the majority of studies examining muscle activity of the lower body have used predominantly male participants. Muscle activation has been shown to differ between sexes likely due to females having lower relative muscle mass, higher relative body fat percentage, differences in neuromuscular activation, and lower relative force generation in comparison to males (Clark, Manini, Dwight, Doldo, & Ploutz-Snyder, 2003; Hicks, Kent-Braun, & Ditor, 2001). However, at relatively heavy loads, it has been theorized that males and females will have similar muscle activation in the lower body, though this has not been extensively studied. For example, Laforest, St-Pierre, Cry, and Gayton (1990) found no differences in fatigability between sexes in knee extensors at 80% 1RM.

One major anatomical difference between sexes that is observed is the Q-angle. The Q-angle has been described as the angle between the quadriceps load vector and the patellar tendon load vector (Mizuno et al., 2001). Zeller, McCrory, Kibler, and Uhl (2003) found women had significantly greater muscle activation of the rectus femoris, vastus lateralis, medial gastrocnemius, biceps femoris, gluteus maximus, gluteus medius, rectus abdominis, and erector spinae during the single leg squat exercise in comparison to men. Furthermore, the rectus femoris had significantly greater muscle activation when each muscle was analyzed separately. It must be noted that Zeller et al. (2003) used only participants' body weight with no external load. This differs from Laforest et al. (1990) who found no differences in sexes at heavy external loads (80% 1RM). Because previous research has produced equivocal muscle activation results between sexes, there is a need for future research to examine muscle activity patterns during traditional lower body exercise for females. It is also important to examine if the rest-pause method is a valuable tool for females to increase both volume lifted and muscle activation during the squat exercise.

*Purpose*

The investigations within this dissertation were designed to measure volume and muscle activation patterns during traditional and altered lower body exercises in females. The purpose of the first study was to examine muscle activation patterns across the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, and gluteus maximus muscles with a lifting load of 75% 1RM for three repetitions during the front squat, back squat, and deadlift exercises. The purpose of the second study was to compare total load lifted and muscle activation patterns of the rectus femoris, vastus lateralis, vastus medialis, and gluteus maximus muscles while performing a traditional vs 4 second inter-repetition pause (rest-pause) Smith machine squat to movement failure.

*Significance of Studies*

Being able to determine which lower body strength training exercises and specific training techniques produce the greatest muscle activation can aid strength and conditioning professionals, athletic trainers, personal trainers, and physical therapists in maximizing strength and hypertrophy gains, potentially improving training and rehabilitation programs. Furthermore, if differences in training volume between protocols are found, this can aid strength and conditioning professionals to increases hypertrophy in athletes, recreational weightlifters, clients, and patients where total volume lifted is the main emphasis.

# CHAPTER II

# LITERATURE REVIEW

This review of the literature begins with an explanation of the health-related fitness components and the athletic performance parameters of the ACSM and the National Strength and Conditioning Association (NSCA), respectively. The next section includes the background, history, placement, artifact, sampling and processing procedures, normalization procedures, and relationship of force production to EMG. This review then transitions to muscle activity using EMG during traditional lower body exercises including: the back and the front squat, Smith machine squat, knee extension, deadlift, straight leg deadlift, and the leg press exercises. Ensuing transitions to muscle activity during alterations in traditional lower body exercises such as altered foot width and stance, and squat depth. Lastly, this review of literature covers nontraditional training strategies such as the rest-pause method and the scientific explanation between sex differences regarding resistance training using EMG data.

## *Muscular Fitness Standards*

The ACSM (2014) defines five health-related physical fitness components including cardiorespiratory endurance, body composition, muscular strength, muscular endurance, and flexibility. Muscular strength is defined as the ability of a muscle to exert force while muscular endurance is defined as the ability of a muscle to continue to perform without fatigue (ACSM, 2014). Resistance training strategies are generally utilized to improve either muscular strength or muscular endurance. The ACSM (2014) recommends using resistance training for each major muscle group a minimum of two times per week. The recommended training intensity for healthy adults between the ages of 18-65 years old is 60-80% of a 1RM, for 8-12 repetitions per set, with 2 minutes rest between sets (ACSM, 2014).

There are multiple parameters of athletic performance including: muscular strength, muscular power, anaerobic capacity, aerobic capacity, agility, speed, flexibility, body composition, and anthropometry (Baechle & Earle, 2008). Baechle and Earle (2008) suggests that resistance training can be used to achieve goals for muscular endurance, hypertrophy, strength, and power. The goal of muscular endurance training is to delay the onset of fatigue during repeated resistance training bouts. The recommended training load for muscular endurance is ≤ 67% of 1RM, for ≥ 12 repetitions, with < 30 secs of rest between sets, for 2-3 sets (Baechle & Earle, 2008). The main objective of hypertrophy training is to increase muscle size, and involves a training load of 67-85% 1RM, 6-12 repetitions, with 30-90 secs of rest between sets, for 3-6 sets (Baechle & Earle, 2008). The emphasis of hypertrophy training is total volume lifted. High volume increases metabolic demand which is needed for muscular hypertrophy (Baechle & Earle, 2008). Strength training is used to promote the greatest recruitment of muscle fibers to overcome the load placed on the body and involves a training load of > 85% 1RM, for ≤ 6 repetitions, with 2-5 minutes of rest between 2-6 sets (Baechle & Earle, 2008). Power lifters and athletes are two populations that commonly use strength training strategies. Lastly, the objective of power training is to produce the greatest amount of force in a short amount of time. The recommendation for power training are 3-5 sets of 1-5 repetitions at 75-90% of 1RM with 2-5 minutes rest between sets (Baechle & Earle, 2008). Baechle and Earle (2008) recommends a minimum of 48 hours recovery for each muscle group trained. Strength and conditioning specialist and trainers use these guidelines to design lifting protocols. However, as can be seen below, there are certain measurement tools that can further aid in health and performance improvements for resistance training.

*Electromyography*

Electromyography (EMG) is the process of measuring the electrical activity of muscle during contractions (Basmajian & DeLuca, 1985). Electromyography can be traced back to the mid-1600s by Francesco Redi when measuring electric rays from fish (Wu, 1984). In the 1790's, it was discovered that there is a relationship between muscle contraction and discharge of static electricity (Criswell, 2011). Surface EMG was first examined in a clinical setting by Inman, Saunders, and Abbot (1944) whom were able to measure muscle activity during dynamic movement of the shoulder. Floyd and Silver (1955) demonstrated surface EMG could measure muscle activation in the erector spinae muscles during forward flexion of the trunk. A half of decade later, EMG has been used on every major muscle group to measure muscle activity during various movement tasks.

To understand EMG, one must understand the process of muscle contraction. The nervous system is made up of three parts: peripheral nerves, spinal cord, and brain (Reaz, Hussain, & Mohd-Yasin, 2006). Reaz et al. (2006) indicated that conduction of electrical potentials are similar in nervous and muscle tissue. Surface EMG measures these electrical potentials. When a motor neuron stimulates a muscle fiber, the depolarization and movement of ions generates an electrical field near each muscle fiber. Electromyography records the motor unit action potential showing the muscle's response to stimulation (Reaz et al., 2006). A muscle contraction is initiated at the neuromuscular junction by the release of acetylcholine (Ach) across the synaptic cleft which causes depolarization of the sarcolemma. As the wave of depolarization is dispersed across and within the muscle, calcium is released from the lateral sacs. These events cause calcium to bind to troponin-tropomyosin in the actin filaments. This action causes actin and myosin filaments to bind to each other and slide past each other as the muscle shortens. This summarized process is known as the sliding filament theory (McArdle, Katch, & Katch, 2014). When nerve stimulation ceases, calcium is rapidly decreased and moved back in the lateral sacs of the sarcoplasmic reticulum.

There are two methods of using EMG to measure muscle activity. Needle EMG, or indwelling EMG, uses a needle sensor that penetrates the skin and subcutaneous adipose tissue while surface EMG uses skin-mounted electrodes. The advantage of needle EMG are that the test administrator does not have to consider the effects of cross-talk between muscles or the superficial fat layer between the muscle and skin which can cause signal impedance. Furthermore, with needle EMG, impedance from skin oils, hair, or blood vessels are not a concern. However, this method is invasive to the participant and is not practical during isotonic muscle actions making surface EMG the most common method of measuring muscle activity. The advantages of surface EMG are that it is safe, easy, and noninvasive in comparison to needle EMG, and has the ability to objectively quantify energy of muscle (Criswell, 2011). Disadvantages of surface EMG will be discussed in greater detail below.

*Factors influencing surface EMG*

Muscle activity has been examined during lower body movements such as the squat, deadlift, leg press, and leg extension exercises. A major obstacle for using surface EMG is signal impedance. Disadvantages also include repeated measure placement error, electrode movement, and sweat. Furthermore, a sensor might pick up muscle activity of a muscle located close to the muscle being examined known as “cross talk” (Criswell, 2011). With repeated measure protocols, it is important that reliable electrode placement is performed by the investigator to limit error. Dehydration has been shown to cause greater EMG increases in comparison to euhydration conditions (Bigard et al., 2001). Greater amounts of subcutaneous adipose tissue will increase the impedance of EMG signals. Hair will also cause signal noise and therefore must be removed. Other factors influencing the signal include, but are not limited to, moisture of the skin, skin oil, and density of the horny dead-cell layer of skin (Criswell, 2011). A common approach to limit skin impedance is to vigorously abrade or wear away dead skin cells through friction or erosion of the skin. Once this process has been completed, it is important to clean the skin with alcohol to remove the substance left on the skin. Impedance can also be reduced by correct anatomical placement of the EMG sensors by technicians.

*Placement and location of electrodes.* It is crucial to ensure the location of surface electrodes are consistent across and within participants. Even the slightest deviation from a location can give inconsistent results. For example, Krol, Sabota, and Nawrat (2007) found different muscle activity patterns at nine separate sites on the pectoralis major during an isomeric barbell press. For consistency purposes, most researchers only place EMG electrodes on either the right side of the body or the dominate limb (Caterisano et al., 2002; Gullett, Tillman, Gutierrez, & Chow, 2009; Krause et al., 2009). Fridlund and Cacioppo (1986) suggested six strategies for electrode placement including suggested selecting sites that have minimum tissue between the electrode and the muscle fiber, placing the electrodes parallel to fibers vs. perpendicular, avoiding straddling the motor end plate region which causes lower differential amplification, and choosing easy to locate sites that do not obstruct vision and movement.

The major muscles examined from lower body surface EMG include, but are not limited to, the gluteus medius, rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus, medial and lateral gastrocnemius, tibialis anterior, and erector spinae. Most EMG companies recommend the SENIAM guidelines for electrode placement (Hermens et al., 1999). The gluteus medius placement is traditionally half the distance between the greater trochanter and the iliac crest. The rectus femoris site is midway between the anterior inferior iliac spine and the patella on the anterior side of the body. The vastus lateralis electrode should be two-thirds of the thigh length from the greater trochanter on the lateral side of the thigh while the vastus medialis electrode is three-fourths of the thigh length from the anterior inferior iliac spine on the medial side of the thigh. The biceps femoris placement is midway between the ischial tuberosity and the lateral condyle of the femur on the posterior side of the thigh while the semitendinosus placement is midway between the ischial tuberosity and the medial condyle of the femur on the posterior side of the thigh. Lastly, the erector spinae is generally measured 3 cm lateral to the L3 spinous process (Gullet et al., 2009; Krause et al., 2009). However, placement sites differ among studies. For example, Criswell (2011) suggested that the vastus medialis oblique (VMO) should be measured at the oblique angle, 2 cm medially from the superior rim of the patella on the distal third of the vastus medialis.

*Limiting artifact.* Signal noise and artifact are defined by Criswell (2011) as undesired signals within EMG. Movement artifact takes place when electrodes move over the skin. Double-sided tape designed specifically by electrode manufacturers is placed between the electrode and the skin for proper adhesion. Use of additional tape is common to further ensure that electrodes do not move over the skin. However, sweat during prolonged movements must be considered which can increase signal artifact. Artifact from lights, offices, computers, and cell phones is designated as 60-cycle energy noise. It is important that practitioners limit these electrical noise signals as best as possible. Other possibilities of artifact are from respiration of the participant and blood flow in large vessels around the muscle being examined. Furthermore, De Luca et al. (2010) suggested that there are several intrinsic (e.g., thermal noise and electrochemical noise) and extrinsic (e.g., power line noise and cable motion artifact) sources of artifact which can contaminate the signal. As mentioned previously, artifact can come from cross-talk (Criswell, 2011). DeLuca and Merletti (1988) stated that distant muscles may produce energy up to 30% of that of the active muscle. An example of this includes the vastus medialis EMG electrode picking up muscle activity from the vastus intermedius. The tester must ensure proper placement of the sensors to limit this cross talk. Furthermore, Vugt and Dijk (2001) found using a double differentiating electrode caused a six fold improvement of EMG selectivity in comparison to a standard branched electrode. Furthermore, Bonato, D'Alessio, and Knaflitz (1998) found that double threshold detectors are superior to single threshold detectors due to yielding higher detection probabilities.

*Sampling and processing EMG signals*

Surface EMG, while useful, inevitably comes with challenges. For example, various noise components which can be unavoidable (De Luca et al., 2010). Sampling frequency is the process of signal digitization and is typically expressed in Hz. It is important to adequately filter EMG signals to eliminate unwanted noise and avoid erroneous signal interpretation. Sampling frequency can also viewed as the number of samples taken per second or the speed in which the data are gathered (De Luca 2003). Basmajian and De Luca (1985) stated that sensors should range from 0-400 Hz depending on the electrode spacing, subcutaneous adipose tissue, muscle type and orientation, and direction of action potentials. Furthermore, electrodes should not be placed over muscle insertions into tendons due to increased noise. Beck et al. (2008) stated that this is due to the amplitude of the signal being sensitive to this location. De Luca (2003) defined a filter as a device that attenuates specific range frequencies while allowing others to pass which will limit the frequency spectrum signal. Furthermore, the frequency band which is attenuated is known as the stopband while the range which is transmitted is the passband. There are four basic filter types defined by De Luca (2003) including low-pass, high-pass, band-pass, and band-stop. Low-pass filters the frequencies higher than the selected amplitude while high-pass filter all frequencies below the set amplitude (De Luca, 2003). Additionally, a band-pass filters all the frequencies below and above the set amplitudes while band-stop filters all frequencies higher than the low amplitude and frequencies lower than the high set amplitude (De Luca, 2003). Notch filters are a band reject filter that are used to eliminate any of the electrical noise and are most frequently set at 60-Hz. This means the notch filter will reject signals that are between 59 and 61 Hz. A band pass filter however only allows a selected frequency range often between 25-500 Hz (Criswell, 2011). Criswell (2011) stated that certain filters are better than others due to different muscle sizes. For example, the muscles in the face may need a 25-500 Hz range while the upper trapezius muscle might use a 100-200 Hz range. Furthermore, EMG activities are greater with increases in joint velocity (Carpentier, Duchateau, & Hainaut, 1996).

Previous research suggests there is a wide variety of selected sampling and filter ranges to measure muscle activity. These variations can be dependent upon the size of the muscle being examined and the type of movement performed (isometric, isotonic, or isokinetic). However, most authors state that selection of sample and filter ranges are chosen from preceding research with similar testing protocols. This can be problematic if the original protocol was done incorrectly causing replicated research to be invalid. Gullett et al. (2009) had the preamplified signals at 500 Hz while the band-pass was filtered at 8-1500 Hz for muscle activity measurements during the front and back squat. Krause et al. (2009) set the sampling frequency at 1000 Hz with a bandwidth of 40 Hz to 6 KHz and a rejection ratio of 87dB at 60 Hz during five weight bearing exercises. Lastly, Wilk et al. (1996) selected a sampling frequency at 960 Hz on the vastus medialis, vastus lateralis, rectus femoris, biceps femoris, semitendinosus, and semimembranosus during the knee extension, leg press, and squat exercise. However, Wilk et al. (1996) did not state how the data were filtered. Furthermore, neither of the three authors propose a reason for the selection of the sampling frequencies or filtering methods. This is important because all three protocols used different filter and sampling frequencies while performing similar dynamic resistance training movements. This makes comparisons of EMG difficult across studies.

