INVESTIGATIONS OF OPTIMAL LOADING DURING RESISTANCE TRAINING

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I would like to dedicate this work first and foremost to my wife, Brittany Mehls. Without your continued love and support throughout these years this would not have been possible. I would also like to dedicate this to my family and friends. Your constant visits, love and support as I pursued this degree have helped make this possible. Finally, to the coaches that taught that showing up and working the plan will lead you to success, you will never truly know the impact your friendship and mentorship has had on my life.

This is dedicated to all of you.

I love you all,

Kelton

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ABSTRACT

Resistance training is widely accepted as a superior method for enhancing muscle size, strength, and athletic performance, making appropriate resistance training prescription a priority for strength coaches and personal trainers. The purpose of the first study was to identify the loads that produced the greatest amount of muscle activity in the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), gluteus maximus (GM), semitendinosus (ST), and bicep femoris (BF) muscles in resistance trained females (N = 20). The second study aimed to determine the training load which optimizes peak power (PP) output and peak rate of force development (RFD) in male youth athletes during the hang power clean (N = 16).

When examining the muscle activity of the six muscles during the back squat, the most interesting finding was that the GM produced more muscle activity at 80% and 90% of one-repetition maximum (1RM) than at 1RM (ratios of 1.01 and 1.03, respectively) during the ascending phase of the squat. It was also found that the VM produced its greatest amount of muscle activity at 80% of 1RM in both the descending and ascending phase of the squat (ratios of 1.11 and 1.03, respectively). Strength coaches and trainers can use this information to prescribe specific loads to target muscles during the back squat.

The second study examined the load which optimizes PP and peak RFD in youth athletes during the hang power clean. It was found that PP was greatest at 80% of 1RM which was significantly greater than 30%, 40%, 50%, and 60% ($p < 0.05$) of 1RM, but not significantly greater than 70% or 90% of 1RM. Peak RFD was greatest at 70% of

1RM (11663.672 $N \cdot Sec^{-1}$) which was significantly greater than 30% and 40% ($p < 0.05$) of 1RM, but not significantly greater than 50%, 60%, 80% or 90% of 1RM. Strength and conditioning practitioners should use this knowledge to prescribe loads to maximize PP and RFD based on the athlete and goal of the training session.

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CHAPTER I: DISSERTATION INTRODUCTION

Resistance training promotes increases in muscular strength, hypertrophy, and power and enhances neuromuscular activation in trained muscles, making optimal resistance training prescription vital for fitness professionals. Currently the National Academy of Sports Medicine (NASM) and the National Strength and Conditioning Association (NSCA) provide models and recommendations outlining prescription applications for resistance training. Both organizations advocate that resistance training prescription follow the principles of overload, specificity, and variability to ensure that biomechanical and bioenergetic needs of the client or athlete are met (Haff & Triplett, 2015; Kraemer & Ratamess, 2004; Ratamess, Alvar, Evetoch, Housh, Kibler, & Kraemer, 2009; Stone, Collins, Plisk, Haff, & Stone, 2000). Applying these principals to resistance training requires the manipulation of several training variables, one of which is training load. To achieve specific muscular adaptations the proper training load must be applied to promote gains in strength, hypertrophy, and power and enhancement of neuromuscular activation (Mangine, Hoffman, Fukuda, Stout, Ratamess, 2015; Ratamess et al., 2009).

The National Academy of Sports Medicine promotes resistance training as an intervention to correct muscle imbalances, a state in which some muscles are overactive while others are underactive (Clark, Lucett, McGill, Montel, & Sutton, 2018). Training to correct muscle imbalance requires that overactive muscles be stretched, and underactive muscles be strengthened by using integrative dynamic movements to target underactive muscles during a functional movement pattern (Clark, Lucett, & Sutton, 2014). The squat is a common dynamic lower body training exercise used to complete this task. However, the squat is a movement which requires the use of several muscle groups across several joints, thus isolating a muscle group can be difficult and requires the identification of the optimal load which will target specific muscle groups.

Investigations regarding changes in muscle activity with varying training load have primarily assessed if sets until failure at light loads can recruit the full motor unit pool as well as heavy loads. However, these investigations have produced varying results, likely because of differences in training status of the participants, training loads prescribed, and the selected exercises. Several studies have found no differences in peak muscle activity between high and low training loads when sets are performed until failure in the leg press and bench press (Gonzalez, Ghigiarelli, Sell, Shone, Kelly, & Mangine, 2017; Schoenfeld, Contreras, Vigotsky, Ogborn, Fontana, & Tiryaki-Sonmez, 2016). Other studies have shown that higher training loads result in higher peak muscle activity in the squat, leg press, and leg extension (Looney et al., 2016; Jenkins et al., 2015; Schoenfeld, Peterson, Ogborn, Contreras, & Somez, 2015). While these studies discussed the differences in peak muscle activity between high and low loading conditions, currently no studies have assessed the peak muscle activity across a variety of loads.

Optimal training load must also be considered when training to increase muscular power in athletes because muscular power is an important predictor of athletic performance (Haff, Whitely, & Potteiger, 2001). It has been suggested that to increase maximal power production, athletes should train at or near maximal power output (Wilson, Newton, Murphy, & Humphries, 1993). This belief has led to several investigations identifying the load which maximizes PP in various athletic groups; though variations in methodology, loading schemes, training status of participants, and competency with the lifts has led to mixed results.

In professional rugby players the current literature suggests that the load which optimizes PP occurs anywhere from 0% of one-repetition maximum (1RM) in a jump squat to 80% of 1RM in a power clean depending on the lift tested (Bevan et al., 2010; Kilduff et al., 2007). When examining colligate athletes in different lower body lifts including the power clean, squat and mid-thigh clean pull the load which maximized PP ranged from 40% of 1RM to 80% of 1RM (Comfort, Fletcher, & McMahon, 2012; Comfort, Udall, & Jones, 2012; Comie, Mccaulley, Triplett, & McBride, 2007). These wide ranging and varied results support the notion that the optimal load to maximize power may depend on the lift being performed and the skill level of the athletes training. To date, no studies have examined the load which maximizes PP in youth athletes, despite the wide use of Olympic style lifts in youth resistance training programs (Duehring, Feldmann, and Ebben, 2009).

While the safety of resistance training in youth populations has been questioned, a 2009 position paper from the NSCA states that resistance training for youth is a safe and effective way to increase muscular strength and power and prevent injury (Faigenbaum et al., 2009). With regards to power training, Olympic lifting has been shown to be the most effective training method to increase power in youth athletes. Channel and Barfield (2008) found that an eight-week Olympic lifting program increased jump height 4.5%. Additionally, Hopkins, Marshall, Batterham, and Hanin (2009), used magnitude-based inferences to determine that Olympic lifting was a better way to increase measures of athletic performance than both plyometric and traditional resistance training. While these studies note the importance of Olympic lifting in youth populations, no studies have examined the load which maximizes power in youth athletes.

Purpose of Study 1

The purpose of the first study was to identify the load which produced the greatest amount of muscle activity in the vastus lateralis, vastus medialis, rectus femoris, gluteus maximus, biceps femoris, and semitendinosus muscles during a back squat in resistance trained females.

Delimitations

1. The study was limited to resistance trained females who have been regularly resistance training for the last two months.
2. Participants were free from lower body injury for the past three months.
3. Participants were required to squat in accordance with NSCA guidelines.
4. Participants were required to squat at a tempo of a two second eccentric and one second concentric phase.
5. Participants were asked to refrain from lower body training for at least twenty-four hours before testing.

Limitations

1. There is no way to ensure that participants gave a maximal effort during their 1RM attempt.

Basic Assumptions

1. Participants provided maximal effort during their testing session.
2. Participants were truthful when providing past medical history.

Significance of Study 1

This study provided information regarding the changes in muscle activation patterns under varying training loads. By understanding these interactions, practitioners are better able to prescribe dynamic resistance training exercise to enhance strength and correct muscle imbalances to improve the performance of the human movement system.

Purpose of Study 2

The purpose of this study was to determine the training load which optimizes PP output and RFD in youth athletes during the hang power clean.

Delimitations

1. The study was limited to male youth athletes competing in power-based sports who are familiar with performing a hang power clean and who have been involved in a structured strength and conditioning program for at least the last four weeks.

2. All repetitions were performed in the presence of a certified strength and conditioning specialist.

3. All participants were instructed to perform the lift as fast as possible.

Limitations

1. There is no way to ensure each participant performed the lift as fast as possible or provided maximal effort.

2. As data was collected on athletes who are currently training, there is no way to ensure that athletes were fully rested when performing testing.

Basic Assumptions

1. All athletes provided maximal effort during their training sessions.

2. Competency with the lift was similar among all athletes tested.

Significance of Study 2

The study provided information regarding the optimal load to maximize PP and RFD in youth athletes using the hang power clean. The study provides practitioners who work with youth athletes information that can help them determine the most appropriate load when training for improvements for power and RFD. By enhancing the athletes' power and RFD capabilities off the field they should see an improvement in performance on the field.

CHAPTER II: REVIEW OF LITERATURE

This review of the literature begins with an introduction to muscle imbalances including an explanation of the current recommendations for muscle imbalance correction. Next, changes in muscle activity, as measured by surface electromyography, which occur across various loads and lifting tasks is examined. The discussion of muscle activity closes with the current literature which examines muscle activity during the squat in females. Next, the implications of muscular power in athletic performance and exercise prescriptions that optimize and increase maximal power are discussed. This literature review concludes with a discussion of population specificity with regards to power training; specifically, the use of resistance and power training in youth athletes.

Muscle Imbalance

Muscle imbalance is described as a dysfunction of an agonist/antagonist pair of muscles that increases the risk of injury and decreases function and performance of the human movement system (Burnham, May, Nelson, Steadward, & Reid, 1993; Clark et al., 2018; Sahrmann, 1987; Wang, & Cochrane, 2001; Wang, Macfarlane, & Cochrane, 2000). The National Academy of Sports Medicine describes muscle imbalance as being associated with abnormal levels of neuromuscular activation, specifically, when one muscle or muscle group becomes overactive and its antagonist underactive (Clark et al., 2018). While the complex nature of the musculoskeletal system makes muscle imbalances difficult to describe, there are several proposed mechanisms that are hypothesized to facilitate the development of a muscle imbalance. These mechanisms include improper repetitive movement, cumulative trauma, incompletely rehabilitated injuries, lack of core strength, lack of neuromuscular efficiency, chronic overuse/underuse, and postural distress (Clark et al., 2018; Clark et al., 2014; Janda, 1993; Kendall, McCreary, Provance, Rodgers & Romani, 2005).

While all causes of muscle imbalance may not be known, it is generally accepted that dysfunction is perpetrated through daily living activities. Examples of these activities may include work tasks, such as sitting at a desk or working on an assembly line, that force the body into compromising positions (Clark et al., 2014). While muscle imbalances are common in general populations, many athletes that perform repetitive motions during training and game play are susceptible. For example, a volleyball player who repetitively protracts the shoulders to pass the ball is a player at risk to develop a muscle imbalance. Chronically over-activating the shoulder protractors and under-activating the shoulder retractors may result in alterations the neuromuscular activity of the region (Houglum and Bertoti, 2012).

Altered reciprocal inhibition and synergistic dominance are types of neuromuscular activity alterations that may result in or be caused by a muscle imbalance (Clark et al., 2018). Reciprocal inhibition is described as a synchronized contraction of a muscle with relaxation of its functional antagonist and is a mechanism essential to optimal muscle function. Alterations in neuromuscular activity that disrupt the balance between a muscle and its antagonist may lead to synergistic dominance; a condition where a synergist muscle is preferentially activated instead of a weak or inhibited prime mover (Clark et al., 2018; Sahrmann, 1987). Both altered reciprocal inhibition and synergistic dominance occur in the presence of altered neuromuscular activity about a joint. The altered activity modifies the agonist antagonist relationship, and a tight agonist may decrease the neural drive to the antagonist, altering the force-coupling and length-tension relationship between the two muscles (Clark et al., 2018). The alteration of these relationships may lead to underused or underactive muscle within synergist pair becoming weakened from disuse atrophy and ultimately lengthening (Janda, 1993).

While a cause and effect relationship has not been clearly defined, a common example illustrating these complex relationships is altered reciprocal inhibition leading to synergistic dominance about the hip joint. When hip flexor muscles such as the psoas are shortened or tight, they may inhibit the neural drive of the large hip extensor muscle such as the gluteus maximus (GM). Prolonged reduction in the neural drive of the GM then results in muscle atrophy and weakening of the muscle. To compensate for the weakened GM, the hamstrings must be consistently overactivated during sprinting and jumping movements, altering body kinematics and increasing the risk of injury (Clark et al., 2018; Sharman, 2005)

Muscle imbalances may become evident through postural deformities and arthrokinetic dysfunction, both of which are associated with movement pattern compensations. These conditions can be observed by a fitness professional using a variety of assessments such as the overhead squat, the single leg squat and static postural observation assessments (Clark et al., 2018; Clark et al., 2014). When movement pattern compensations or postural deformities are present they increase the risk of pain, discomfort, and may result in a cumulative injury cycle requiring intervention from a fitness professional (Clark et al., 2018; Kendall et al., 2005).