Just as muscle size effects sampling and filter ranges, speed of contractions must be considered when selecting ranges. There are many factors that increase force output including an increase in motor unit recruitment and an increase in motor unit firing rates. Therefore, muscles that rely on increased firing rate to match force requirements, such as smaller muscles, may require higher band-pass cut-off frequencies whereas larger muscles may require lower band-pass cut-off frequencies. Furthermore, band-pass signals are dependent on the speed of contractions. For example, the band-pass signal of the triceps during a throwing motion will require a higher band-pass cut-off in comparison to a standard triceps push down exercise. Selecting the correct frequency ranges are important, but rectifying the signal must be performed to analyze the data.

Electromyography signals are random in nature mostly due to recruited motor units continuously changing within available motor units (Konrad, 2005). To help address this problem, researchers need to first convert all negative amplitudes to positive amplitude or in other words, rectify the signal. Once a signal is rectified, researchers can then compute amplitude parameters such as the mean, the peak (highest recorded), and the maximum indicating the highest physiologically possible value (Konrad, 2005). Furthermore, raw EMG cannot be reproduced a second time by its precise shape. Konrad (2005) stated that because of this, the signal must be minimized by applying a digital smoothing algorithm that shows the mean trend of the signal development. This means the amplitude spikes are cut away. The two most common algorithms for smoothing data are moving average and root mean square (RMS). The moving average method averages the data during the sliding window technique and serves as an estimator of the amplitude behavior (Konrad, 2005). Konrad (2005) stated that this method serves as an estimator of the amplitude behavior. However, the preferred method is the RMS which is based on the square root calculation that reflects the mean power of the signal (Konrad, 2005). Fukuda et al. (2010) stated that once the muscles' electrical signal has been measured, it can be analyzed or processed by the RMS value. The RMS value is then submitted for mathematical treatments designed to quantify the intensity and duration of the EMG signal (Fridlund & Cacioppo, 1986; Fukuda, Alvarex, Nassri, & Godoy, 2008). The RMS value is commonly chosen because it reflects the level of physiological activity during motor unit activation (Fukuda et al., 2010). One advantage of the RMS method is that it is the optimal method for estimating the standard deviation of the distribution which will aid in the statistical analysis of the data. However, if the signals are not normally distributed, then the RMS is likely to result in an estimation error (Konrad, 2005).

Recently, Reaz et al. (2006) proposed more recent mathematical techniques and artificial intelligence ways to process the EMG signal. Mathematical techniques include wavelet transform, time-frequency approaches, fourier transform, Wagner-Ville Distribution, statistical measure, and higher-order statistics. Artificial intelligence approaches include artificial neural networks, dynamic recurrent neural networks, and fuzzy logic system (Reaz et al., 2006).

*Normalization procedures of EMG*

Some of the greatest challenges when analyzing muscle activity via EMG are the high variability across muscle groups, intra-subject day-to-day fluctuations, and intersubject variability (Clark, Lambert, & Hunter, 2012). To compare EMG data, one must normalize the data to a reference value. These reference values are generally a maximal voluntary isometric contraction (MVIC), or a functional/relative movement.

*MVIC.* The most common normalization method performed by authors from previous research is to take a MVIC prior to the testing protocol to compare the isotonic exercise EMG data (Bressel, Willardson, Thompson, & Fontana, 2009; Gullett et al., 2009; Hamlyn, Behm, & Young, 2007; Nuzzo, McCaulley, Cormie, Cavill, & McBride, 2008; Pereira et al., 2010; Smilios, Hakkinen, & Tokmakidis, 2010; Wilk et al., 1996; Willardson, Fontana, & Bressel, 2009; Zink, Whiting, Vincent, & McLaine, 2001). Using this method, the EMG signal during the participants' isotonic contractions are normalized to the MVIC signal and reported as a percentage (i.e., %MVIC). Previous research has indicated normalizing data to a MVIC during low-intensity actions like gait, isolated muscle actions, and occupational tasks is valid (Burden, 2010). However, high-velocity exertion activities may require an alternate normalization approach due to increased neuromuscular requirements (Mero & Komi, 1987). This means that the high velocity movements can produce EMG amplitudes that are greater than the MVIC EMG amplitudes. In fact, Ball and Scurr (2013) cited multiple publications on normalization procedures used within high-velocity running and sprinting protocols.

Criswell (2011) stated that the proper method to obtain MVIC EMG data are to conduct three MVICs lasting 6 seconds each. The middle 2 seconds of each trial are then averaged and used as the benchmark signal. Electromyography signals during the experimental movement tasks are then divided by the average MVIC signal. A limitation for this method is that it is difficult to be certain whether or not the MVIC is truly a maximum effort due to the voluntary nature of the test (Criswell, 2011). Furthermore, MVICs may not be suitable for patients experiencing pain or range of motion limitations caused by pre-existing conditions such as arthritis or pervious injuries in participants.

Wilk et al. (1996) inspected muscle activity in participants' vastus medialis, vastus lateralis, rectus femoris, biceps femoris, semitendinosus, semimembranosus, and gastrocnemius during three exercises: squat, knee extension, and leg press. The EMG signals were gathered, full-wave rectified, and integrated from the surface electrodes. A MVIC was performed during the leg press and leg extension exercise while at 90° of hip flexion and 90° knee flexion according to previously collected pilot data. The MVIC for the squat exercise was not described in the methodology of the current study. For the exercise session, muscle activity was gathered during the last three repetitions during 12 completed repetitions of each set for all three exercises. Electromyography data for the exercise trials was then normalized as a percentage of the MVIC by averaging the last three repetitions for all three exercises. However, there are other normalization procedures that can be utilized outside of the MVIC technique.

*Functional/relative movement normalization.* A second method commonly used is to normalize the EMG signal to a submaximal voluntary contraction. For example, a participant may hold a contraction for 15 seconds with the practitioner averaging the middle 5 seconds over four repetitions. This method is scientifically known as the percentage of the reference voluntary contraction (%RVC; Knutson, Soderberg, Ballantyne, & Clarke, 1994). Dankaerts, O'Sullivan, Burnett, Straker, and Danneels (2004) found that normalization procedures using submaximal EMG were more consistent than normalization using a MVIC. A third normalization method involves recording muscle activity during a dynamic movement cycle such as walking which is a more functional movement (Criswell, 2011). All three methods mentioned (maximal and relative contraction) appear to have reasonable test-retest reliability with 11-15% coefficient of variation (Criswell, 2011). However, the MVIC is more sensitive to isotonic contractions that require more effort, but sensitivity is lost during low levels of effort. On the contrary, relative voluntary contraction is more useful during lower levels of activation, but is not suitable at contractions that produce high effort. Criswell (2011) stated that it is not feasible to select one normalization technique for all occasions making it the practitioners' job to select the most appropriate technique. Previous resistance training protocols generally used intensity ranges from 60-90% of predetermined 1RM. These intensity ranges require high effort to complete the movement while recruiting a large number of muscle fibers. This makes the normalization to the reference MVIC the most common approach to compare muscle activity. Knutson et al. (1994) compared normalization methods among different individuals and gathered muscle activity of the gastrocnemius on participants. Normalization methods included the MVIC, peak dynamic EMG, and mean dynamic EMG. Knutson et al. (1994) proposed the MVIC is the best reference value against to normalize data. The authors suggested reproducibility is highest when the MVIC is used due to the lower standard deviation in comparison to the dynamic values. It must be noted that data were collected only on the gastrocnemius. It is possible findings would have been different across separate muscle groups.

Gullet et al. (2009) performed an abnormal way of normalizing EMG data when comparing back and front squat muscle activity compared to more traditional methods from previous research. Participants performed both a 1RM for the front and back squat exercises, and an MVIC prior to the testing protocol. The rectus femoris, vastus lateralis, and vastus medialis MVIC data were obtained through a 90° knee extension exercise for 5 seconds. The biceps femoris and semitendinosus MVICs were gathered through a 5 second MVIC knee flexion exercise. Lastly, an MVIC was performed on the erector spinae for 5 seconds using a truck extensor exercise. Electromyography data was obtained during the MVIC procedures. For the testing protocol, participants performed three repetitions at 70% of predetermined 1RM for both exercises. Researchers collected muscle activity during the second repetition of the second set. Data were then normalized by taking the highest EMG data during the front and back squat for each examined muscle group and comparing it as a percentage to the MVIC for all six muscles. This methodology is unique in that the MVIC was an exercise that was not performed during the testing protocol (knee extension, knee flexion, trunk extension). It must be noted that the MVICs performed were all concentric contractions on the six muscles examined. However, these muscles performed both concentric and eccentric contractions during the dynamic front and back squat assessment. For example, the quadriceps muscles performed an eccentric contraction during the decent phase and a concentric contraction during the ascent phase. This further indicates the challenges associated with normalizing EMG data.

Though MVIC are usually the best way to normalize data, some researchers have expressed EMG data as a percentage of total electrical activity. For example, Caterisano et al. (2002) expressed EMG data as both peak and mean electrical activity and normalized data as a percent contribution to the total electrical activity of the examined muscles. This method was chosen to avoid upper-body deviations from upper body position changes during changes in squat depth (Caterisano et al., 2002). Schwanbeck, Chilibeck, and Binsted (2009) reported mean EMG without normalization due to repeated trials among participants. Permanent markers were used to identify the exact site during the first testing session. Schwanbeck et al. (2009) then compared the two sessions' mean EMG across seven muscles. Lastly, Korak et al. (2016) took the RMS signals during the last repetition of the last set and normalized it to the first repetition of the first set (i.e. percent change from peak first repetition). The results of these studies indicate multiple procedures can be applied to gather EMG data.

*Relationship of force and EMG*

The relationship between muscle activity and the generation of force has been extensively examined with equivocal results. Research has also indicated that some muscles produce force in a linear relationship while others follow a nonlinear trend with increases in voluntary concentric and eccentric contractions (Basmajian & De Luca, 1985). Alkner, Tesch, and Berg (2000) compared the relationship of EMG and isometric force production in the vastus lateralis, vastus medialis, rectus femoris, biceps femoris at 20%, 40%, 60%, 80%, and 100% of MVIC force for the knee extension and leg press exercise at 90° knee bend in participants. The results indicated no significant differences of mean muscle activity amplitude for all examined muscles between the leg press and knee extension exercises. The vastus lateralis indicated no deviation from linearity during both isometric exercises. However, vastus medialis and rectus femoris EMG/force relationship increased nonlinearly with increased force. Lastly, the biceps femoris EMG/force relationship increased in a linear relationship with an increase in force. The authors concluded that some muscles produce force in a nonlinear pattern due to differences in muscle size, differences in recruitment patterns, antagonist activation at heavy loads for stabilization, and co-activation of muscle groups (Alkner et al., 2000). Pincivero and Coelho (2000) examined muscle activity in participants' vastus medialis, vastus lateralis, and rectus femoris during a 5 sec isometric contraction at $60^0$ of knee flexion at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of MVIC force. The vastus lateralis had the greatest muscle activation while the vastus medialis had the lowest activation across all intensities. The authors concluded that muscle activity of the three muscles increased linearly at low and moderate force ranges. However, non-parallelism of muscle activity was observed at higher isometric forces indicating nonlinearity (Pincivero & Coelho, 2000).

The two previous studies included an examination of muscle activity with increases in force during isometric movements at a percentage of MVIC. Pincivero, Coelho, Campy, Salfetnikov, and Suter (2003) examined muscle activity and torque during perceived isometric voluntary effort contractions of 5 secs on points 1-9 on an 11-point modified category Borg ratio scale. This is the first study examined that prescribed intensities based on a participants' perceptual effort instead of a percentage of a MVIC. The protocol consisted of an isometric leg extension with a 60° knee bend on the right leg. Vastus medialis, vastus lateralis, and rectus femoris muscle activity and, peak and average torque were collected during a 5 sec isometric contraction. Electromyographic data were gathered during the middle 3 seconds of each isometric contraction. These data were compared to equivalent percent values of the MVIC taken on the first day of data collection. Muscles resulted in an under-production of knee extensor torque during voluntary contractions by perceptual sensations. For example, participants that contracted at a 4 on the Borg ratio scale produced lower than 40% activation of the equivalent MVIC. This suggests that participants' produced lower activation during perceived effort voluntary isometric contractions when compared to the equivalent percent values of the MVIC. The vastus lateralis had significantly greater muscle activity than the rectus femoris and vastus medialis overall. Furthermore, the rectus femoris had significantly greater muscle activation in comparison to the vastus medialis. These findings indicate that three examined muscles in the quadriceps have different recruitment patterns. However, all three muscles showed a linear EMG and force relationship. The findings of Pincivero et al. (2003) disagree with the findings of Alkner et al. (2000) and Pincivero and Coelho (2000) who found some muscles produce force in a linear fashion while other muscles have nonlinear recruitment patterns. It must be noted that the vastus medialis had significantly higher muscle activity from 70-90% MVIC in comparison to the vastus lateralis and rectus femoris. Conversely, vastus medialis muscle activity was significantly lower in comparison to the other two muscles across contractions of 20-70% MVIC. Pincivero et al. (2003) suggested that differences in muscle activation across the vastus lateralis, vastus medialis, and rectus femoris are likely due to differences in cross-sectional area, muscle fiber type, and force generating ability.

It has been speculated that the vastus lateralis has greater activation at lower loads due to larger cross-sectional area while the vastus medialis has greater activation at higher loads due to greater type I oxidative muscle fibers. This pattern can be seen in data from Pincivero et al. (2003) with the vastus lateralis producing the highest EMG data. Furthermore, the vastus medialis might have greater low threshold motor neurons that need heavier loads to activate. Previous literature has indicated that the vastus lateralis produces higher EMG with increases in force in comparison to the vastus medialis and rectus femoris during isometric contractions (Alkner et al., 2000; Pincivero & Coelho, 2000; Pincivero et al., 2003). Furthermore, some muscles in the quadriceps recruit in a linear fashion with increases in force while others follow a nonlinear recruitment pattern (Alkner et al., 2000; Pincivero & Coelho, 2000). This is important when practitioners make comparison between quadriceps muscles during exercise.

*Muscle activity during traditional lower body exercises*

Traditional lower body exercises include the back and front squat, traditional and straight leg deadlift, leg curl and extension, and leg press. The following section will detail muscle activity responses during selected muscles across traditional lower body exercises.

*Back squat vs. front squat EMG.* Escamilla et al. (1998) define the squat exercise as a closed kinetic chain exercise. However, there are many variations of the squat exercise including the back squat, overhead squat, and front squat. The two most common variations are the front squat and the back squat. Hand placement during the front squat can be either the parallel arm position with the bar grasped slightly wider than the shoulders in a closed pronated grip and the bar resting on the anterior deltoids, or the crossed-arm position with arms crossed in front of the chest while the bar rests on the anterior deltoids and the hands are placed on top of the bar (Baechle & Earle, 2008). The back squat can have a low bar position (across the posterior deltoids at the middle of the trapezius) or a high bar position (above the posterior deltoids at the base of the neck) (Baechle & Earle, 2008).

Gullett et al. (2009) completed a biomechanical analysis of back and front squats in 9 males and 6 females who had trained both lifts for a minimum of once a week for 1 year. Participants performed two sets of three repetitions for the front and back squat at 70% of a predetermined 1RM. Participants' data were normalized to a MVIC with the knee flexed at 90° during the knee extension, flexion, and truck extensor exercise. Muscle activity was recorded at the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus, and erector spinae. The average muscle activity data were recorded from the second repetition of the front and back squats. The authors stated that the back squat load averaged 90% of participant's body weight while the front squat averaged approximately 70% of participant's body weight (Gullett et al., 2009). No significant differences in muscle activity were found between the squat variations, but there was significantly higher muscle activity during the ascending phase in comparison to the descending phase for both exercises. Furthermore, the back squat resulted in significantly higher compressive forces and knee extensor moments in comparison to the front squat. The authors suggested the load applied to the participants failed to stimulate significant differences between the two modes of the squat exercise. Gullett et al. (2009) concluded that the front squat was just as effective as the back squat in overall muscle recruitment. It must be noted that though no differences in muscle activity were found, participants' lifted greater weight during the back squat exercise. If greater volume lifted is the goal, the back squat should be chosen. Consequently, if reduction in net compressive forces and extensor moments are the goal, the front squat should be the selected exercise.