Training to Correct Muscle Imbalance

Rehabilitation measures for muscle imbalances must address both neuromuscular activation and strengthening of weak or lengthened muscles, as well as lengthening of tight or overactive muscles (Clark et al., 2014; Sahrmann, 1987). The National Academy of Sports Medicine promotes using a corrective exercise continuum for muscle imbalance that includes inhibiting, lengthening, activating, and integrating techniques. The activation phase of the continuum focuses on stimulating muscles that are considered to be underactive. This phase uses positional isometrics and strengthening techniques that isolate muscles to correct underactivity by enhancing intramuscular coordination and increasing motor unit activation, synchronization, and firing rate (Clark et al., 2014). This is accomplished using several tools like bands, exercise balls, and cabled machines that allow a person to isolate and target a specific muscle. By enhancing the intramuscular coordination in an isolated movement, the fitness professional can be sure that there is carry over affect when clients are progressed into integrated dynamic movements (Clark et al., 2014; Carroll, Riek, & Carson, 2002).

After neuromuscular activation of weak muscles has improved, clients then progress to the integration phase where dynamic movements are incorporated in to exercise prescription to further increase strength and intramuscular coordination in weak muscles (Clark et al., 2014). In this phase, it is imperative that lifts are selected which optimize the neuromuscular activation of the underactive muscles of interest. As an example, if the gluteus muscles were isolated and targeted outside the movement pattern, they must continue to be targeted during the chosen dynamic exercise. A common integrated dynamic movement used to address muscle imbalance in the lumbo-pelvic hip complex is the squat and its variations (Clark et al., 2014). The squat is a dynamic movement that requires the use of several prime movers and synergist muscles, making it a staple in both training and rehabilitation (Rahmani, Viale, Dalleau & Lacour, 2001). Acute training variables such as load and volume are manipulated in an exercise prescription to enhance increases in strength and neuromuscular activation of the weak muscles.

Muscle Activity

Electromyography

Electromyography (EMG) is a tool for monitoring and measuring the amount of motor units firing in muscle at a given time, often referred to as muscle activity. EMG data allows researchers to quantify muscle activity data by detecting electrical activation of muscles during contraction (Rau, Schulte & Klug, 2004). Some of the earliest work using EMG investigated EMG amplitude during fatiguing tasks and the relationship posture and muscle activity in the spinal erectors (Cobbs & Forbes, 1923; Floyd and Silver, 1955). More recently, EMG has been frequently used to quantify and describe the muscle activity of nearly every major muscle group during various tasks.

Normalization Procedures

There are several external factors that can cause variation in EMG signal and amplitude such as signal impedance from hair, dead skin, or body fat, orientation of the electrode relative to the muscle fiber and the stability of the electrode on the body (DeLuca, 1997). These factors may affect signals in a short period of time, therefore, it is prudent that the data undergo a normalization procedure (Halaki & Ginn, 2012). As EMG has evolved from its original use, many methods of EMG normalization have emerged.

Two primary methods of normalization are maximal voluntary isometric contractions (MVIC) and dynamic measure at maximal effort (1RM).

Maximal voluntary isometric contractions are the most often used method of normalizing EMG data because they are simple to perform and take very little time. Most commonly, the peak muscle activity during the MVIC is used as the reference point for the data, meaning all data obtained during testing is then divided by the peak amplitude of the MVIC data. This method establishes a reference point that represents the maximum neural activation of the muscle during an isometric contraction. If maximal neural activation is achieved for each muscle tested, it is highly reliable and allows for the comparison between muscles, tasks, and individuals (Halaki & Ginn, 2012). For dynamic movements that require only submaximal effort like walking, this method of normalization maybe most appropriate because there is no way to obtain data during walking which maximally activates the motor unit pool. However, a common problem with this method is the debate surrounding the best way to manually muscle test individuals to elicit the greatest peak muscle activity. While there is no single standard, it would seem good practice to match the body position when the MVIC is obtained to the dynamic movement to be tested as closely as possible (Halaki & Ginn, 2012).

Electromyography data can also be normalized by using a maximum dynamic effort during specific movements as the 1RM (Halaki & Ginn, 2012). This method helps investigators avoid obtaining EMG levels of over 100%, a common pitfall when normalizing dynamic muscle actions using MVIC data (Halaki & Ginn, 2012). Normalization to a 1RM requires the muscle activity of all muscles be recorded during a 1RM attempt. Each muscle is normalized to its own peak muscle activity, establishing a reference point specific to the dynamic movement tested. However, the interplay of several large muscle groups during a dynamic movement may prevent any one muscle from reaching maximal neuromuscular activity during a 1RM (Halaki & Gin, 2012). For example, in a back squat the quadriceps, hamstrings, and gluteus muscles must all work as synergists to produce maximum force, which is measured by 1RM. Additionally, when muscle imbalance is present, prime movers like the gluteus muscles may be inhibited as synergist muscles are recruited, reducing the maximal amount of muscle activity in the prime mover even at a maximal load.

With resistance training, the most common way to prescribe intensity is using a percentage of 1RM (Haff & Triplett, 2016). For a dynamic movement involving multiple muscles and joints such as a squat, this is used to determine the overall strength of an individual allowing for the prescription of training loads based on goals of the training session. When examining the muscle activity during a dynamic movement, normalization procedures should be modified to match the dynamic activity (Ball & Scurr, 2013). This is particularly important when conducting studies with varying intensity levels. The 1RM serves as a reference point to prescribe resistance training to optimize gains in strength, power, hypertrophy or muscle endurance implying that when conducting EMG research, the reference point used to normalize data should also be the 1RM.

Changes with External Load

Customized exercise prescription requires the variation of training load to produce desired training effects. It has been hypothesized that muscle activity increases when muscles are required to produce more force in response to an increase in external load (Newton et al., 1997; Rahmani et al., 2000; Zink, Perry, Robertson, Roach, and Signorile, 2006). However, evidence exists that suggests neuromuscular activation is not always greatest at high or maximal training loads. Gonalez et al. (2017) had ten resistance trained men perform a set of leg press at 90% and 70% of 1RM until momentary muscle failure. Surface EMG data was collected on the vastus lateralis (VL), rectus femoris (RF), and vastus medialis (VM) to monitor muscle activity levels. When matched repetitions were compared the mean muscle activity across all muscles was greater during the 90% of 1RM condition. Interestingly, mean EMG values were significantly different between loads, but peak EMG group differences were not, indicating that lower loads might activate the same number of motor units as higher loads when sets are performed until failure.

Similarly, when resistance trained males (N=12) performed sets of the bench press until muscle fatigue at loads of 80% and 50% of 1RM, mean EMG amplitude in the high load set was 30.67% greater than the low load set, but only in the triceps brachii (Schoenfeld et al., 2016). This finding may indicate that as load increases, there is an increase in synergist muscle activity of smaller muscles required during a movement. The lack of differences in muscle activity in the anterior deltoid and pectoral muscles suggest that for larger prime mover muscles, a motor unit threshold may exist where 50% of 1RM is a heavy enough load to maximally recruit the full motor unit pool when sets are performed until fatigue.

In contrast, several studies reported differences in peak muscle activity during high versus low load conditions. In a study assessing the EMG differences between drop-sets and sets to failure, ten resistance trained men performed two different training sessions using the smith machine back squat. During the first session participants performed repetitions until failure at 90%, 70%, and 50% of 1RM with no rest between sets. The second session was a standard set to failure using 50% of 1RM. Results indicated that peak EMG amplitude was higher in the 90% 1RM condition than all other sets for both the VL and VM (Looney et al., 2015). Similar finds were reported when, resistance trained men (n=9) and women (n=9) performed three sets of leg extensions at 80% of 1RM and 30% of 1RM until failure. Electromyography amplitude was significantly greater during the 80% compared to the 30% condition (Jenkins et al., 2015).

Additionally, Schoenfeld et al. (2014) had a cohort of ten resistance trained men perform a set of the leg press until momentary muscle fatigue using a high-load (75% 1RM) and low-load (30% 1RM) condition. When muscle activity was summed for all muscles, the high load condition displayed 25.12% greater peak muscle activity than the low load condition, a significant difference between the two conditions. Mean EMG activity was also significantly greater during the high load condition (41.91%) compared to low load. These results contradict those seen by Schoenfeld et al. (2016) further supporting the idea of a “motor unit threshold” where a certain load can recruit all the motor units within the pool. Based upon the contrasting results from Schoenfeld et al. (2014) and Schoenfeld et al. (2016), it would appear if a “motor unit threshold” exists, 30% of 1RM is not high enough to recruit the entire motor unit pool but 50% of 1RM may be.

Studies assessing muscle activity in different loading conditions where sets were not performed to failure are sparse. Resistance training is not always performed to failure, making it important to investigate muscle activity changes across load when sets are not performed until failure. Sundstrup et al. (2011) compared the muscle activation patterns of fifteen healthy untrained women in non-fatiguing heavy loading sets vs. repetitions to failure conditions. Participants performed the lateral side raise using elastic tubing which represented a heavy load (3RM) and a set with a lighter load which was performed to failure. Significantly higher normalized EMG values were seen in the 3RM condition during the first repetition, but EMG values were significantly lower in the high load condition when compared to the later repetitions of the low load condition. This suggests that high loading may produce greater muscle activity early on, but if sets are performed to failure, lighter loads may produce equal or greater levels of muscle activity.

When considering the effects of training load on EMG activity in exercise not performed until failure, the current evidence would suggest that as relative load increases so does EMG activity for all muscles involved in the movement. One study examined the relationship between relative load and muscle activity during the bench press using a fixed bar isometric system at loads representative of 60%, 70%, 80% and 90% of their MVIC in resistance trained men (n=11). Analysis showed that muscle activity was greatest at 80% and 90% 1RM conditions with weak to moderate positive correlations between strength and muscle activity of the pectoralis major (r = 0.43), anterior deltoid (r = 0.52), and posterior deltoid (r = 0.32). The weak correlation of the posterior deltoid may be indicative of antagonist coactivation (Pinto et al., 2013), a neuromuscular mechanism that promotes joint stabilization and force reduction. Alternatively, excessive coactivation may limit maximal force production by the agonist muscle (Haff & Triplett, 2015). Chronic resistance training has been shown to reduce antagonist coactivation, a factor potentially contributing to strength gains with training (Carolan & Cafarelli, 1992;

Pensini, Martin, & Maffiuletti, 2002; Pinto et al., 2013). Pinto et al. (2103) only used resistance trained individuals in the study, meaning the weak correlation between force production and muscle activity of the antagonist is expected and that these participants are displaying appropriate joint kinematics.

Synergist muscles may respond to higher loads increasing their contribution to the overall muscle activation thus decreasing the muscle activity contribution of the prime mover. When resistance trained females performed the back squat the GM produced greater muscle activity in a 75% of 1RM loading condition when compared to a 1RM (Korak, Caputo, Fuller, Paquette, & Coons, 2017). These findings suggest that as load is increased, synergist muscles contribute more to the overall muscle activation, subsequently decreasing the muscle activity of the prime movers. A limitation to this study is that only one load other than the 1RM was tested, therefore data regarding the full loading spectrum is limited.

These studies describe the relationship between high and low training load conditions; however, few describe how muscle activity patterns change across training load in submaximal sets. Evidence suggests that increased training load may alter the agonist antagonist relationship (Pinto et al. 2013) and synergist muscles may inhibit prime movers at maximal training loads (Korak et al., 2018). Despite this evidence, useful information describing muscle activity changes across a full loading spectrum is limited. A dynamic movement such as the squat requires the cooperation of an entire movement system composed of a variety of prime mover and synergist muscle groups (McKean, Dunn, & Burkett, 2010). Understanding the complex relationship between prime movers and synergist muscles during varied loading conditions is essential to selecting the appropriate exercise and load that optimizes activation of the prime mover of interest.

Muscle Activity during Squatting in Females

To date there are few studies that describe the muscle activity patterns of females during the traditional back squat. Contreras, Vigotsky, Schoenfeld, Beardsley, and Cronin (2015) compared the muscle activity of the GM, BF, and VL while performing a 10RM of the back squat and hip thrust exercise in a sample of resistance trained females. The barbell hip thrust elicited greater mean and peak muscle activity of the upper GM, lower GM, and of the BF (Contreras et al., 2015). There were no significant differences in the VL, suggesting that the hip thrust may be superior in posterior chain musculature activation in females. However, the hip thrust is not typically thought of as a functional dynamic movement like the squat, making its application to muscle imbalance rehabilitation limited.