*Squat vs. Smith machine EMG.* Cotterman, Darby, and Skelly (2005) stated that the most commonly selected types of strength training equipment are free weights (free-form) and machine weight modes (fixed-form). Free-form exercises use all planes of motion and require balance while fixed-form exercise maintain the pattern movement with reductions in planes of motion and balance (Cotterman et al., 2005). The Smith machine is a fixed-form exercise. Schwanbeck, Chilibeck, and Binstead (2009) analyzed muscle activity in the tibialis anterior, gastrocnemius, vastus lateralis, vastus medialis, biceps femoris, lumbar erector spinae, and the rectus abdominus during the free bar squat and the Smith machine. Participants used an 8RM load for both exercises. There was 43% higher muscle activity for all muscles during the free bar back squat exercise in comparison to the Smith machine (Schwanbeck et al., 2009). The authors stated that the largest increases in muscle activity were seen at the gastrocnemius, biceps femoris, and vastus medialis and were likely due to the stabilization role during the free weight movement. Furthermore, these muscles played a greater stabilization role of the ankle, knee, and hip muscles during the more unstable free weight exercise. It must be noted that the Smith machine exercise had a heavier load ranging from 14-23 kg between participants. The authors stated that the higher vastus lateralis and medialis activation ($p = .057$) during the free weight squat is most likely attributed to increases in stabilization roles during the isotonic movement. A review completed by Clark et al. (2012) stated that the lack of significance of Schwanbeck et al. (2009) was most likely due to the low participant number ($N = 6$).

Anderson and Behm (2005) examined muscle activity differences in the soleus, vastus lateralis, biceps femoris, abdominal stabilizers, upper lumbar erector spinae, and lumbo-sacral erector spinae while performing the free squat, Smith machine squat, and free squat standing on two balance discs with 14 males. The three intensities conducted include body mass (two disc squat), 29.5 kg (Smith machine exercise), and 60% of body mass (free squat). Muscle activity was significantly higher in the soleus, abdominal stabilizers, upper lumbar erector spinae, and lumbo-sacral erector spinae during the two discs squat and lowest during the Smith machine squat. Furthermore, muscle activity was highest during the concentric phase in comparison to the eccentric phase during all three exercises (Anderson & Behm, 2005). The authors stated that this is due to the increased stabilization roles during the unbalanced free weight movements. The results agree with the findings from Schwanbeck et al. (2009). From a practical standpoint, strength coaches and trainers should select free weight exercises to increase muscle activation. This in theory should cause greater increases in strength and hypertrophy. Free weight exercises are also more applicable to activities of daily living using all planes of motion vs fixed form exercises. However, fixed form exercises are safer and are commonly used in rehabilitation clinics (Baechle & Earle, 2008).

*Squat vs. knee extension and leg press EMG.* The leg press exercise can be defined as eccentrically lowering weight from a machine towards the body and concentrically pressing the weight away from the body. Major muscles activated include the gluteus maximus, semimembranosus, semitendinosus, biceps femoris, vastus laterals, vastus medialis, and rectus femoris (Baechle & Earle, 2008). The leg/knee extension exercise is performed by sitting in a machine and concentrically pressing weight upwards and eccentrically lowering the weight into the starting position. Major muscles activated are the vastus lateralis, vastus intermedius, vastus medialis, and rectus femoris (Baechle & Earle, 2008).

As previously discussed, Wilk et al. (1996) inspected muscle activity in the vastus medialis, vastus lateralis, rectus femoris, biceps femoris, semitendinosus, semimembranosus, and gastrocnemius during three exercises: squat, knee extension, and leg press. Male participants (*N* = 10) completed four repetitions with a load of 12RM. The researchers found all seven muscles produced the greatest muscle activity during the closed chain squat exercise vs. the open chain knee extension and closed chain leg press. According to the authors, the results confirm that the squat exercise produces greater prime mover activation in comparison to movements that isolate the limb (Wilk et al., 1996). Furthermore, the squat exercise was performed with the participant erect, placing the load vertically, while the leg press load was placed horizontally. This caused the authors to suggest there are greater compressive forces during the squat exercise. This causes the force of gravity to become a factor, possibly leading to greater muscle activation. Also, the squat was a free weight exercise while the knee extension and leg press were machine-based exercises. Previous research indicates increased muscle activity during free weight exercises in comparison to fixed form machine exercises, specifically the Smith machine (Anderson & Behm, 2005; Schwanbeck et al., 2009). The authors stated major limitations were muscle force was assumed to be proportional to EMG, and EMG was assumed that the force per cross-sectional area generated was constant for all muscles examined. However, the authors stated that these incorrect assumptions are common in the biomechanics field which justified the limitations. Lastly, the authors used a relatively small sample size (*N* = 10) possibly skewing the results, including the standard deviations (Wilk et al., 1996). This is one of the few reviewed protocols that used light loads for the selected exercises (4 repetitions at a 12RM load). Previous research indicates muscle activity increases with an increase in intensity (Alkner et al., 2000; Pincivero & Coelho, 2000; Pincivero et al., 2003).

A similar study was conducted by Signorile et al. (1994). A total of 10 recreational lifters performed a 10RM for the leg extension exercise and the parallel squat. Muscle activity data were gathered on the vastus lateralis and vastus medialis during the first and last repetition of both exercises. Signorile et al. (1994) found no significant muscle activity differences between muscles during the exercises. However, the parallel squat elicited greater muscle activity in both muscles in comparison to the leg extension exercise (Signorile et al., 1994). The conclusions made the authors question the value of the leg extension exercise as a supplemental exercise to the parallel squat caused by the lack of overload on the muscles.

As previously discussed, Alkner et al. (2000) compared surface EMG of the quadriceps femoris during the double joint leg press exercise and the single joint leg extension exercise. Repetitions were performed at 20%, 40%, 60%, 80%, and 100% of 1RM. Muscle activity was recorded at the vastus lateralis, vastus medialis, rectus femoris, and biceps femoris (Alkner et al., 2000). There were no statistical differences between the two exercises, though differences in muscle activity differed among the vastus medialis, rectus femoris, and vastus lateralis (Alkner et al., 2000). Due to the differences in EMG/force relationships, the authors suggested the results indicate a difference in recruitment patterns. Also, differences in muscle size could elicit different recruitment patterns between the movements. For example, the rectus femoris is approximately one third the size of the vastus lateralis, which can potentially cause the vastus lateralis to contribute greater generation of force. Alkner et al. (2000) found the rectus femoris showed a non-linear recruitment pattern during the knee extension in comparison to the linear recruitment pattern of the vastus lateralis. Lastly, Alkner et al. (2000) concluded that EMG/force relationships are similar between the single joint and the double joint exercise (Alkner et al., 2000). However, the major limitations included cross talk between adjacent muscles, inability to measure certain muscles or proportions of muscles, and a lack of linearity in signal output (Alkner et al., 2000). Future studies must factor in the knowledge that some muscles in the quadriceps will have a linear recruitment pattern with an increase in intensities while smaller quadriceps muscles may show a non-linear recruitment pattern.

*Squat vs. deadlift EMG.* Research comparing the electrical activity of the back squat and deadlift exercise is lacking. Most studies reviewed to this point have used EMG data as variables. However, no study to date has used EMG as a measurement tool between the squat and deadlift exercise. Hales, Johnson, and Johnson (2009) compared the biomechanical parameters of the deadlift and back squat exercise on 25 male competing power lifters. Hales, Johnson, and Johnson (2009) used four video cameras set at 60 Hz to view the sticking points of both lifts and differences in kinematic means scores. Bar velocities were significantly faster during the squat (0.09 m/s) than the deadlift (0.20 m/s) exercise. Also, angular position of the hip, knee, and ankle differed between both lifts. Moreover, the sticking point during the squat was observed at 32.54$^{\circ}$ while the deadlift was apparent at 52.42$^{\circ}$ (Hales, Johnson, & Johnson, 2009). The authors' indicated that the back squat caused a lumbar lordosis with a slightly rigid spinal column while the deadlift exercise indicated an abnormal curvature of the spine. Lastly, the back squat demonstrated a synergistic muscular contraction, though the authors did not specify which synergistic muscles were activated, while the deadlift demonstrated a sequential or segmented movement. Due to these findings, Hales, Johnson, and Johnson (2009) concluded that there was not a cross-over effect between the two exercises indicating there are different training characteristics that will yield different training results.

The three most common exercises to train the hamstrings are the squat, leg curl, and the stiff-leg deadlift. Wright, Delong, and Gehlsen (1999) studied 11 male participants to see which of these three exercises elicited the greatest muscle activity in the biceps femoris and semitendinosus. Participants completed three repetitions at 75% of 1RM while muscle activity was analyzed independently during the concentric and eccentric phases of all exercises. The leg curl and the stiff-leg deadlift stimulated the greatest muscle activity during the concentric phase. However, the squat exercise produced muscle activity of approximately 70% of the leg curl and stiff-leg deadlift exercises. This is due to the hamstrings not being a contributing factor during the back squat exercise during the concentric phase. However, the authors suggested the hamstrings are used most during the eccentric portion of the lift for stabilization of the knee joint (Wright et al., 1999). The authors concluded that the leg curl and stiff-leg deadlift involve the hamstrings to a similar extent while the squat produced half as much muscle activity (Wright et al., 1999). For practical purposes, if fitness professionals want to isolate the hamstring muscles, the leg curl and stiff-leg deadlift should be chosen due to higher muscle activity (Wright et al., 1999). However, the squat exercise is more useful for activities of daily living. Selection of these exercises are dependent upon the goals of the athlete, client, or patient.

Only one study has examined muscle activity patterns between the front and back squat exercises (Gullet et al., 2009). Furthermore, no study has examined muscle activity between the squat and deadlift exercises in the leg musculature. However, alterations in the squat exercises has been extensively examined. Future research is needed to examine muscle activation patterns during squat and deadlift exercises to increase knowledge in the exercise physiology field, and for practical application purposes for strength and conditioning professionals.

*Alterations of Traditional Lower Body Exercises*

*Stance width and foot progression angle*

As discussed previously, the squat and leg press exercises are commonly used by athletes, recreational weightlifters, and the clinical population due to multiple joint use and large muscle recruitment (Escamilla et al., 2001). Furthermore, these populations frequently alter techniques according to personal preferences and effectiveness (Escamilla et al., 2001). Escamilla et al. (2001) observed muscle activation during technique variations of the squat and leg press exercise in 10 male lifters. Participants performed four variations of the squat exercise: narrow stance at 0° forefoot abduction, at narrow stance 30° forefoot abduction, at wide stance at 0° forefoot abduction, and at wide stance 30° forefoot abduction. The same foot position variations were examined during the high and low foot placement during leg press totaling eight variations for leg press, for a total of 12 lower body variations. Only four repetitions were completed for all exercises using the predetermined 12RM load. Muscle activity was measured only for repetitions two through four at the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semimembranosus, and gastrocnemius. There were no significant muscle activity differences for foot angle variations for the 12 altered exercises. However, the squat exercise produced a 20-60% increase in muscle activity of the quadriceps and a 90-225% increase in hamstring activity in comparison to the high and low foot placement leg press exercise. The authors suggested that the squat exercise may be more effective for muscle development in comparison to the leg press exercise due to greater muscle activation of the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, and semimembranosus (Escamilla et al., 2001). The results are in agreement with previous findings that the free weight squat exercise elicits greater muscle activation due to increased stabilization needs in comparison to the machine based leg press exercise (Anderson & Behm, 2005; Schwanbeck et al., 2009; Signorile et al., 1994). However, it must be noted that Signorile et al. (1994) examined the vastus lateralis and vastus medialis while Schwanbeck et al. (2009) examined the tibialis anterior, gastrocnemius, vastus medialis, vastus lateralis, biceps femoris, lumbar erector spinae and rectus abdominus. Lastly, Anderson and Behm (2005) gathered EMG data on the soleus, vastus lateralis, biceps femoris, abdominal stabilizers, upper lumbar erector spinae, and lumbo-sacral erector spinae.

McCaw and Melrose (1999) measured muscle activity on the rectus femoris, vastus medialis, vastus lateralis, adductor longus, gluteus maximus, and biceps femoris with 9 male lifters while conducting five nonconsecutive reps of squat using narrow (75%) and wide stance width (140%) relative to shoulder width with low (60% 1RM) and high loads (75% 1RM). The authors established that stance width does not affect muscle activity of the quadriceps muscles, but does affect vastus medialis, adductor longus, and gluteus medius possibly due to prevention of excessive thigh abduction during the descent phase (McCaw & Melrose, 1999). A similar study examined muscle activation of participants' gluteus medius during five weight bearing exercises: bilateral stance, single limb stance, single limb stance on both firm and airex cushion, and single limb squat on firm and airex cushion (Krause et al., 2009). Statistical differences were found between the single limb stance in comparison to the double limb stance and single limb squat, respectively (Krause et al., 2009). Furthermore, the single limb stance increased muscle activity of the gluteus medius in comparison to the double limb stance. The researchers concluded that dynamic, single limb exercises performed on airex cushions increases muscle activity of the gluteus medius more than stable surfaces (Krause et al., 2009). Lastly, Paoli, Marcolin, and Petrone (2009) compared EMG during a back squat with three different stance widths with no load, 30% of 1RM, and 70% of 1RM with 6 experienced lifters. Muscle activity of the vastus medialis, vastus lateralis, rectus femoris, semitendinosus, biceps femoris, gluteus maximus, gluteus medium, and adductor major were studied. Only the gluteus maximus produced higher muscle activity with the wide stance at 0% and 70% of 1RM with no significant differences among all other examined muscles (Paoli et al., 2009). The authors suggested a larger stance width will provide larger muscle activity in the gluteus maximus.  Strength and conditioning professionals can utilize this information if isolating the gluteus maximus muscle is the focus during lower body training days.

*Squat depth*

Clark et al. (2012) stated that coaches believe manipulating the squat with either stance width or depth can target specific muscle groups and influence training adaptations. The depth of the squat exercise has been debated and examined by a number of authors on whether to recommend a partial squat, parallel squat, or full squat for both training adaptations and EMG alterations (McCaw & Melrose, 1999; Signorile, Kwiatkowski, Caruso, & Robertson, 1995; Wretenberg, Feng, & Arborelius, 1996). Caterisano et al. (2002) examined muscle activity on the vastus medialis, vastus lateralis, biceps femoris, and gluteus maximus when performing a partial squat, parallel squat, or full squat. A total of 10 experienced male weightlifters performed three repetitions of a load ranging from 100-125% of the participants' body weight. There was a significant difference in gluteus maximus muscle activation among the partial squat (16.9%), parallel squat (28.0%), and the full squat (35.4%) during the concentric phase (Caterisano et al., 2002). No significant differences were found in any of the quadriceps muscles or for any muscles examined during the eccentric phase. The authors' conclusions indicated that muscle activity will increase in the gluteus maximus as squatting depth increases (Caterisano et al., 2002). The findings are important for future studies to consider when selecting squat depth due to greater muscle activation of the gluteus maximus with increased depths. Furthermore, coaches and trainers can apply this knowledge for rehabilitation strategies or prevention of lower body injuries. As can be seen from previous literature, squat depth and foot placement have been extensively examined. However, training alterations such as inter-repetition rest periods have not been as thoroughly examined.

*Training Strategies*

Strength and conditioning professionals and coaches implement different training strategies to produce favorable gains over traditional training strategies. Nontraditional training protocols can be prescribed for reasons such as preventing plateau, alterations of a mesocycle, and prevention of mental fatigue. Alterations of traditional training strategies include: rest-pause, breakdowns (reduction of load after fatigue is reached), heavy weight training (traditional lifting with large loads and volumes), eccentrics (4 sec eccentric movement with no concentric contraction), super slow motion (5 sec contraction during the eccentric and concentric phase), and power training (explosive movements usually at light loads). However, the rest-pause training strategy has been the least examined method from previous research.

*Rest-pause*

Rest-pause has been defined as a brief pause or rest period between each repetition during the exercise set. Keogh et al. (1999) defined rest-pause as an unloaded 2 sec rest period at the end of each concentric phase. However, Lawton, Cronin, and Lindsell (2006) used inter-repetition rest periods of 20 secs, 50 secs, and 100 secs. Marshall et al. (2012) defined rest-pause as an initial set to failure with subsequent sets performed with a 20 sec inter-set rest interval. Lastly, Korak et al. (2016) used inter-repetition rest periods of 4 secs during the Smith machine bench press exercise. It appears that there is no consensus in the definition of rest-pause. During resistance training, a large amount of energy comes from creatine phosphate using the adenosine triphosphate-phosphocreatine (ATP-PCr) system (McArdle, Katch, & Katch, 2014). This system can sustain bouts of effort that generally last for 10 secs. Full ATP-PCr system re-synthesis after highly intense exercise bouts may require greater than 170 seconds (Bogdanis, Nevill, Boobis, Lakomy, & Nevill, 1995; Dawson et al., 1997). Inter-set rest periods allow for replenishment of intramuscular creatine phosphate. This should allow a prolonged time period to fatigue allowing greater volume to be achieved during a resistance training session.