Muscle activity patterns in females have been analyzed across various versions and depths of the squat exercise. Contreras, Vigotsky, Schoenfeld, Beardsley and Cronin (2016) examined the differences in muscle activity between front, partial and parallel squat in the upper GM, lower GM, BF, and VL. Thirteen healthy women performed ten repetitions with their estimated 10RM in the front, partial and parallel squat. There were no significant differences in any muscles in any of the squatting conditions (Contreras et al., 2016) indicating that the neuromuscular stimulus required for the front squat is similar to that of the back squat in females.

Muscle activity differences between resistance training protocols have also been examined in females. Korak, Paquette, Fuller, Caputo, and Coons (2017) studied the percent change in muscle activity of the VL, VM, RF, and GM when performing traditional resistance training sets versus rest-pause training. The GM was the only muscle to show any significant differences between the two training styles where muscle activity had a greater percent change increase (27.1%) in the traditional resistance training protocol when compared to the rest pause protocol (10.6%). While these few studies have examined various aspects of muscle activity during the squat in females, muscle activity changes with load have yet to be assessed.

Power as a Predictor of Athletic Performance

Power can be arithmetically expressed as Power = Force x Time, making both maximal force and the RFD import determents of peak and maximal power production. Many movements in athletics require large amounts of force generated in a short period of time, thus maximal power is an important predictor of athletic performance (Haff et al., 2001). The link between power production and jumping tasks has been thoroughly established. Riggs and Shepperd (2009) found that PP during jumping tasks was significantly correlated with jump height in elite male and female volleyball players. Similarly, Nikolaidis et al. (2016) showed that PP measured by the anaerobic Wingate test is significantly correlated to squat jump, countermovement jump and Abalakov jump height in both adolescents (M = 16 yrs.) and adult volleyball players. While correlations for adolescents ($r = 0.28 - 0.46$) were weaker than the adults ($r = 0.58 - 0.61$) in this study, others have found stronger correlations between jump height and PP in adolescent populations. Cakir-Atabek (2014) saw correlations between PP and both squat jump ($r = 0.709$) and countermovement jump ($r = 0.69$) heights in adolescent track and field athletes, strengthening link between PP and jump height in adolescent athletes.

Power production also has a significant impact on the sprinting capabilities of athletes because sprinting requires the athlete to exert large amounts of force with minimal ground contact time. Chelly and Denis (2001) found that forward leg power is significantly correlated with initial acceleration (r = 0.80) and maximal running velocity (r = 0.73) in male handball players (n = 11). Similarly, Sleivert and Taingahue (2004) found a significant correlation (r = -0.64) between PP during the squat jump and five-meter sprint times in a group of male athletes (n = 30). Both studies tested the acceleration phase of the sprint, a phase typically described as covering the first ten meters of a linear sprint (Cronin and Hansen, 2006). During this time large amounts of force are rapidly produced, making power production and RFD important determining factors in the athletes' sprint ability. It has been argued that the most important phase during straight line sprinting is the maximum velocity phase; however, many athletes rarely have the opportunity to reach maximum velocity, making acceleration, power, and RFD more important for sports like soccer, basketball, and football (Cronin & Hansen, 2006). In fact, power has been used to distinguish between levels of athletes.

When Cronin and Hansen (2005) examined the strength, power, and speed profiles of professional rugby players they found "faster" players had significantly greater relative power outputs during the squat jump then "slower" players. Baker and Newton (2008) performed a battery of tests on two groups of rugby players: first-division national rugby league (NRL) players and second division state rugby league (SRL) players. A loaded squat jump test indicated that the NRL players were 11.5% more powerful than those at the state level. These results demonstrated that power is related to and can help to predict athletic performance.

Training to Increase Muscular Power

Velocity Specific Training

Training to improve maximal power in athletes is characterized by explosive movements that occur at a high velocity such as vertical jumping, power cleans, snatches and derivatives of these lifts (Kraemer & Ratamass, 2004). Following the principal of specificity, training to increase maximal power exercises must be performed at a high velocity, training often referred to as “velocity specific.” Behm and Sale (1993) outline several mechanisms that may be responsible for improvements in performance after training at high velocities including: selective activation of higher threshold motor units, selective activation of fast twitch over slow twitch muscles, and increased motor unit synchronization. They conclude that resistance training at a specific speed or velocity should increase performance at the trained velocity (Reilly, Morris, & Whyte, 2009; Stone et al., 2000). For an athlete to train with velocity specificity, exercises are selected that best mimic the movements performed during competition and then performed at a high rate of speed, often with an increased training load. When twenty-one female netball players were divided into a strength, power or control group, both training groups increased their netball throwing velocity by 12.4% and 8.8%, respectively. The training protocol consisted of two training sessions a week of bench press and seated rows, with either 60% of 1RM (power group) or 80% of 1RM (strength group) and all participants were instructed to move the load explosively. However, the authors note that the training velocity varies greatly from the actual velocity of the netball throw and suggest that actual velocity may play less of a roll than the intent to move an external load as rapidly as possible during a movement that mimics sport (Cronin, McNair, & Marshall, 2001)

Training Strategies to Improve Maximal Power

The principals of specificity and overload suggest that training to increase maximal power requires training with a load which elicits near maximal power outputs. Based on these principles, several training studies have evaluated different training methods to increase maximal power using high and low load training. Additionally, some have evaluated the effectiveness of mixed method training strategies; however, results are conflicting because of variations in population, methodology, and measurement tools.

Moss, Refsnes, Abildgaard, Nicolaysen, and Jensen (1997) investigated the load-power relationship of the elbow flexors using three training groups which performed training for nine weeks at either 15%, 35% or 90% of their 1RM. Maximal power was assessed pre and post-training at 15%, 25%, 35%, 50%, 70%, and 90% of the participant’s 1RM. Only the group that trained at 90% of their 1RM had significantly increased maximal power measured at 70% and 90% of 1RM conditions. Similarly, Toji, Suei, and Kaneko (1997) examined the changes of maximum strength and power in the elbow flexors after training three days a week for eleven weeks. The first training group performed five repetitions at 30% of max force followed by five isometric contractions against at 100% of max force. The second training group performed five repetitions with 30% of maximum force followed by five isometric contractions with no load. While both groups increased their maximum power, the group which trained at 30% and 100% showed a greater increase in maximum power. However, as only the elbow flexors were measured, the practical applicability of these studies may be limited. Movements like the bench press, push press, power clean, squat, and snatch are dynamic movements involving multiple muscle groups across several joints, thus power production may differ from isometric exercises performed at one joint. Additionally, these studies show that maximal power may be increased by training at near maximal loads, supporting the conventional view of power training. However, high training loads may limit the speed of the movement and RFD, ultimately decreasing maximal power and minimizing the potential gains in maximal power.

Alternatively, one training study supported the superiority of low load training for optimizing PP. When the effects of squat training load on squat jump PP were assessed, resistance trained males were assigned to either a 30% or 80% 1RM squat training intervention. After an eight-week period jump squat PP was significantly increased in the 30% of 1RM training group at 30%, 55%, and 80% of 1RM, while the 80% training group only increased in the 55% and 80% loading conditions. Additionally, the 30% of 1RM group trended towards improvements in their 20-meter sprint ability while the 80% of 1RM group sprint performance was significantly slowed (McBride, Triplett, Davie & Newton, 2002).

Wilson et al. (1993) used three training modalities over the course of ten weeks to train sixty-four recreationally trained athletes. The participants were placed into a traditional weight-training group, a plyometric training group, or an explosive weight-training group that trained at a load that maximized their individual PP. Thirty-meter sprint, countermovement jump, squat jump, and maximal cycle test performance were tested before and after the intervention. After ten weeks, the individualized PP group significantly improved in all performance measurements most notably the squat (15.2% increase) and countermovement (17.6% increase) jumps. The weight training group improved in the squat (5.1%) and countermovement (6.8%) jumps, while the plyometric group had increases of 7.2% and 10.3%, both respectively.

While there may be some advantage to prescribing only loads believed to increase maximal power to train for maximal power, several studies have assessed the ability to increase maximal power by using a mixed method training strategy. These studies employ the use of training programs focused on increasing maximal force and maximum velocity, the two variables needed to increase power. One study split forty-two resistance trained men in three training groups: high force, high power, and combined methods training for a nine-week period. Vertical jump PP and the Margaria-Kalamen stair-climb power tests were both significantly increased in the combined group and the high-power only group (Harris, Stone, O'Bryant, Proulx, & Johnson, 2000). The combined training group received the added benefits decreasing their 10-yard shuttle (pre M = 3.04s; post M = 2.97s) and increasing maximum squat (pre M = 146kg; post M = 163kg), suggesting that training to increase both strength and power may provide benefits that power or strength training alone do no provide.

Similar results were produced by Comie, McCaulley, and Mcbride (2007) when they compared power and strength-power training. The power group performed six sets of unloaded jump squats, and the strength-power group performed five sets of six repetitions of unloaded jump squats and three sets of three repetitions of squats at 90% of their squat 1RM. PP at no load and 20kg was increased in the power only group, while the strength-power group increased their power output at no load, 20kg, 40kg, 60kg and 80kg. These results demonstrate that strength-power training can be as effective at increasing power as power training alone when only using bodyweight loads. However, strength-power training increases performance across a larger range of loads.

Wilson et al. (1993) suggests that there are two important factors when developing power training programs. First, a combined methods training program is needed to increase both maximal force and velocity. Second, and in agreeance with Harris et al. (2008) there is an advantage to training at a load that optimizes an individual's PP output. This has led to a large body of literature investigating optimal loading to produce PP in several different training exercises.

Optimal Load to Produce Peak Power

The optimal load needed to elicit peak muscular power in athletes is a heavily disputed topic. Kawamori and Haff (2004) suggested that several factors should be considered when selecting the optimal load for PP: number of joints, upper or lower body, and training status of the athlete. For untrained subjects in upper body or single joint exercises, it would appear loads between 30 – 45% of 1RM are optimal for maximizing power. Conversely, studies using trained subjects performing multi-joint or lower body exercises found that higher percentages of 1RM (30 – 70%) may be necessary for PP production (Kawamori & Haff, 2004). These findings may be predictable, as lower body and multi-joint exercises utilize a greater amount of muscle mass, increasing the amount of force production. The same may be true with trained subjects, as they are often stronger than untrained subjects and capable of greater force production allowing for heavier loads to be moved as rapidly lighter loads. Ideally maximum power output would occur at the point which there is a perfect interplay of force and velocity, and this appears to be true for less trained individuals (Suchomel, Beckhmam, & Wright, 2015). However, those who are collegiate or elite athletes and weightlifters may need higher loads to elicit PP because of their increased competency with the lift (Kawamori & Haff, 2004).

Most studies to this point have investigated collegiate or elite level athletes using Olympic lifts, power lifts and derivatives of these lifts like hang cleans and high pulls. Bevan (2010) and his colleagues examined optimal load in the ballistic bench throw and the jump squat in professional rugby players. Ballistic bench throw was performed at 20%, 30%, 40%, 50%, and 60% of their 1RM bench press and the squat jump at no load, 20%, 30%, 40%, 50%, and 60% of their 1RM back squat. Load had a significant effect on power output in both lifts where power decreased as load was increased after the point of maximal power production. Power was optimized at 30% of 1RM bench throw and 0% of 1RM in the jump squat, highlighting the importance of lift specificity when determining optimal load. In this study the upper body lift did not require the athlete to also propel their own bodyweight, possibly accounting for the difference in load required to elicit maximal power. Additionally, the bench press may be a more familiar movement to the participants than a loaded jump squat, supporting the notion that a higher level of competency with the lift may increase the load where power is maximized (Bevan et al., 2010).

Comie et al. (2007) investigated the optimal loading to elicit PP in the jump squat, squat, and power clean in twelve Division I male athletes. Loads of 0%, 12%, 27%, 42%, 56%, 71%, and 85% of 1RM were used in the squat and jump squat and 10% intervals from 30% to 90% of 1RM in the power clean. The load that produced the greatest PP in the jump squat was at 0% of 1RM, which was significantly different from loads ≥ 42% of 1RM. PP in the squat occurred at 56% of 1RM but was not significantly different across the loading spectrum. PP in the power clean was achieved at 80% of 1RM which was significantly higher than the 30% and 40% of 1RM conditions. These findings support those of Bevan et al. (2010) that suggest PP be dependent on exercise selection. The jump squat and power clean require the person to execute the movement at a high velocity to complete the lift. Conversely the squat is typically performed at a controlled tempo, possibly accounting for the lack of significant difference between all loads during the squat.