One of the first studies conducted viewing muscle activity utilizing rest-pause was conducted by Keogh et al. (1999). Resistance trained males (*N* = 12) used a 6RM load and completed a normal isoinertrial lift with a 2 second rest period at the end of each concentric phase to failure using a smith machine. Muscle activity was measured at the pectoralis major and triceps brachii throughout the movement. Testing procedures took place on a Plyometric Power System that allows kinematic data to be collected during eccentric and concentric isokinetic contractions for force production. The rest-pause data were compared to two previous procedures, a predetermined MVIC, and to the standard heavy weight training (HWT) session at a predetermined 6RM with the same load. The rest-pause and HWT sessions had similar force production between participants. However, muscle activity was lower during rest-pause training when compared to HWT especially during the middle and later repetitions. Due to these findings, the authors suggested rest-pause could be inferior to HWT in promoting strength. Lastly, participants completed an average of 1.33 more repetitions during rest-pause vs. HWT at the same loads (Keogh et al., 1999). This is most likely due to replenishment of intramuscular creatine phosphate which will prolong the ATP-PCr energy system. Though the rest-pause elicited lower EMG levels, participants were able to complete more total volume lifted. Volume is the key goal during the hypertrophy phase within a mesocycle (Baechle

& Earle, 2008). One limitation to the current study is the relatively low amount of time during the inter-repetition rest period (2 seconds). It is likely that if the inter-repetition rest period was increased, total completed repetitions would have increased from 1.33 in comparison to the HWT group.

As previously stated, the definition of time during rest periods of rest-pause differs among published research. Lawton et al. (2006) examined power output of 26 males using a 6RM bench press load with 3 intervention groups. The singles group performed six repetitions with 23 seconds inter-repetition rest. The doubles group performed three sets of two repetitions with 56 secs rest between sets, while the triples group performed two sets of three repetitions with 109 secs rest between each set. Muscle activity was not measured in this protocol via EMG. Power output was measured with a linear encoder. Drinkwater, Galna, McKenna, Hunt, and Pyne (2007) validated the optical encoder for measurements of power. The highest power output was measured in the triples group, while the lowest power output was detected in the singles group. Furthermore, significantly greater power was measured in repetitions four through six for all three groups in comparison to traditional continuous 6RM power output with no differences observed between groups. The authors stated that previous research indicates 3 to 7 minutes rest are optimal to replenish creatine phosphate, restore pH levels, remove metabolic end products, and return impaired muscle membrane resting levels (Lawton, et al., 2006). Inter-repetition pauses may help possible restoration of these previously mentioned outcomes from contractions.

A similar study was conducted by Marshall et al. (2012) who included 14 males to observe acute neuromuscular and fatigue responses to the rest-pause method.

Participants completed 20 repetitions of the squat exercise at 80% of a 1RM using three different protocols: A) five sets of four repetitions with 3 minutes rest between sets, B) five sets of four repetitions with 20 secs rest between sets, and rest-pause consisting of an initial set to failure with subsequent sets performed with a 20 sec inter-set rest interval. Muscle activity was recorded at the erector spinae, gluteus maximus, biceps femoris, rectus femoris, vastus lateralis, and vastus medialis. The rest-pause group completed the 20 repetitions in 103 secs while participants for protocols A and B needed 780 and 140 secs, respectively. Furthermore, the rest-pause protocol elicited a significantly higher motor unit recruitment (12 - 46%). Marshall et al. (2012) suggested that this is due to increased task demand and probably increased local metabolic demand. Both of these are needed for hypertrophy and strength increases. The findings of Marshall et al. (2012) indicate that the rest-pause protocol will elicit greater motor unit recruitment and allow participants to complete a set number of repetitions in a shorter amount of time in comparison to traditional protocols. This is important for high school and collegiate strength coaches where time with athletes is limited.

Rest-pause has been termed cluster training and inter-repetition rest by previous researchers, though all three terms imply the same thing. Joy, Oliver, McCleary, Lowery, and Wilson (2013) defined the term cluster training as short rest between repetitions or groups of repetitions. Ten males performed the parallel back squat exercise using a traditional protocol (four sets of 10 repetitions), and a cluster protocol (four sets of two clusters of five repetitions) using 75% of a 1RM. Muscle activity was measured at the vastus lateralis and biceps femoris during both protocols while mean power output was measured using a linear position transducer and ultimately, linear velocity. Furthermore, mean peak power and EMG of both muscles were gathered for every repetition of both training protocols. The cluster protocol elicited significantly greater mean lifting power output in repetitions four, and six through 10. Also, significant differences were observed in muscle activity between protocols. Specifically, muscle activity was higher in repetitions six through 10 for the traditional protocol in comparison to the cluster protocol for the vastus lateralis and biceps femoris. The authors suggested that higher EMG during the latter repetitions of the traditional protocol is due to increases in rate coding of the oxidative type I muscle fiber types due to fatigue of the higher threshold type II muscle fiber types (Joy et al., 2013). This means that the cluster sets allowed the type II fiber types to recover which agrees with the findings of greater mean power output during cluster sets. Lastly, the authors suggested that if hypertrophy is the goal, traditional training should be utilized due to greater muscle activity. However, if acute increases in power are the goal, cluster training should be used (Joy et al., 2013).

Korak et al. (2016) recently examined muscle strength, lifting volume, and muscle activity on the smith machine bench press exercise. Trained males ($N$ = 20) were randomly assigned to either a rest-pause or a traditional training group. Pretest and posttest 1RMs were recorded. Training sessions were completed twice a week for 4-weeks and consisted of four sets of bench press to volitional fatigue at 80% of pretest 1RM with a 2-minute rest between sets. The rest-pause group utilized a 4 sec inter-repetition pause. Total volume completed was recorded on each training day. Muscle activity of the pectoralis major was measured on the first and last training days. The RMS signals of the last repetition in the last set were normalized to the RMS peak values of the first repetition in the first set for each participant during the 1$^{st}$ and 8$^{th}$ training sessions.

Both groups significantly increased their 1RMs following the 4-week training protocol. However, no significant differences were found in 1RM and muscle activity between the two groups. Total volume lifted was significantly higher for the rest-pause group throughout the protocol and independently during weeks 2, 3, and 4. While strength and muscle activity changes did not differ between groups, the rest-pause group achieved greater increases in volume than the traditional group. The authors stated that the non-significance in strength changes between groups was likely due to the short duration of training (i.e. 4 weeks). If volume is the focus of training (i.e., hypertrophy phases), the rest-pause resistance training method should be utilized.

In conclusion, numerous studies have found that the inter-repetition rest period allows for greater volume lifted, greater total loads placed on the body, alterations in muscle activity, prolonged power output, changes in 1RM, and possible greater replenishment of the ATP-PC energy system during the squat and bench press exercise (Keogh et al., 1999; Korak et al., 2016; Lawton, et al., 2006; & Marshall et al., 2012). However, many studies examined had participants complete a set number of repetitions vs performing to volitional fatigue. Rest-pause's greatest use is for increased volume which is needed produce greater hypertrophy in comparison to traditional training. Keogh et al. (1999) and Korak et al. (2016) were the only previous reviewed literature that required participants to perform repetitions to volitional fatigue. It must be noted that all five studies reviewed in the section only recruited male participants. This is important because muscle activation patterns between sexes have produced equivocal results.

*Sex Differences in EMG*

Previous research has shown that females have greater muscular endurance capacity compared to males possibly due to differences in muscle mass and neuromuscular activation patterns (Clark et al., 2003; Hicks et al., 2001). Furthermore, it has been proposed that females generate lower absolute muscle forces when performing the same relative work in comparison to males. This, in theory, should place a lower demand for muscle oxygen which aids in prolonged contraction times (Hicks et al., 2001; Miller, MacDougall, Tarnopolsky, & Sale, 1993).

Clark et al. (2003) studied sex differences in skeletal muscle activity and fatigability between isotonic and isometric truck extensor contractions at 50% of MVC force. Muscle activity was measured at the right and left lumbar paraspinal, right gluteus maximus, and right biceps femoris in 10 females and 10 male college aged participants. Females had significantly longer endurance times during the isometric exercise with no significant differences during the isotonic exercise while males fatigued faster in the lumbar extensor muscles than the biceps femoris. Males likely fatigued more quickly due to the greater force production which caused greater activation of more anaerobic fast-twitch muscle fibers. Clark et al. (2003) stated that 34% of the variance in fatigue is explained by absolute load between sexes. Furthermore, EMG indicated no significant differences in neuromuscular activities between sexes. Males fatigued more quickly in the truck muscles compared to females while females fatigued more quickly in the biceps femoris in comparison to males. Clark et al. (2003) concluded that sex differences are prevalent between muscles contraction type and frequency shifts in EMG and not by alterations in the synergistic activation patterns. The authors suggested that the findings are due to the anatomic structure of women having a wider pelvis and a more pronounced lordosis of the spine.

Previous research as shown that EMG does not differ at high intensities between sexes. Hunter and Enoka (2001) demonstrated that females have longer endurance times than males during isometric contractions at low to moderate intensities. Hunter and Enoka (2001) hypothesized that this was due to males having a greater absolute force production which would cause greater intramuscular pressures, occlusion of blood flow, accumulation of metabolites, heightened ventilation and increased efferent sympathetic nerve activity, and larger impairment of oxygen delivery to active muscles. Fatigability was measured with 7 males and 7 females at the brachialis, brachioradialis, biceps brachii long, biceps brachii short, and triceps brachii during isometric elbow flexion. Participants performed an MVIC with the elbow flexor and elbow extensor muscles and an isometric contraction at 20% of MVC until volitional fatigue. The authors found females had greater endurance times to failure (118% longer) while males produced greater absolute sustained force. Furthermore, males had greater measured muscle activity and greater pressure response. Hunter and Enoka (2001) suggested males had greater motor unit recruitment causing higher muscle activity that likely lead to faster fatiguing times. Hunter, Critchlow, Shin, and Enoka (2004) conducted a follow-up study comparing time to failure during an isometric contraction at 20% of MVC until volitional fatigue for males and females matched for strength. Muscle activity was measured at the same muscles as in the previous study in 10 males and 10 females. There were no significant differences in time to fatigue, arterial pressure, heart rate, torque fluctuations, and ratings of perceived exertion (RPE) between sexes. However, EMG activity was significantly higher in males compared to females. Hunter et al. (2004) concluded that EMG differences are likely due to greater motor unit recruitment by males and greater synergistic muscle recruitment by females. Males in general have a greater amount of muscle mass in comparison to females which would explain the higher muscle activity. However, it is interesting to find no significant differences in the other measured variables between sexes. Theoretically, if males have a greater amount of muscle, males should recruit less muscle to perform the same relative load equating to lower muscle activity levels in comparison to females.

In conclusion, females have been shown to have longer times to volitional fatigue during resistance training likely due to muscle mass, substrate utilization, neuromuscular activation, and muscle morphology (Hicks et al., 2001). However, the prolonged time to exhaustion tends to decline with intensities greater than 80% of MVC (Laforest et al., 1990; Maughan, Harmon, Leiper, Sale, & Delman, 1986). Further research is needed to investigate sex differences in muscle fatigue and activation between sexes.

*Conclusion*

In summary, EMG is a method that can be successfully used to measure muscle activity during traditional and altered lower body exercises. Surface EMG is more applicable to isotonic and isometric movements as long as methodological procedures are followed properly to limit impedance, reduce noise, and artifact. This includes hair removal, skin abrasion, and proper electrode placement by a trained technician. The most common way to normalize the EMG data are to compare it as a percentage to an MVIC, though other methods may have better functional application. Filtering the EMG signal comes from properly setting the notch and band pass filters at the correct ranges. The relationships of force and muscle activity has shown to increase in a linear and non-linear rate depending upon the muscles examined, intensities used, type of exercise, and contraction type. Muscle activity does differ between traditional lower body exercises. For example, muscle activity is higher in closed chain free weight exercises such as the front or back squat in comparison to the open chain leg press and leg extension exercises. This is most likely due to the increase activation in the stabilization muscles. Furthermore, there is greater muscle activation in the gluteus maximus during increased depth and stance width of the squat exercise. Research has also indicated that the rest-pause training method will elicit greater increases in repetitions equating to greater volume achieved. This is likely due to replenishment phosphocreatine, restoration of pH levels, and increased removal of metabolic end products. Differences in EMG during rest-pause produce equivocal results. Lastly, previous research has shown that females have greater muscular endurance capacity compared to males possible due to differences in muscle mass and neuromuscular activation patterns. However, muscle activation patterns between sexes have shown equivocal results. This is likely due to many factors including, but not limited, to the anatomic structure of females having wider pelvis and a more pronounced lordosis of the spine. The majority of previous literature pertaining to resistance training includes only the male population. Future studies are needed to examine muscle activation patterns and total volume lifted during traditional and nontraditional lower body exercises in the female population.

# CHAPTER III

# MUSCLE ACTIVATION PATTERNS OF LOWER BODY MUSCULATURE AMONG THREE TRADITIONAL LOWER BODY EXERCISES IN TRAINED WOMEN

## *Introduction*

The American College of Sports Medicine (ACSM) recommends training each major muscle group a minimum of two days a week to increase muscular fitness, lower cardiometabolic risk factors, and decrease risk of non-fatal injuries (2018). Strength and conditioning coaches routinely recommend squat variations and deadlift exercises to target lower body musculature due to large muscle recruitment, use of multiple joints, and similarities to activities of daily living (Escamilla, 2001).

Squat variations and deadlift exercises are used interchangeably in training due to a belief that they have similar lifting characteristics and produce comparable training results (Hales, Johnson, & Johnson, 2009). The two common forms of the squat exercise are the front and the back squat. Gullett, Tillman, Gutierrez, and Chow (2009) suggested that greater muscle activation can be found in the distal quadriceps during the front squat exercise, however, empirical evidence of muscle activity via surface electromyography (EMG) is lacking to support this conclusion. Previous research has indicated that loads placed on the front of the body produce significantly higher lumbar paraspinal muscle activity in comparison to loads placed on the back of the body (Cook & Neumann, 1987). To our knowledge, only one study has included an examination of muscle activation patterns of the lower body for the front and back squat exercises. Gullet et al. (2009)

found no significant differences in muscle activity of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), semitendinosus (ST), and erector spinae (ES) between the front and back squat exercises during two sets of three repetitions of a 70% of 1 repetition maximum (1RM) load. Some authors have rationalized that the lack of muscle activity differences were due to the relatively low submaximal load that was used in this study (Clark, Lambert, & Hunter, 2012).

Likewise, there are limited data on muscle activity differences between squat and deadlift exercises. Lumbar-sacral erector spinae and upper lumbar erector spinae muscle activity are greater during 80% 1RM squat and deadlift exercises in comparison to superman and side-bridge exercises, with no difference between the squat and the deadlift (Hamlyn, Behm, & Young, 2007). Understanding lower body muscle activation patterns between squat variations and the deadlift exercise is important for strength and conditioning professionals, trainers, and therapists who want to isolate or create greater activation of selected lower body muscles for training adaptions, performance increases, injury prevention, or rehabilitation techniques. Lastly, the majority of studies examining muscle activity during lower body resistance training have used predominantly male participants leading a potential void in the literature.

Therefore, the purpose of this study was to compare peak muscle activity of the VL, VM, RF, BF, and gluteus maximus (GM) among the back squat, front squat, and deadlift in trained women. It was hypothesized that the front squat and deadlift exercises would elicit higher muscle activity of the VL, VM, and RF in comparison to the back squat. Furthermore, it was hypothesized the back squat would produce greater muscle activity of the GM.

*Methods*

*Participants*

Trained women (*N* = 13) participated in the study (22.8 ± 3.1 years; 166.4 ± 4.2 cm; 73.4 ± 14.0 kg). All participants had a minimum of 1 year lifting experience and had been actively participating in resistance training for 6 months prior to beginning the study (ACSM, 2018). Furthermore, participants were asked to refrain from alcohol consumption and lower body resistance training 48 hours prior to testing.This study was approved by the university Institutional Review Board (see Appendix A). Participants were informed of the benefits and risks of the investigation prior to signing the informed consent document.

*Procedures*

Participants were required to attend two sessions which included a familiarization session and a training session. Session one included completion of all required paper work and anthropometric measurements. Height was assessed using a stadiometer (SECA Corporation, Model 222, Germany) to the nearest 0.1 cm while body mass was measured to the nearest 0.1 kg using a digital scale (SECA Corporation, Model 770, Germany). Anthropometric measurements were taken with participants wearing gym shorts and a t-shirt, without shoes. Furthermore, participants completed practice repetitions for the deadlift, front squat, and back squat exercises with a standard size Olympic lifting bar with bumper plates. The practice repetitions were completed using relatively heavy loads (≤ 5 repetitions) to gather estimates of participants' 1RM for the three exercises using a training load estimation table (Baechle & Earle, 2008).

Participants returned for the second session three to four days later to assess muscle activity during the three exercises. Upon arrival, EMG electrodes were secured to the skin using double-side adhesive tape over the VL, VM, RF, BF, and GM muscles on each participants' dominant leg (i.e., leg used to kick a soccer ball). Electrode placement locations are outlined in Table 1 (Hermens et al., 1999). Hair was shaved from the electrode sites, when necessary, and the skin was exfoliated with redux paste prior to placement of the electrodes to reduce signal impedance. Adhesive stretch covering was placed over top of each electrode to further secure the electrodes to the skin. Participants were then asked to warm-up by walking on a treadmill at a self-selected pace for 3-5 minutes. Participants then performed 15 repetitions for each exercise with a standard Olympic weight bar. The electrode signals were checked while participants completed the warm-up. In a randomized order, participants completed a 1RM of either the deadlift, front squat, or back squat exercise followed by the measurement trials at 75% 1RM (ACSM, 2018). Each 1RM was obtained in three or fewer attempts. The first 1RM attempt was with the starting load obtained from the National Strength and Conditioning Association (NSCA) 1RM estimation table gathered during the familiarization trial (Baechle & Earle, 2008). Once the 1RMs were determined, participants were given 10 minutes of rest prior to performing the set of three repetitions at 75% 1RM for the first exercise (Wright, DeLong, & Gehlsen, 1999). Repetitions were performed at a pace of 2 seconds for the eccentric action and 1 second for the concentric action with a 2 second rest between repetitions set by a metronome (Hamlyn et al., 2007). Once the 1RM and three repetitions were completed for one exercise, participants were given 5 minutes rest before moving to the next exercise (see Figure 1).

Table 1

*Electromyography Electrode Placement Locations*

| Muscle | Electrode placement |
|---|---|
| Vastus medialis | 4/5$^{ths}$ the distance between anterior spina iliaca superior and joint space in front of the anterior border of medial ligament |
| Vastus lateralis | 2/3$^{rds}$ the distance from anterior spina iliaca superior to lateral patella |
| Biceps femoris: | Half the distance between ischial tuberosity and lateral epicondyle of tibia. |
| Gluteus maximus | Half the distance between sacral vertebrae and greater trochanter |
| Rectus femoris | Half the distance between anterior spina iliaca superior and superior border of the patella |

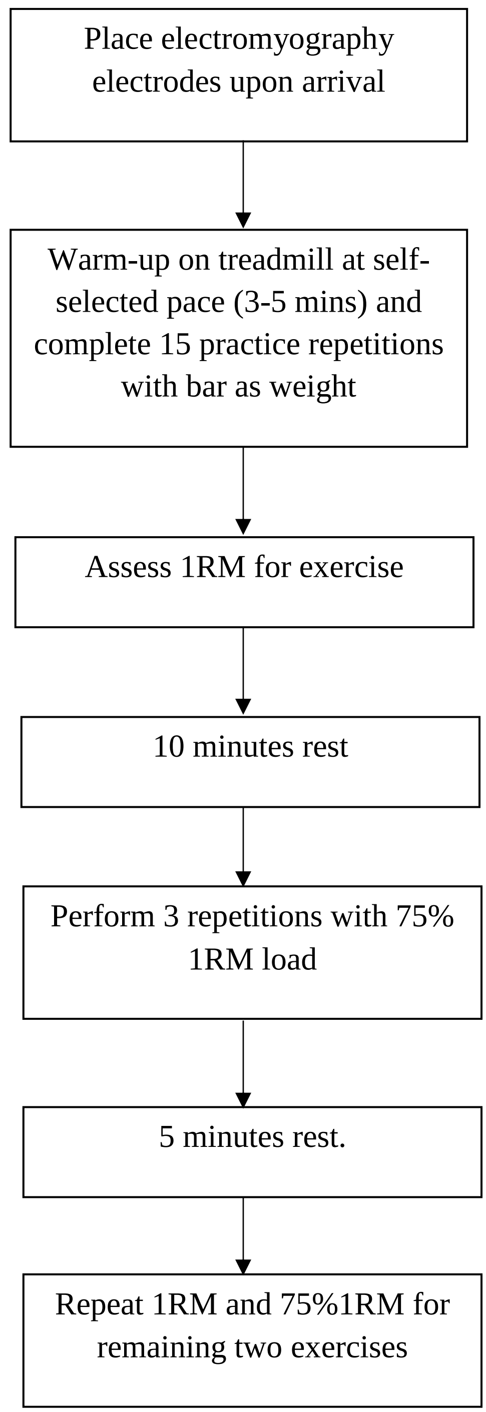


*Figure 1.* Participant flow chart for testing protocol for back squat, front squat, and deadlift exercises (randomized order). RM: repetition maximum.

Surface EMG was obtained during both the 1RM and 3 repetitions at 75% 1RM for all three exercises using a wireless EMG system (1996Hz, Trigno, Delsys, Natick, MA). Participants were required to complete each repetition during the front and back squat exercise with feet shoulder width, toes facing forward, and to descend until thighs were parallel with the floor. A bungee cord was placed at parallel height for each participant who descended until the buttocks touched the cord for the repetition to count. A high bar placement across the posterior deltoids at the middle of the trapezius was used with the back squat while either a parallel or crossed-arm position, according to participants' preference, was used with the front squat (Baechle & Earle, 2008). The deadlift exercise was performed according to NSCA guidelines (Baechle & Earle, 2008). A Certified Strength and Conditioning Specialist collected all data and ensured proper technique throughout all repetitions.

*Data processing*

Surface EMG data were band-pass filtered with high pass and low pass cut-off frequencies of 20 and 450 Hz, respectively. The data were then full-wave rectified and smoothed using a root-mean-square (RMS) filter with a moving window of 250 ms (Allen, Dean, Jung, & Petrella, 2013). The peak RMS signals of the three repetitions of each muscle during the total exercise period were averaged and normalized as a percentage of the peak RMS signals obtained during the 1RM lifts for the deadlift, front squat, and back squat, respectively. A repetition included the eccentric and concentric portions of each exercise.

*Statistical analyses*

A one-way repeated measures analysis of variance (ANOVA) using Hyunh-Feldt adjustment with exercise type as the within-subject factor (back squat, front squat, and deadlift) were conducted for each of the five muscles (VL, VM, RF, BF, and GM) to compare muscle activity among the exercises. Post-hoc analysis included the Sidak procedure. An alpha level was set at .05 for all statistical procedures. Effect sizes were calculated for all analysis performed using partial eta squared ($\eta^2$). Outlier muscle activity data were removed for statistical analysis if recordings were greater than ±2 SD from the mean.

*Results*

Descriptive statistics for 1RM and the three repetition training loads are shown in Table 2. No significant differences were found in muscle activity for the VM, $F(2, 18) = 0.49$, $MSE = 0.02$, $p = .62$, $\eta^2 = .05$, the VL, $F(1.6, 16.1) = 0.16$, $MSE = 0.11$, $p = .81$, $\eta^2 = .02$, the BF, $F(2, 24) = 0.08$, $MSE = 0.07$, $p = .92$, $\eta^2 = .01$, or the RF, $F(1.1, 13.3) = 0.03$, $MSE = 0.33$, $p = .89$, $\eta^2 < .01$. However, muscle activity of the GM differed among exercises, $F(1.7, 17.3) = 6.46$, $MSE = 0.03$, $p = .01$, $\eta^2 = .39$. Post hoc analysis indicated muscle activity was greater for the GM during the front squat exercise compared to the deadlift exercise ($p = .04$). See Table 3 and Figure 2.

*Discussion*

In this study, we compared muscle activity of the VL, VM, RF, BF, and GM among the back squat, front squat, and deadlift exercises in trained women. Contrary to our hypothesis, the primary finding is that GM muscle activity was greater during the front squat exercise in comparison to the deadlift exercise (see Table 3 and Figure 2).

Table 2

*Loads for 1RM and 75%1RM Repetitions*

| Exercises | *M* | *SD* |
| --- | --- | --- |
| Back squat 1RM (lbs) | 171.9 | 29.5 |
| Back squat L (lbs) | 123.9 | 22.4 |
| Front squat 1RM (lbs) | 133.8 | 30.4 |
| Front squat L (lbs) | 100.4 | 22.7 |
| Deadlift 1RM (lbs) | 186.5 | 29.7 |
| Deadlift L (lbs) | 140.4 | 22.5 |

*Note*. 1RM = 1 repetition maximum. L = load of 3 repetitions at 75% 1 repetition maximum.

Table 3

*Peak RMS Muscle Activity among Deadlift, Front Squat, and Back Squat Exercises as a Percentage of Peak RMS Muscle Activity during Respective 1RM*

| | Back squat | | Front squat | | Deadlift | |
|---|---|---|---|---|---|---|
| Muscle | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Vastus medialis (*N* = 10) | 0.97 | 0.15 | 0.98 | 0.15 | 0.93 | 0.11 |
| Vastus lateralis (*N* = 11) | 0.98 | 0.21 | 1.02 | 0.22 | 1.04 | 0.38 |
| Biceps femoris (*N* = 13) | 0.78 | 0.20 | 0.82 | 0.26 | 0.82 | 0.26 |
| Gluteus maximus (*N* = 11) | 0.80 | 0.12 | 0.94 | 0.15* | 0.72 | 0.16 |
| Rectus femoris (*N* = 13) | 1.01 | 0.18 | 1.01 | 0.24 | 1.05 | 0.65 |

*Note*. * = Front squat > Deadlift, $p < .05$.

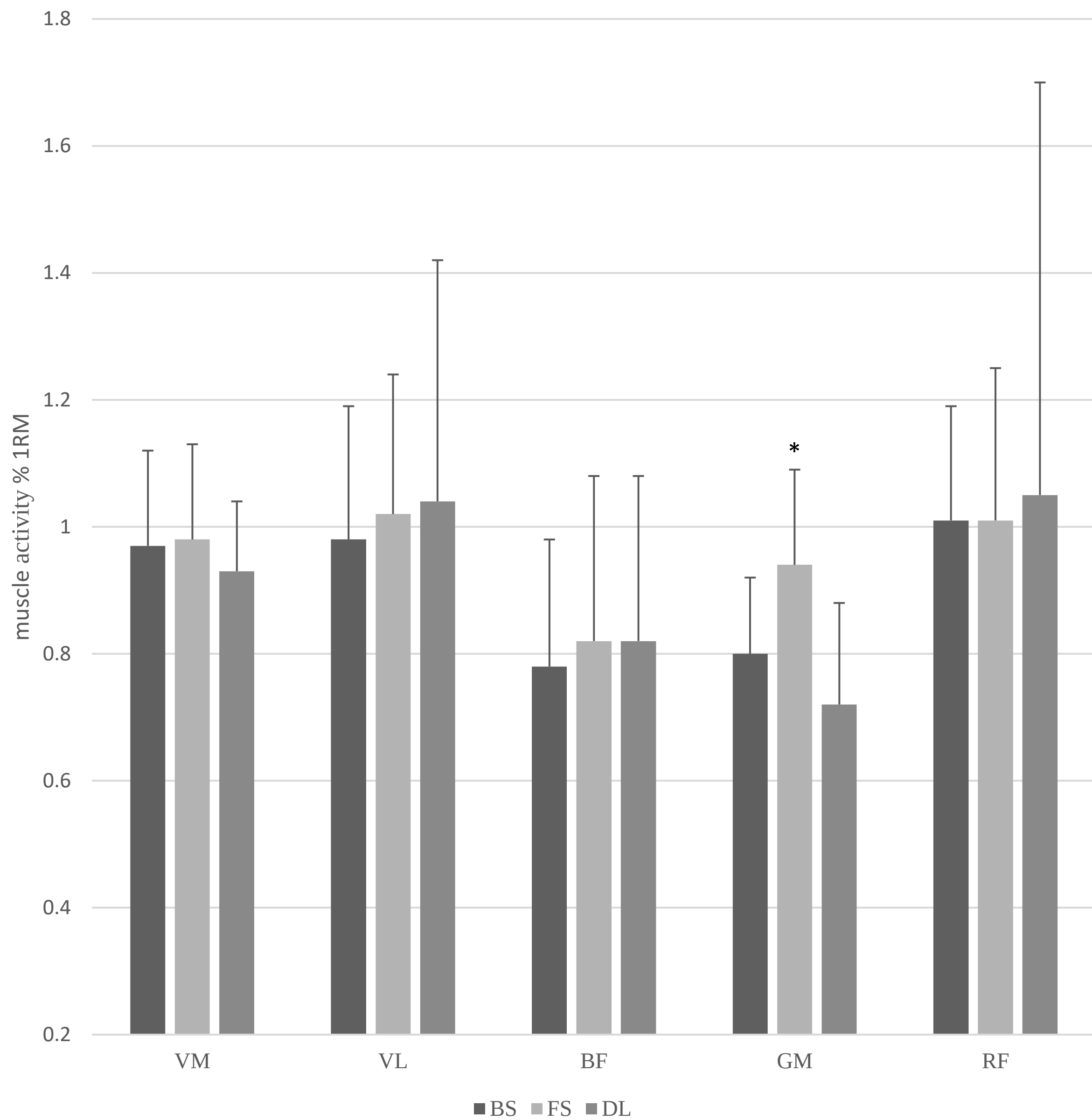


*Figure 2.* Muscle activity among the deadlift, front squat, and back squat as a percentage of 1RM. VM = vastus medialis. VL = vastus lateralis. BF = biceps femoris. GM = gluteus maximus. RF = rectus femoris. BS = back squat. FS = front squat. DL = deadlift. * = Front squat > Deadlift, $p < .05$.

While both the squat and deadlift are lower body multi-joint exercises, the technique of the lifts is different (Hales et al., 2009). The NSCA describes the lowest depth of the deadlift as the thighs being above parallel to the floor whereas the lowest depth of the front squat is described as the thighs being parallel to the floor (Baechle & Earle, 2008). Caterisano et al. (2002) reported that as squat depth increased due to greater hip flexion from a partial squat to a full squat, muscle activity of the GM also increased. Furthermore, Kang et al. (2017) indicated VM and VL muscle activity increased as hip flexion angle increased. A possible explanation for the greater GM muscle activity during the front squat is related to the larger hip flexion leading to a greater external lever arm of the external load in comparison to the deadlift. A larger sagittal plane lever arm of the external load to the hip joint would effectively increase the hip extensor torque required to counteract the external flexor torque, thus increasing muscular tension at different muscle lengths during the movement. Muscle spindles respond to changes in muscle tension and length of stretch and, when stimulated, initiate muscle contraction (McArdle, Katch, & Katch, 2014). It is possible the front squat caused greater muscle spindle activation in the GM than the deadlift because of increased hip flexion of the lift and subsequent increased muscle fiber length and tension.

The results of the current study suggest that if a client/athlete has a weak GM, the front squat provides optimal activation of this muscle. This information is important when the goal of a training or rehabilitation program is to target the GM. Synergistic dominance is defined as a neuromuscular phenomenon when synergist muscles dominate a weak or inhibited prime mover. This dominance can lead to arthrokinetic dysfunction and injury (Clark, Sutton, & Lucett, 2014). A common example of synergistic dominance is thought to occur between the GM and the hamstring complex. If the GM is weak, the hamstrings will dominate the primary mover role, thereby placing disproportionate stress upon the hamstrings and increasing the risk of injury. In a scenario of synergistic dominance, strength and conditioning specialists use resistance training exercises that optimally activate musculature to address muscular weakness and therefore, the front squat may be a more favorable exercise to target gluteus maximus involvement.

The great majority of previous literature examining lower body muscle activity during a squat protocol has primarily included the back squat (Escamilla, 2001; Hales et al., 2009; Hamlyn et al., 2007; Wilk et al., 1996; Wright et al., 1999). Gullett et al. (2009) also found no difference in muscle activity between the front squat and the back squat with exercise loads of 70% 1RM, similar to the loads in the current study (i.e., 75% 1RM). The lack of difference in muscle activity across squat variations is likely linked to similarities in load placement location and to both variations requiring similar hip flexion.