Another study with National Collegiate Athletic Association athletes used nineteen males to determine optimal loading for the power clean (Comfort et al., 2012). These athletes performed three reps of the power clean on a force plate at 30%, 40%, 50%, 60%, 70%, and 80% of the athletes 1RM. Peak power occurred at 70% of 1RM and was significantly greater than 30%, 40%, and 50% of 1RM, but was not significantly different from the 60% and 80% 1RM conditions. This study also reported that the highest instantaneous RFD at 0.001 seconds occurred at 70% of 1RM, which was not significantly different from other loads tested. The authors indicated that as load increased the peak RFD increased until 70% of 1RM, indicating that any velocity loss during the movement was negated by the force produced to move the load (Comfort et al., 2012).

One study with professional rugby players in the hang power clean found that PP output occurred at 80% but was not significantly different from loads between 40-90%. These findings may indicate that a wide range of loads could be used to optimize PP. Based on this finding the authors suggest that the optimal way to train for PP is for each individual to train at the load which optimizes their PP. This study also reported peak

RFD occurring at 90% of 1RM but it was not significantly different from loads between 40%-90% of 1RM (Kilduff et al., 2007).

Comfort et al. (2012) investigated PP and rate force production in the mid-thigh clean pull, a derivative lift of the power clean. Sixteen collegiate athletes performed three repetitions of the midthigh clean pull at intensities of 40%, 60%, 80%, 100%, 120%, and 140% of their 1RM power clean. PP decreased as load increased where 40% of 1RM produced a significantly higher PP than the 80%, 100%, 120% and 140% loading conditions. However, the 40% loading condition was not different 60% loading condition. These results somewhat align with those of Cormie et al. (2007), who saw PP maximized at 56% of 1RM in a similar population in full power clean, yet they contrast those of Comfort et al. (2012) who found both PP and peak RFD to occur at 70% of 1RM in a full power clean. These findings may relate to the specificity of the lift and the ability to overload the midthigh clean pull with loads greater than power clean 1RM. In fact, Comfort et al. (2012) found that peak RFD occurred at 120% of 1RM which was significantly greater than 40%, 60%, 80%, and 100% loading conditions.

Supporting findings from Comie et al. (2007), Baker, Nance, and Moore (2001) found that loads ranging from 50-59% of 1RM produced maximal power in recreationally trained rugby players. However, it is also mentioned that loads between 47-63% of 1RM appeared to have a similar level of effectiveness when eliciting PP (Baker et al., 2001). These intensity ranges are similar to that of both Comie et al. (2007) and Comfort et al. (2012). As evidenced by the varying results across several studies, optimal load to elicit PP has yet to be determined. Results are dependent on training status, sport, experience and possibly sex.

Population Specificity in Power Training

While previously discussed studies determined optimal loading to produce PP, several note high intrasubject variability and suggest optimal load may be dependent on strength level or training status of the participant (Bevan et. al., 2010; Kilduff et. al., 2007; Comfort et al., 2012). Other studies note the necessity of training specificity and suggest athletes train at loads matching the requirements of their sport. In other words, athletes that work against an external load (e.g. American football linemen) should perform training requiring heavy loads like power cleans. For athletes that do not work against loads (volleyball players), emphasis should be on lightly loaded jumping activities (Cormie et al., 2007). The wide variability and need for specificity suggest strength level of the participant be considered when prescribing loads for power training.

To date three studies have examined the relationship between 1RM strength and percentage of 1RM which maximizes PP. Baker (2001) conducted a series of studies comparing the performance of college level rugby players to that of national rugby league players. The results showed that less strong college league players used a significantly higher load (55% of 1RM) to elicit PP during testing when compared to stronger national league players (51% of 1RM). While this is a statistically significant difference the small difference in load may not be practically relevant. Additionally, this data was re-analyzed from various testing sessions meaning participants may not have been in the same training state at the time of data collection thereby providing misleading results.

Kawamori et al. (2005) found that in recreationally trained men 70% of 1RM for the power clean seems to maximize PP. This group performed three repetitions of 30%, 40%, 50%, 60%, 70%, 80%, and 90% of their 1RM hang power clean on force plates. In this study PP was maximized at 70% of 1RM, but this was only statistically significantly different from 30% and 40% of 1RM conditions. Interestingly, this study choose to examine the influence of 1RM on the load which optimized PP. Participants were separated into a strong category (1RM > 110kg) and a weak group (1RM < 110 kg). When data was analyzed separately, the strong group maximized their PP at 70% of 1RM while the weak group maximized their power at 80% of their 1RM.

In contrast to the previous studies, others have suggested that stronger athletes produce maximal power at higher percentages of 1RM. Stone (2003) and his colleagues designed a study to investigate the relationship between 1RM squat and power output during the countermovement jump and the static weighted vertical jump. The countermovement jump and static squat jump were then performed with loads ranging from 10% - 90% of the participants squat 1RM. Analysis using all twenty-two participants showed strong correlations between squat 1RM and the countermovement and static jump (r = 0.77-0.94). Ten participants were further subdivided into the five strongest and five weakest participants to allow for comparison between the two groups. The results showed that as maximal strength of the participant increased, the load at which PP occurred also increased. Weaker participants experienced maximal power at 10% of 1RM while stronger participants experienced maximal power at 40% of 1RM (Stone et al., 2003). While these studies do not agree on the effect that maximal strength has on the necessary load to produce PP, they do highlight the necessity for population specificity when prescribing power training.

With regards to sex influence regarding optimal power production there does appear to be some differences between male and females depending on the lift. When a group of male and female NCAA athletes were tested there were significant differences in PP in the squat jump where PP occurred between 30-40% for men and 30-50% for females. There were similar differences in the bench throw 30% of 1RM for men and 30-50% for females. However, there were no differences in optimal power for the hang pull exercise were PP was achieved between 30-60% for both sexes (Thomas et al., 2007). The notable variance between sexes in this study further supports the idea that power training programs must be tailored to specific populations based on sport, sex, strength level and possibly age.

Resistance Training in Youth Athletes

For a long time, resistance training was discouraged in youth athletes because it was believed to result in injuries and disrupt natural growth patterns. However recent meta-analyses have stated that resistance training in youth athletes is not only safe but an effective method for enhancing muscle strength and size in youth athletes (Faigenbaum et al., 2009; Harries, Lubans, & Callister, 2012; Lesinski, Prieske, & Granacher, 2016; Malina, 2006). One review article examined forty-three studies to study the effects of resistance training on muscle strength, vertical jump performance, linear spring, agility, and sport-specific performance. It was determined that there were moderate effects of resistance training on muscle strength and vertical jump performance and small effects of linear sprint, agility and sports-specific performance. They also determined that there exists a dose-response relationship where training periods of at least twenty-three weeks consisting of five sets/exercise, and six-eight repetitions/sets at an intensity of 80-89% 1RM were most effective to improve muscle strength (Lesinki et. al., 2016).