The lack of muscle activity significance in the three examined quadriceps muscles (VM, VL, and RF) among the two squat variations and deadlift was surprising. Hales et al. (2009) concluded the deadlift and squat exercise differ in three specific ways: the squat is a simultaneous movement while the deadlift is a segmented movement; both lifts require different joint movements; and the squat and deadlift pose different trunk configurations, though no muscle activity was measured. However, the findings Hales et al. (2009) further support our findings of greater GM muscle activity in the front squat compared to the deadlift likely from increased hip flexion during the squat movement. Furthermore, greater hip flexion during the front squat and back squat causes a greater external lever arm resulting in higher demand for the hip flexors to contract (GM) in comparison to the deadlift exercise. Since the front squat has a frontal load placement vs the back squat having rear load placement, the front squat would have an even greater external lever arm in comparison to the back squat which likely lead to the differences observed in GM muscle activity between the front squat and deadlift.

One interesting finding of the current study is that some muscles during the three exercises actually produced greater muscle activity during the 3 repetitions at a 75% 1RM load than the 1RM trial (Table 3, Figure 2). It is plausible that there was more activation of stabilizing and accessory musculature during the 1RM than during the three repetitions at a 75% 1RM load. This could mean that there was more primary mover activation during the lower load trials (75% 1RM), but higher total motor unit recruitment during the 1RM and recruitment of additional muscle groups synergistic to GM. However, stabilizing and accessory muscles were not examined and future studies are needed to corroborate this postulation.

In conclusions, the front squat exercise elicited greater muscle activation of GM compared to the deadlift exercise likely due to greater hip flexion equating to greater external lever arm of the external load and subsequent higher muscle spindle activation. Strength and conditioning specialist and trainers can utilize these findings to address of synergistic dominance that can result in arthrokinetic dysfunction and injury.

CHAPTER III REFERENCES

Allen, C. C., Dean, K. A., Jung, A. P., & Petrella, J. K. (2013). Upper body muscular activation during variations of push-ups in healthy men. *International Journal of Exercise Science*, *6*(4), 278-288.

American College of Sports Medicine. (2018). *Guidelines for exercise testing and prescription*. Philadelphia, PA: Williams & Wilkins.

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning.* Champaign, IL: Human Kinetics.

Caterisano, A., Moss, R. E., Pellinger, T. K., Woodruff, K., Lewis, V. C., Booth, W., & Khadra, T. (2002). The effect of back squat depth on the EMG activity of 4 superficial hip and thigh muscles. *The Journal of Strength and Conditioning Research*, *16*(3), 428-432.

Clark, D. R., Lambert, M. I., & Hunter, A. M. (2012). Muscle activation in the loaded free barbell squat: A brief review. *The Journal of Strength and Conditioning Research*, *26*(4), 1169-1178.

Clark, M. A., Sutton, B. G., & Lucett, S. C. (2014). *NASM essentials of personal fitness training (revised).* Burlington, MA: Jones & Bartlett Publishing.

Cook, T. M., & Neumann, D. A. (1987). The effects of load placement on the EMG activity of the low back muscles during load carrying by men and women. *Ergonomics*, *30*(10), 1413-1423.

Escamilla, R. F. (2001). Knee biomechanics of the dynamic squat exercise. *Medicine & Science in Sports & Exercise*, *33*(1), 127-141.

Gullett, J. C., Tillman, M. D., Gutierrez, G. M., & Chow, J. W. (2009). A biomechanical comparison of back and front squats in healthy trained individuals. *The Journal of Strength and Conditioning Research*, *23*(1), 284-292.

Hales, M. E., Johnson, B. F., & Johnson, J. T. (2009). Kinematic analysis of the powerlifting style squat and the conventional deadlift during competition: Is there a cross-over effect between lifts? *The Journal of Strength and Conditioning Research*, *23*(9), 2574-2580.

Hamlyn, N., Behm, D. G., & Young, W. B. (2007). Trunk muscle activation during dynamic weight-training exercises and isometric instability activities. *The Journal of Strength and Conditioning Research, 21*(4), 1108-1112.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., & Hägg, G. (1999). European recommendations for surface electromyography. *Roessingh Research and Development*, *8*(2), 13-54.

Kang, J. I., Park, J. S., Choi, H., Jeong, D. K., Kwon, H. M., & Moon, Y. J. (2017). A study on muscle activity and ratio of the knee extensor depending on the types of squat exercise. *Journal of Physical Therapy Science*, *29*(1), 43-47.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2014). *Exercise physiology: Nutrition, energy, and human performance.* Philadelphia: Lippincott, Williams & Wilkins.

Wilk, K. E., Escamilla, R. F., Fleisig, G. S., Barrentine, S. W., Andrews, J. R., & Boyd, M. L. (1996). A comparison of tibiofemoral joint forces and electromyographic activity during open and closed kinetic chain exercises. *The American Journal of Sports Medicine*, *24*(4), 518-527.

Wright, G. A., DeLong, T. H., & Gehlsen, G. (1999). Electromyographic activity of the hamstrings during performance of the leg curl, stiff-leg deadlift, and back squat movements. *The Journal of Strength and Conditioning Research*, *13*(2), 168-174.

APPENDIX FOR STUDY I

# APPENDIX A

## IRB Letter of Approval

September 27, 2016

Investigator(s): Mr. Adam Korak / Dr. John M. Coons
Department: Health & Human Performance
Investigator(s) Email: jak5a@mtmail.mtsu.edu john.coons@mtsu.edu

Protocol Title: "COMPARISONS OF MUSCLE ACTIVATION AND VOLUME DURING TRADITIONAL AND ALTERNATIVE LOWER BODY RESISTANCE EXERCISES IN TRAINED WOMEN."

Protocol Number: 17-2023

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 and 21 CFR 56.110, and you have satisfactorily addressed all of the points brought up during the review.

Approval is granted for one (1) year from the date of this letter for 20 participants.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918. Any change to the protocol must be submitted to the IRB before implementing this change.

You will need to submit an end-of-project form to the Office of Compliance upon completion of your research located on the IRB website. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions. Failure to submit a Progress Report and request for continuation will automatically result in cancellation of your research study. Therefore, you will not be able to use any data and/or collect any data. Your study expires 9/27/2017.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete the required training. **If you add researchers to an approved project, please forward an updated list of researchers to the Office of Compliance before they begin to work on the project.**

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

Sincerely,

Richard C. Meeks DNP, RN, COI
Institutional Review Board
Middle Tennessee State University

# CHAPTER IV

# EFFECT OF A REST-PAUSE VS TRADITIONAL SQUAT ON ELECTROMYOGRAPHY AND LIFTING VOLUME IN TRAINED WOMEN

*Introduction*

Resistance training is performed by recreational weightlifters, powerlifters, bodybuilders, and athletes to increase muscular endurance, hypertrophy, strength, and/or power. The National Strength and Conditioning Association (NSCA) recommends at least one recovery day, but no more than three days, between sessions that stress the same muscle groups (Baechle & Earle, 2008). In conjunction with traditional training protocols, nontraditional resistance protocols can be beneficial to prevent or overcome plateaus, provide alterations within a mesocycle, and prevent mental fatigue during a training program (Keogh, Wilson, & Weatherby, 1999; Marshall, Robbins, Wrightson, & Siegler, 2012).

Rest-pause, defined as a brief inter-repetition unloaded rest period, is one example of a nontraditional resistance training protocol (Keogh et al., 1999). The rest-pause technique may lead to increases in muscle hypertrophy by permitting the completion of a greater total work volume during a training session (Baechle & Earle, 2008). Resistance training relies predominantly on the adenosine triphosphate-phosphocreatine (ATP-PCr) system for energy production which lasts approximately 10 seconds (McArdle, Katch, & Katch, 2014). The rest-pause method, in theory, should allow for greater creatine phosphate replenishment, allowing the ATP-PCr system to sustain muscular efforts for a longer duration.

Keogh et al. (1999) defined rest-pause as a 2 second unloaded rest period after each concentric repetition, and found participants averaged 1.3 more repetitions on the Smith machine bench press in comparison to a traditional protocol with a 6 repetition maximum (RM) load. The rest-pause group had lower muscle activity of the pectoralis major and triceps muscles in comparison to traditional training which suggests greater motor unit recruitment in different areas of the same muscle to lift the required workload. Marshall et al. (2012) found the rest-pause technique elicited higher muscle activity of six thigh and hip muscles in comparison to traditional five sets of four repetitions with 3 minutes rest, and five sets of four repetitions with 20 seconds rest at 80% 1RM for the squat exercise. Lastly Korak, Paquette, Fuller, and Coons (2016) indicated a 4 second inter-repetition rest significantly increased volume lifted over a 4 week training protocol in comparison to a traditional bench press protocol at 80% 1RM but the increase in 1RM was the same between training protocols. However, no significant differences were found in muscle activity of the pectoralis major muscle (Korak et al., 2016). These findings suggest that the rest-pause method may yield greater lifting volumes, but current findings on muscle activation between traditional and rest-pause training are conflicting. Further, research on differences between traditional and rest-pause training on lifting volume and muscle activity has only included male participants and upper body exercises (Hardee, Triplett, Utter, Zwetsloot & Mcbride, 2012; Iglesias-Soler et al., 2012).

Muscle activity has been found to increase linearly across sets to movement failure during traditional lifting protocols (Keogh et al. 1999). Interestingly, Joy, Oliver, McCleary, Lowery, and Wilson (2013) indicated muscle activity was significantly greater during the later repetitions during a traditional protocol at 75% 1RM for the back squat in comparison to a rest-pause method. These findings suggest muscle activity differs across sets between a rest-pause vs traditional lifting protocol.

Knowledge on how prime mover muscle activation and training volume are impacted by training technique can be helpful to strength and conditioning professionals, trainers, and therapists who wish to design programs to target adaptations in specific muscles to increase performance and prevent and/or treat injury. Therefore, the purpose of this study was to examine muscle activation patterns of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), and gluteus maximus (GM) using surface electromyography (EMG) and total volume lifted between a traditional and rest-pause back squat protocol in trained women. It was hypothesized that the rest-pause protocol would result in greater total volume lifted and produce larger percent change (%Δ) in muscle activity between the first and last repetitions of the testing sessions compared to the traditional protocol.

*Methods*

*Participants*

Participants included resistance trained women ($N$ = 13) with a minimum of 1 year lifting experience who had been actively participating in resistance training for 6 months prior to beginning the study. Descriptive statistics for  the participants characteristics are presented in Table 1. Participants were informed of the benefits and risks of the investigation prior to signing an informed consent document to participate in the study.

Table 1

*Descriptive Characteristics of Participants (N = 13)*

| Characteristic | *M* | *SD* |
|---|---|---|
| Age (year) | 22.8 | 3.1 |
| Height (cm) | 166.4 | 4.2 |
| Body mass (kg) | 73.4 | 14.0 |
| 1RM (lbs) | 168.3 | 26.1 |
| TL (lbs) | 134.8 | 21.2 |

*Note*. 1RM = 1 repetition maximum. TL = training load 80% of 1 repetition maximum.

This study was approved by the university Institutional Review Board prior to data collection (see Appendix A).

*Procedures*

Participants were required to attend three sessions spaced a minimum of 48 hours apart and were asked to refrain from alcohol consumption and lower body resistance training 48 hours prior to each session. Session one included completion of paper work and anthropometric measurements and a 1RM for the Smith machine back squat. Height was assessed using a stadiometer (SECA Corporation, Model 222, Germany) to the nearest 0.1 cm. Body mass was measured using a digital scale (SECA Corporation, Model 770, Germany) to the nearest 0.1 kg. To prepare for the 1RM, participants completed a warm up by walking on a treadmill for 3-5 minutes at a self-selected pace, followed by squatting with a load that could be performed for approximately 15 repetitions. A back squat1RM was then determined following the American College of Sports Medicine (2018) guidelines.

Participants reported for sessions two and three in a randomized order to perform the rest-pause and traditional lifting protocols. Upon arrival, the skin was prepped by exfoliation with redux paste, and hair was shaved, as necessary, to reduce signal impedance. Electromyography electrodes were secured to the skin using double-side adhesive tape over the VL, VM, RF, and GM muscles (Hermens et al., 1999; see Table 2) on participants' dominate leg defined as the leg used to kick a soccer ball. Adhesive stretch covering was placed over top of each electrode to further secure it to the skin. Electromyography data were obtained for all repetitions using a wireless system

Table 2

*Electromyography Electrode Placement Location*

| Muscle | Electrode placement |
|---|---|
| Vastus medialis | 4/5$^{ths}$ the distance between anterior spina iliaca superior and joint space in front of the anterior border of medial ligament |
| Vastus lateralis | 2/3$^{rds}$ the distance from anterior spina iliaca superior to lateral patella |
| Gluteus maximus | Half way between sacral vertebrae and greater trochanter |
| Rectus femoris | Half way between anterior spina iliaca superior and superior part of the patella |

(1996Hz, Trigno, Delsys, Natick, MA). As in session 1, participants walked on a treadmill at a self-selected pace for 3-5 minutes to warm-up. Participants then performed 15 repetitions with no weight placed on the bar. There was a 5 minute rest period between the end of the warm-up and the beginning of the training protocol.

The training protocols used a load of 80% of the 1RM from session 1. Participants' performed four sets to movement failure with 2 minutes rest between sets. Movement speeds were performed with a 2 second eccentric action followed by a 1 second concentric action set by a metronome. Movement failure was defined as two technique corrections being made or participants' inability to keep pace with the metronome. Participants were required to complete each repletion using a high bar placement across the posterior deltoids at the middle of the trapezius with feet shoulder width, toes facing forward, and descend until the thighs were parallel with the floor (Baechle & Earle, 2008). A bungee cord was placed this squat depth to ensure consistent form. For a repetition to be successful, participants had to touch the cord with their buttocks at the bottom of the squat.

During the rest-pause testing session, a 4 second unloaded rest period was included between each repetition following the concentric action while a 1 second loaded rest followed the concentric action during the traditional protocol. A Smith machine (Pro Elite Strength Systems, Salt Lake City, UT) was used with standard weights during all squats for increased safety during un-racking and re-racking the bar. Volume for each session was calculated by the product of sets, repetitions, and load (Baechle & Earle, 2008). A Certified Strength and Conditioning Specialist collected all data and ensured proper technique throughout all repetitions.

*EMG data processing*

A band-pass filter was applied with cut-off frequencies of 20 and 450 Hz, respectively. The signals were then full-wave rectified and smoothed using a root-mean-square (RMS) filter with a moving window of 250 ms (Allen, Dean, Jung, & Petrella, 2013). Muscle activity %Δ was calculated by subtracting the average of the peak amplitude of the last three repetitions of the fourth set from the average of the peak amplitude of the first three repetitions of the first set and then dividing by the average of the peak amplitude of the last three repetitions of the fourth set. Total muscle activity (i.e., both eccentric and concentric phases) was included in the analysis.

*Statistical analyses*

An alpha of .05 was used for all statistical procedures. Two paired samples *t*-tests were used to compare volume and repetition differences from the rest-pause and traditional squat protocols. Additional paired samples *t*-tests were used to determine muscle activity %Δ differences between the rest-pause and traditional squat protocols for each of the four muscles. Effect sizes were calculated for all analyses using Cohen's *d*. Participants' muscle activity data were removed from statistical analysis if their recordings were ±2 SD from the sample mean. One outlier was removed for the VM EMG data analysis while two outliers were removed for RF EMG data analysis. Further, muscle activity data were not recorded during the testing protocol for one participant who had to be removed from the EMG analyses.

*Results*

Descriptive statistics for volume and repetitions are shown in Table 3. Total volume lifted was significantly higher for the rest pause protocol in comparison to the

Table 3

*Differences between Volume and Total Repetitions Completed*

| | Traditional | | Rest-pause | |
|---|---|---|---|---|
| Variable | *M* | *SD* | *M* | *SD* |
| Volume (lbs) * | 4,489 | 1,214 | 5,584 | 1,595 |
| Total repetitions* | 33.2 | 6.7 | 41.8 | 10.5 |

*Note*. *Significant group difference; $p < .05$.

traditional protocol, $t$ (12) = 3.49, $p < .01$, $d$ = .50.

The increase in GM %Δ muscle activity was greater in the traditional protocol in comparison to the rest-pause protocol, $p$ = .03, $d$ = .36 (see Table 4 and Figure 1). However, no significant differences were found in VM for traditional versus rest-pause, $t$ (10) = 1.37, $p$ = .20, $d$ = .16, in VL for traditional versus rest-pause, $t$ (11) = 1.51, $p$ = .16, $d$ = .17, and in RF for traditional versus rest-pause training, $t$ (9) = 1.21, $p$ = .26, $d$ = .14.

*Discussion*

Differences in volume and muscle activity during the back squat exercise to movement failure using a traditional and a rest-pause protocol in trained women were assessed in this study. Our hypothesis of greater lifting volume following the rest-pause protocol was supported while the hypothesis of greater %Δ muscle activity in the rest-pause protocol was not supported. No group differences were observed for %Δ muscle activity of the VM, VL, and RF, but GM %Δ muscle activity was significantly greater following the traditional protocol compared to the rest-pause protocol.

For both lifting techniques, participants completed four sets to movement failure, likely leading to the depletion of the substrate creatine phosphate which resynthesizes ATP from adenosine diphosphate (McArdle et al., 2014). Because the rest-pause protocol had a greater inter-repetition rest period than the traditional protocol (i.e., 4 seconds of unloaded rest compared to 1 second loaded rest following concentric contraction), it is plausible there was greater replenishment of creatine phosphate during the rest-pause sets, thereby delaying movement failure. This could have contributed to the significantly greater volume achieved during the rest-pause session. Participants performed an average of 2.2 more repetitions for each set completed during the rest-pause compared to the

Table 4

*Muscle Activity %Δ*

| Muscle | Traditional *M* | Traditional *SD* | Rest-pause *M* | Rest-pause *SD* |
|---|---|---|---|---|
| Vastus medialis (*N* = 11) | 11.9 | 16.5 | 2.6 | 15.8 |
| Vastus lateralis (*N* = 12) | 4.8 | 11.3 | -8.3 | 29.6 |
| Gluteus maximus (*N* = 12) * | 27.1 | 29.2 | 10.6 | 29.8 |
| Rectus femoris (*N* = 10) | -0.3 | 13.0 | -11.2 | 27.7 |

*Note*. *Significant group difference; $p < .05$.

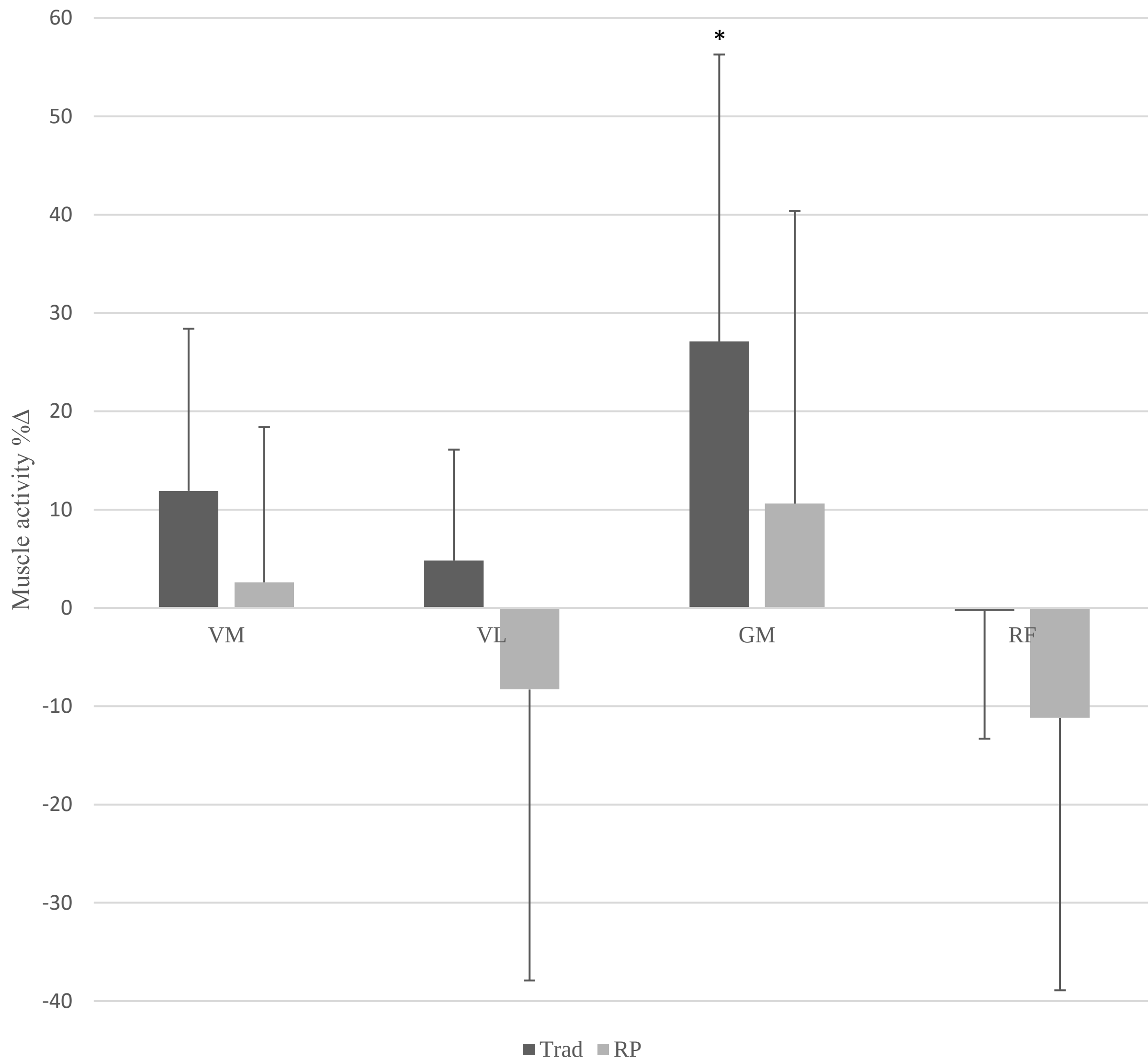


*Figure 1*. Muscle activity %Δ. Values are mean ± standard deviation. Trad = Traditional. RP = Rest-pause. VM = vastus medialis. VL = vastus lateralis. GM = gluteus maximus. RF = rectus femoris. * = $p < .05$.

traditional protocol. This finding agrees with Keogh et al. (1999) who found participants completed 1.3 more repetitions, on average, during a rest-pause bench press with a 6RM load compared to a traditional protocol. Furthermore, Korak et al. (2016) indicated males achieved 2.4 more repetitions per set during a rest-pause protocol comparted to a traditional protocol performing four sets of bench press to movement failure at 80% 1RM load. As the magnitude of hypertrophy increases has been linked to a combination of lifting heavy loads, inclusion of eccentric muscle actions, greater recruitment of muscle fibers, and increases in lifting volume (Kraemer & Ratamess, 2004), these results may be beneficial during a hypertrophy mesocycle where a key focus is total volume lifted.

Our second hypothesis was not supported as a greater increase in GM muscle activity %Δ was observed in the traditional protocol compared to the rest-pause protocol. While, the majority of studies assessing differences in muscle activity between rest-pause and traditional lifting protocols have also included protocols with matched lifting volume (Denton & Cronin, 2006; Hansen, Cronin, & Newton 2011; Hardee et al., 2012; Iglesias-Soler et al., 2012; Joy et al., 2013; Lawton, Cronin, Drinkwater, Lindsell, & Pyne, 2004; Lawton, Cronin, & Lindsell, 2006; Marshall et al., 2012), to the authors' knowledge, muscle activity to movement failure has only previously been assessed by Keogh et al. (1999), and Korak et al. (2016). Keogh et al. (1999) found a rest-pause bench press elicited lower mean pectoralis major muscle activity and triceps brachii during the later repetitions compared to a traditional protocol with a 6RM load, though large standard deviations were observed. Muscle activity is known to increase across a traditional set as more motor units are activated when muscle fibers movement failure (Gonzalez-Izal et al., 2010; Keogh et al., 1999; Marshall et al., 2012). However, it must be noted different normalization methods occurred with Keogh et al. (1999) normalizing data to a percentage of a 110° maximal voluntary isometric contraction (MVIC) bench press, and Marshall et al. (2012) normalizing repetitions 5-20 as a %Δ from repetitions 1-4.

Our finding of greater %Δ muscle activity in the GM during a traditional lifting protocol compared to rest-pause is in agreement with Joy et al. (2013) who found muscle activity was greater during the later repetitions. While different normalization procedures occurred and separate muscles were evaluated, the results are similar between studies. The current authors are in agreement with Joy et al. (2013) who hypothesized a traditional protocol recruits greater type I muscle fibers as fatigue reduces the activity of the higher threshold type II fibers. This, in theory, means the rest-pause method results in less recruitment of type I muscle fibers which would equate to the lower muscle activity observed in the later repetitions of the GM. Furthermore, the traditional protocol is more demanding on the GM at the end of sets to movement failure due to lack of interrepetition rest causing greater muscle activation recruitment to overcome the external load. Future studies are needed to examine muscle activity across sets to movement failure between a rest-pause and a traditional lifting protocol.

One possible limitation to the current study is the different normalization method used for examining muscle activity via EMG. There is a brevity of previous research examining muscle activity to movement failure. Future studies should use consistent normalization procedures when examining muscle activity to movement failure.

*Conclusions*

Present findings indicate that utilizing a rest-pause protocol elicits greater total volume lifted, via increased repetitions, compared to a traditional protocol in trained women. These data indicate that the rest-pause method may be a superior to a traditional method of training during a hypertrophy mesocycle, where a main focus is total volume lifted. Furthermore, %Δ muscle activity in the GM will be greater while performing a traditional back squat protocol in comparison to a rest-pause.

# CHAPTER IV REFERENCES

Allen, C. C., Dean, K. A., Jung, A. P., & Petrella, J. K. (2013). Upper body muscular activation during variations of push-ups in healthy men. *International Journal of Exercise Science*, *6*(4), 278-288.

American College of Sports Medicine. (2018). *Guidelines for exercise testing and prescription*. Philadelphia, PA: Williams & Wilkins.

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning.* Champaign, IL: Human Kinetics.

Denton, J., & Cronin, J. B. (2006). Kinematic, kinetic, and blood lactate profiles of continuous and intraset rest loading schemes. *The Journal of Strength & Conditioning Research*, *20*(3), 528-534.

Gonzalez-Izal, M., Malanda, A., Navarro-Amezqueta, I., Gorostiaga, E. M., Mallor, F., Ibanez, J., & Izquierdo, M. (2010). EMG spectral indices and muscle power fatigue during dynamic contractions. *Journal of Electromyography and Kinesiology*, *20*(2), 233-240.

Hansen, K. T., Cronin, J. B., & Newton, M. J. (2011). The effect of cluster loading on force, velocity, and power during ballistic jump squat training. *International Journal of Sports Physiology and Performance*, *6*(4), 455-468.

Hardee, J. P., Triplett, N. T., Utter, A. C., Zwetsloot, K. A., & Mcbride, J. M. (2012). Effect of interrepetition rest on power output in the power clean. *The Journal of Strength & Conditioning Research*, *26*(4), 883-889.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., & Hägg, G. (1999). European recommendations for surface electromyography. *Roessingh Research and Development*, *8*(2), 13-54.

Iglesias-Soler, E., Carballeira, E., Sanchez-Otero, T., Mayo, X., Jimenez, A., & Chapman, M. L. (2012). Acute effects of distribution of rest between repetitions. *International Journal of Sports Medicine*, *33*(05), 351-358.

Joy, J. M., Oliver, J. M., McCleary, S. A., Lowery, R. P., & Wilson, J. M. (2013). Power output and electromyography activity of the back squat exercise with cluster sets. *Journal of Sports Science*, *1*, 37-45.

Keogh, J. W., Wilson, G. J., & Weatherby, R. E. (1999). A cross-sectional comparison of different resistance training techniques in the bench press. *The Journal of Strength and Conditioning Research*, *13*(3), 247-258.

Korak, J. A., Paquette, M. R., Fuller, D. K., & Coons, J. M. (2016). *Effect of rest-pause vs traditional bench press training on muscle strength, electromyography and lifting volume.* Poster session presented at the Annual Meeting of the American College of Sports Medicine, Boston, MA.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine and Science in Sports and Exercise*, *36*(4), 674-688.

Lawton, T., Cronin, J., Drinkwater, E., Lindsell, R., & Pyne, D. (2004). The effect of continuous repetition training and intra-set rest training on bench press strength and power. *Journal of Sports Medicine and Physical Fitness*, *44*(4), 361.

Lawton, T. W., Cronin, J. B., & Lindsell, R. P. (2006). Effect of interrepetition rest intervals on weight training repetition power output. *The Journal of Strength and Conditioning Research*, *20*(1), 172-176.

Marshall, P. W., Robbins, D. A., Wrightson, A. W., & Siegler, J. C. (2012). Acute neuromuscular and fatigue responses to the rest-pause method. *Journal of Science and Medicine in Sport*, *15*(2), 153-158.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2014). *Exercise physiology: Nutrition, energy, and human performance.* Philadelphia: Lippincott Williams & Wilkins.

APPENDIX FOR STUDY II

APPENDIX A

IRB Letter of Approval

September 27, 2016

Investigator(s): Mr. Adam Korak / Dr. John M. Coons
Department: Health & Human Performance
Investigator(s) Email: jak5a@mtmail.mtsu.edu john.coons@mtsu.edu

Protocol Title: "COMPARISONS OF MUSCLE ACTIVATION AND VOLUME DURING TRADITIONAL AND ALTERNATIVE LOWER BODY RESISTANCE EXERCISES IN TRAINED WOMEN."

Protocol Number: 17-2023

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 and 21 CFR 56.110, and you have satisfactorily addressed all of the points brought up during the review.

Approval is granted for one (1) year from the date of this letter for 20 participants.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918. Any change to the protocol must be submitted to the IRB before implementing this change.

You will need to submit an end-of-project form to the Office of Compliance upon completion of your research located on the IRB website. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions. Failure to submit a Progress Report and request for continuation will automatically result in cancellation of your research study. Therefore, you will not be able to use any data and/or collect any data. Your study expires 9/27/2017.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete the required training. **If you add researchers to an approved project, please forward an updated list of researchers to the Office of Compliance before they begin to work on the project.**

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

Sincerely,

Richard C. Meeks DNP, RN, COI
Institutional Review Board
Middle Tennessee State University

# CHAPTER V

## PROJECT CONCLUSIONS

This dissertation was designed to measure volume and muscle activation patterns during traditional and rest-pause lower body exercises in resistance trained females. The first study was designed to examine muscle activation patterns across the RF, VL, VM, BF, and GM muscles among the front squat, back squat, and deadlift exercises. The purpose of the second study was to compare total load lifted and muscle activation patterns of the RF, VL, VM, and GM muscles while performing a traditional vs rest-pause squat to fatigue.

In study 1, female participants performed 3 repetitions of the back squat, front squat, and deadlift exercises with a 75% 1RM load. Muscle activity was measured via EMG among five lower body muscles. The front squat exercise was found to have significantly higher muscle activity of the GM in comparison to the deadlift exercise. It is postulated that the significantly higher muscle activity in the GM during the front squat was due to greater muscle spindle activation due to the lower depth achieved from greater knee and hip flexion and subsequent increased muscle fiber contractions. No other significant differences were found among the remaining four muscles. The findings of study 1 can be used by strength and conditioning specialist and trainers to address issues of synergistic dominance that may result in arthrokinetic dysfunction linked with injury. If the hamstrings for example, start to take over the prime mover role of the GM, the front squat should be prescribed by professionals to increase motor unit recruitment.

Participants in study 2 performed a rest-pause squat and traditional squat by completing 4 sets to fatigue at 80% 1RM load with 2 minutes rest between sets. Volume totals were calculated and muscle activity was observed for the VM, VL, GM, and RF as a percent change (%Δ). The rest-pause protocol was found to have significantly greater volume achieved in comparison to the traditional group, while the GM in the traditional protocol was found to have significantly greater muscle activity %Δ. The longer time between repetitions during the rest-pause protocol allowed for greater replenishment of the substrate creatine phosphate which likely allowed longer reliance on the adenosine triphosphate-phosphocreatine energy system resulting in significantly higher volume. Furthermore, the authors postulate the greater GM muscle activity in the traditional protocol was due to muscle activity following a linear trend that increases across sets while the rest-pause protocol followed a non-linear trend such as a bell curve. No other muscle activity differences were observed for the remaining three muscles. Therefore, if volume is the key goal during a mesocycle, strength and conditioning specialist and trainers should utilize the rest-pause technique which will result in greater overall volume lifted.

In conclusion, alternative resistance techniques can successfully result in greater lifting volume and provide alterations within a mesocycle. Furthermore, the front squat will elicit greater muscle activity in the GM compared to the back squat and deadlift exercises. Strength and conditioning specialist and trainers can utilize these results to achieve greater lifting volume and address synergistic dominance issues.

# REFERENCES

Alkner, B. A., Tesch, P. A., & Berg, H. E. (2000). Quadriceps EMG/force relationship in knee extension and leg press. *Medicine & Science in Sports & Exercise*, *32*(2), 459-463.

American College of Sports Medicine. (2014). *Guidelines for exercise testing and prescription*. Philadelphia, PA: Williams & Wilkins.

Anderson, K., & Behm, D. G. (2005). Trunk muscle activity increases with unstable squat movements. *Canadian Journal of Applied Physiology*, *30*(1), 33-45.

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning.* Champaign, IL: Human Kinetics.

Ball, N., & Scurr, J. (2013). Electromyography normalization methods for high velocity muscle actions: Review and recommendations. *Journal of Applied Biomechanics*, *29*(5), 600-608.

Basmajian, J. V., & De Luca, C. J. (1985). *Muscles alive: their functions revealed by electromyography*. Philadelphia, PA: Williams & Wilkins.

Beck, T. W., Housh, T. J., Cramer, J. T., Malek, M. H., Mielke, M., Hendrix, R., & Weir, J. P. (2008). Electrode shift and normalization reduce the innervation zone's influence on EMG. *Medicine & Science in Sports & Exercise*, *40*(7), 1314-1322.

Bigard, A. X., Sanchez, H., Claveyrolas, G., Martin, S, Thimonier, B., & Arnaud, M. J. (2001). Effects of dehydration and rehydration on EMG changes during fatiguing contractions. *Medicine & Science in Sports & Exercise*, *33*(10), 1694-1700.

Bogdanis, G. C., Nevill, M. E., Boobis, L. H., Lakomy, H. K., & Nevill, A. M. (1995). Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *The Journal of Physiology*, *482*(2), 467-480.

Bonato, P., Alessio, T. D., & Knaflitz, M. (1998). A statistical method for the measurement of muscle activation intervals from surface myoelectric signal during gait. *IEEE Transactions on Biomedical Engineering*, *45*(3), 287-299.

Bressel, E., Willardson, J. M., Thompson, B., & Fontana, F. E. (2009). Effect of instruction, surface stability, and load intensity on trunk muscle activity. *Journal of Electromyography and Kinesiology*, *19*(6), e500-e504.

Burden, A. (2010). How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25years of research. *Journal of Electromyography and Kinesiology*, *20*(6), 1023-1035.

Carpentier, A., Duchateau, J., & Hainaut, K. (1996). Velocity-dependent muscle strategy during plantarflexion in humans. *Journal of Electromyography and Kinesiology*, *6*(4), 225-233.

Caterisano, A., Moss, R. E., Pellinger, T. K., Woodruff, K., Lewis, V. C., Booth, W., & Khadra, T. (2002). The effect of back squat depth on the EMG activity of 4 superficial hip and thigh muscles. *The Journal of Strength and Conditioning Research*, *16*(3), 428-432.

Clark, D. R., Lambert, M. I., & Hunter, A. M. (2012). Muscle activation in the loaded free barbell squat: A brief review. *The Journal of Strength and Conditioning Research*, *26*(4), 1169-1178.

Clark, B. C., Manini, T. M., Doldo, N. A., & Ploutz-Snyder, L. L. (2003). Gender differences in skeletal muscle fatigability are related to contraction type and EMG spectral compression. *Journal of Applied Physiology*, *94*(6), 2263-2272.

Cotterman, M. L., Darby, L. A., & Skelly, W. A. (2005). Comparison of muscle force production using the Smith machine and free weights for bench press and squat exercises. *The Journal of Strength & Conditioning Research*, *19*(1), 169-176.

Criswell, E. (2011). *Cram's introduction to surface electromyography.* Sudbury, MA: Jones and Bartlett Publishers.

Dankaerts, W., O'Sullivan, P. B., Burnett, A. F., Straker, L. M., & Danneels, L. A. (2004). Reliability of EMG measurements for trunk muscles during maximal and sub-maximal voluntary isometric contractions in healthy controls and CLBP patients. *Journal of Electromyography and Kinesiology*, *14*(3), 333-342.

Dawson, B., Goodman, C., Lawrence, S., Preen, D., Polglaze, T., Fitzsimons, M., & Fournier, P. (1997). Muscle phosphocreatine repletion following single and repeated short sprint efforts. *Scandinavian Journal of Medicine & Science in Sports*, *7*(4), 206-213.

De Luca, C. J., & Merletti, R. (1988). Surface myoelectric signal cross-talk among muscles of the leg. *Electroencephalography and Clinical Neurophysiology*, *69*(6), 568-575.

De Luca, G. (2003). Fundamental concepts in EMG signal acquisition. *Copyright Delsys Inc.*

De Luca, C. J., Gilmore, L. D., Kuznetsov, M., & Roy, S. H. (2010). Filtering the surface EMG signal: Movement artifact and baseline noise contamination. *Journal of Biomechanics*, *43*(8), 1573-1579.

Drinkwater, E. J., Galna, B., McKenna, M. J., Hunt, P. H., & Pyne, D. B. (2007). Validation of an optical encoder during free weight resistance movements and analysis of bench press sticking point power during fatigue. *The Journal of Strength and Conditioning Research*, *21*(2), 510-517.

Escamilla, R. F., Fleisig, G. S., Zheng, N., Barrentine, S. W., Wilk, K. E., & Andrews, J. R. (1998). Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises. *Medicine & Science in Sports & Exercise*, *30*(4), 556-569.

Escamilla, R. F., Fleisig, G. S., Zheng, N., Lander, J. E., Barrentine, S. W., Andrews, J. R., . . . Moorman, C. T. (2001). Effects of technique variations on knee biomechanics during the squat and leg press. *Medicine & Science in Sports & Exercise*, *33*(9), 1552-1566.

Floyd, W. F., & Silver, P. H. S. (1955). The function of the erectores spinae muscles in certain movements and postures in man. *The Journal of Physiology*, *129*(1), 184.

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, *23*(5), 567-589.

Fukuda, T. Y., Alvarez, A. S., Nassri, L. F. G., & Godoy, C. M. G. D. (2008). Quantitative electromyographic assessment of facial muscles in cross-bite female children. *Brazilian Journal of Biomedical Engineering*, *24*(2), 121-129.

Fukuda, T. Y., Echeimberg, J. O., Pompeu, J. E., Lucareli, P. R. G., Garbelotti, S., Gimenes, R. O., & Apolinário, A. (2010). Root mean square value of the electromyographic signal in the isometric torque of the quadriceps, hamstrings and brachial biceps muscles in female subjects. *The Journal of Applied Research*, *10*(1), 32-39.

Gullett, J. C., Tillman, M. D., Gutierrez, G. M., & Chow, J. W. (2009). A biomechanical comparison of back and front squats in healthy trained individuals. *The Journal of Strength and Conditioning Research*, *23*(1), 284-292.

Hales, M. E., Johnson, B. F., & Johnson, J. T. (2009). Kinematic analysis of the powerlifting style squat and the conventional deadlift during competition: Is there a cross-over effect between lifts? *The Journal of Strength and Conditioning Research*, *23*(9), 2574-2580.

Hamlyn, N., Behm, D. G., & Young, W. B. (2007). Trunk muscle activation during dynamic weight-training exercises and isometric instability activities. *The Journal of Strength and Conditioning Research*, *21*(4), 1108-1112.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., & Hägg, G. (1999). European recommendations for surface electromyography. *Roessingh Research and Development*, *8*(2), 13-54.

Hicks, A. L., Kent-Braun, J., & Ditor, D. S. (2001). Sex differences in human skeletal muscle fatigue. *Exercise and Sport Sciences Reviews*, *29*(3), 109-112.

Hunter, S. K., & Enoka, R. M. (2001). Sex differences in the fatigability of arm muscles depends on absolute force during isometric contractions. *Journal of Applied Physiology*, *91*(6), 2686-2694.

Hunter, S. K., Critchlow, A., Shin, I. S., & Enoka, R. M. (2004). Fatigability of the elbow flexor muscles for a sustained submaximal contraction is similar in men and women matched for strength. *Journal of Applied Physiology*, *96*(1), 195-202.

Inman, V. T., & Abbott, L. C. (1944). Observations on the function of the shoulder joint. *Journal of Bone & Joint Surgery*, *26*(1), 1-30.

Joy, J. M., Oliver, J. M., McCleary, S. A., Lowery, R. P., & Wilson, J. M. (2013). Power output and electromyography activity of the back squat exercise with cluster sets. *Journal of Sports Science*, *1*, 37-45.

Keogh, J. W., Wilson, G. J., & Weatherby, R. E. (1999). A cross-sectional comparison of different resistance training techniques in the bench press. *The Journal of Strength and Conditioning Research*, *13*(3), 247-258.

Knutson, L. M., Soderberg, G. L., Ballantyne, B. T., & Clarke, W. R. (1994). A study of various normalization procedures for within day electromyographic data. *Journal of Electromyography and Kinesiology*, *4*(1), 47-59.

Konrad, P. (2005). The ABC of EMG. *A practical introduction to kinesiological electromyography, 1*.

Korak, J.A., Paquette, M.R., Fuller, D.K., & Coons, J.M. (2016, June). *Effect of rest-pause vs traditional bench press training on muscle strength, electromyography and lifting volume.* Poster session presented at the Annual Meeting of the American College of Sports Medicine, Boston, MA.

Krause, D. A., Jacobs, R. S., Pilger, K. E., Sather, B. R., Sibunka, S. P., & Hollman, J. H. (2009). Electromyographic analysis of the gluteus medius in five weight-bearing exercises. *The Journal of Strength and Conditioning Research*, *23*(9), 2689-2694.

Krol, H., Sobota, G., & Nawrat, A. (2007). Effect of electrode position on EMG recording in pectoralis major. *Journal of Human Kinetics*, *17*, 105.

Laforest, S., St-Pierre, D. M., Cyr, J., & Gayton, D. (1990). Effects of age and regular exercise on muscle strength and endurance. *European Journal of Applied Physiology and Occupational Physiology*, *60*(2), 104-111.

Lawton, T. W., Cronin, J. B., & Lindsell, R. P. (2006). Effect of interrepetition rest intervals on weight training repetition power output. *The Journal of Strength and Conditioning Research*, *20*(1), 172-176.

Marshall, P. W., Robbins, D. A., Wrightson, A. W., & Siegler, J. C. (2012). Acute neuromuscular and fatigue responses to the rest-pause method. *Journal of Science and Medicine in Sport*, *15*(2), 153-158.

Maughan, R. J., Harmon, M., Leiper, J. B., Sale, D., & Delman, A. (1986). Endurance capacity of untrained males and females in isometric and dynamic muscular contractions. *European Journal of Applied Physiology and Occupational Physiology*, *55*(4), 395-400.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2014). *Exercise physiology: nutrition, energy, and human performance.* Philadelphia: Lippincott Williams & Wilkins.

McCall, S. T., & Melrose, D. R. (1999). Stance width and bar load effects on leg muscle activity during the parallel squat. *Medicine & Science in Sports & Exercise*, *31*(3), 428-436.

Mero, A. A., & Komi, P. V. (1987). Electromyographic activity in sprinting at speeds ranging from sub-maximal to supra-maximal. *Medicine & Science in Sports & Exercise*, *19*(3), 266-274.

Miller, A. E. J., MacDougall, J. D., Tarnopolsky, M. A., & Sale, D. G. (1993). Gender differences in strength and muscle fiber characteristics. *European Journal of Applied Physiology and Occupational Physiology*, *66*(3), 254-262.

Mizuno, Y., Kumagai, M., Mattessich, S. M., Elias, J. J., Ramrattan, N., Cosgarea, A. J., & Chao, E. (2001). Q-angle influences tibiofemoral and patellofemoral kinematics. *Journal of Orthopedic Research*, *19*(5), 834-840.

Nuzzo, J. L., McCaulley, G. O., Cormie, P., Cavill, M. J., & McBride, J. M. (2008). Trunk muscle activity during stability ball and free weight exercises. *The Journal of Strength and Conditioning Research*, *22*(1), 95-102.

Pereira, G. R., Leporace, G., das Virgens Chagas, D., Furtado, L. F., Praxedes, J., & Batista, L. A. (2010). Influence of hip external rotation on hip adductor and rectus femoris myoelectric activity during a dynamic parallel squat. *The Journal of Strength and Conditioning Research*, *24*(10), 2749-2754.

Pincivero, D. M., & Coelho, A. J. (2000). Activation linearity and parallelism of the superficial quadriceps across the isometric intensity spectrum. *Muscle & Nerve*, *23*(3), 393-398.

Pincivero, D. M., Coelho, A. J., Campy, R. M., Salfetnikov, Y., & Suter, E. (2003). Knee extensor torque and quadriceps femoris EMG during perceptually-guided isometric contractions. *Journal of Electromyography and Kinesiology*, *13*(2), 159-167.

Paoli, A., Marcolin, G., & Petrone, N. (2009). The effect of stance width on the electromyographical activity of eight superficial thigh muscles during back squat with different bar loads. *The Journal of Strength and Conditioning Research*, *23*(1), 246-250.

Reaz, M. B. I., Hussain, M. S., & Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: Detection, processing, classification and applications. *Biological Procedures Online*, *8*(1), 11-35.

Schwanbeck, S., Chilibeck, P. D., & Binsted, G. (2009). A comparison of free weight squat to Smith machine squat using electromyography. *The Journal of Strength and Conditioning Research*, *23*(9), 2588-2591.

Signorile, J. F., Weber, B., Roll, B., Caruso, J. F., Lowensteyn, I., & Perry, A. C. (1994). An electromyographical comparison of the squat and knee extension exercises. *The Journal of Strength and Conditioning Research*, *8*(3), 178-183.

Signorile, J. F., Kwiatkowski, K., Caruso, J. F., & Robertson, B. (1995). Effect of foot position on the electromyographical activity of the superficial quadriceps muscles during the parallel squat and knee extension. *The Journal of Strength and Conditioning Research*, *9*(3), 182-187.

Smilios, I., Häkkinen, K., & Tokmakidis, S. P. (2010). Power output and electromyographic activity during and after a moderate load muscular endurance session. *The Journal of Strength and Conditioning Research*, *24*(8), 2122-2131.

Van Vugt, J. P. P., & Van Dijk, J. G. (2001). A convenient method to reduce crosstalk in surface EMG. *Clinical Neurophysiology*, *112*(4), 583-592.

Wilk, K. E., Escamilla, R. F., Fleisig, G. S., Barrentine, S. W., Andrews, J. R., & Boyd, M. L. (1996). A comparison of tibiofemoral joint forces and electromyographic activity during open and closed kinetic chain exercises. *The American Journal of Sports Medicine*, *24*(4), 518-527.

Willardson, J., Fontana, F. E., & Bressel, E. (2009). Effect of surface stability on core muscle activity for dynamic resistance exercises. *International Journal of Sports Physiology and Performance*, *4*, 97-109.

Wretenberg, P. E. R., Feng, Y. I., & Arborelius, U. P. (1996). High-and low-bar squatting techniques during weight-training. *Medicine & Science in Sports & Exercise*, *28*(2), 218-224.

Wright, G. A., DeLong, T. H., & Gehlsen, G. (1999). Electromyographic activity of the hamstrings during performance of the leg curl, stiff-leg deadlift, and back squat movements. *The Journal of Strength and Conditioning Research*, *13*(2), 168-174.

Wu, C. H. (1984). Electric fish and the discovery of animal electricity: the mystery of the electric fish motivated research into electricity and was instrumental in the emergence of electrophysiology. *American Scientist*, *72*(6), 598-607.

Zeller, B. L., McCrory, J. L., Kibler, W. B., & Uhl, T. L. (2003). Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *The American Journal of Sports Medicine, 31*(3), 449-456.

Zink, A. J., Whiting, W. C., Vincent, W. J., & McLaine, A. J. (2001). The effects of a weight belt on trunk and leg muscle activity and joint kinematics during the squat exercise. *The Journal of Strength and Conditioning Research*, *15*(2), 235-240.