In addition to this review article, in 2009 the NSCA released a position paper discussing the benefits, risks and appropriate resistance training prescription for youth resistance training. This review provides several general recommendations for resistance training including one to three sets of six to fifteen repetitions on a variety of upper and lower body exercises two to three days per week. It is also recommended that loads be increased gradually and to allow appropriate rest and recovery for their athletes. Specifically for power, the NSCA recommends that one to three sets be performed for three to six repetitions in a variety of upper and lower body power exercises. Power exercises are to be performed at a high velocity but in a controlled manner, especially up until the athlete learns proper movement mechanics (Faigenbaum et. al., 2009). These exercises may include the Olympic lifts and plyometrics which have been shown to increase power and athletic performance in youth athletes.

Olympic Lifting in Youth Athletes

In a review survey of high school strength and conditioning coaches, thirty-seven of the thirty-eight coaches surveyed reported the regular use Olympic style lifts in their training programs. When asked about specific lifts utilized, nine of the coaches stated they believed that the clean was the most important lift and six reported that the hang clean was the most important. Additionally, eleven coaches cited the clean as the second most important lift, and four coaches indicated the snatch and clean were the third most important lifts in their training program (Duehring, Feldmann, & Ebben, 2009). These results would indicate that Olympic lifts and their variations are antidotally important to strength and conditioning coaches who work exclusively with youth athletes.

Channell and Barfield (2008) examined the effectiveness of power lifts versus Olympic lifts on jump height in a group of high school football players (*n* = 27; age 15.9 ± 1.2 years). The study consisted of an eight-week training program where athletes were divided into either a power training program, Olympic lifting program or a control group. Vertical jump height was assessed before and after the training intervention to determine the effectiveness of each program on vertical jump height. The Olympic training group saw a 4.5% increase in jump height while the power training group saw an increase of 2.3%. While these results were not statistically significant from one another, the effect sizes when compared to the control groups were quite large for both the Olympic (d = 1.06) and power training (d = 0.94) suggesting that both power training and Olympic lifts are an effective way for youth athletes to improve vertical jump height.

Similar effectiveness of the Olympic lifts has been seen in younger populations. In a group of sixty children aged ten to twelve years a study was conducted to determine the effectiveness of traditional resistance training, Olympic lifting, and plyometric training. Measures of athletic performance included countermovement jump height, maximal isokinetic strength in the dominant leg, standing horizontal jump distance, 5-meter sprint time, and 20-meter sprint time. These authors chose to use magnitude-based inferences and precision estimation as opposed to null hypothesis significance testing for this study as described by (Hopkins et al., 2009). Using this statistical method, Olympic lifting was 96% likely to be better than plyometric training and 93% likely to be better than traditional resistance training at improving counter movement jump height. For horizontal jumping distance Olympic lifting was 90% likely to be better than plyometric training. Olympic lifting was also 93% likely to be better than plyometric training at improving 5-meter sprint time, though it was not likely to be better than traditional resistance training. For 20-meter sprint time, Olympic lifting and traditional resistance training were more likely to improve sprint time, 86% and 81% likely, respectively. This study demonstrated that Olympic lifting can be as beneficial or more beneficial than traditional resistance training in young athletes (Chaouachi et al., 2014).

Conclusions

When training to correct muscle imbalance underactive muscles are targeted during dynamic movements; requiring that loads which maximize muscle activity in targeted muscles be prescribed. Unfortunately, information that describes muscle activation patterns across training load is limited. Examining the complex relationship between muscle activation patterns and load may enhance the ability of practitioners to prescribe loads during training to correct muscle imbalance which more precisely target underactive muscle groups. Optimal training load is also crucial to optimizing training stimuli when training to increase maximal power output. Evidence suggests that training at a load which maximizes PP will enhance maximal power, thus several investigations have sought to identify the optimal training load for maximizing PP in several athletic populations. To date, no studies have investigated the load which maximizes PP in youth athletes, a group which frequently trains to enhance maximal power.

CHAPTER III: MUSCLE ACTIVITY CHANGES WITH TRAINING LOAD VARIATION IN RESISTANCE TRAINED FEMALES

Introduction

Muscle imbalance can be described as a dysfunction of an agonist/antagonist pair of muscles that negatively impacts function and performance of the human movement system and increases the risk of injury (Clark, Lucett, McGill, Montel, and Sutton, 2018; Burnham, May, Nelson, Steadward, & Reid, 1993; Sahrman, 1987). There are several proposed mechanisms that may lead to muscle imbalances including improper repetitive movement, cumulative trauma, unhealed injuries, lack of core strength, chronic over or under use of muscle groups, and chronic postural distress (Clark, Lucett, & Sutton, 2014; Clark et al., 2018). When these conditions arise, it is common that muscle imbalances form and result in alterations of neuromuscular activity where some muscles become overactive while others remain underactive (Clark et al., 2018).

Muscle imbalances can be identified through movement pattern compensations that are observed by fitness/strength and conditioning professionals using assessments like the overhead squat, single leg squat, or static postural observations (Clark et al., 2018; Clark et al., 2014). When a muscle imbalance is identified, it is imperative to correct the imbalance and restore appropriate length-tension relationships within the affected muscles. The National Academy of Sports Medicine (NASM) advocates the use of a corrective exercise continuum which includes inhibiting, lengthening, activation, and integrating techniques (Clark et al., 2018). After enhancing the neuromuscular coordination of the unbalanced musculature, clients progress to the reintegration of functional dynamic movements to promote the development of correct movement patterns (Clark et al., 2014).

The squat is a dynamic functional movement commonly prescribed to correct muscle imbalances because it requires the cooperation of several muscle groups including the hip and knee flexors and extensors (Rahmani, Viale, Dalleau, & Lacour, 2000). Training loads are prescribed with the intent of maximizing the muscle activity of the underactive muscles. While muscle activity tends to increase as training load is increased, some evidence suggests that lower loads are able to recruit the same amount of muscle activity as higher loads in the squat (Gonzalez et al., 2017; Newton et al., 1997). Korak and his colleagues reported greater gluteus maximus muscle activity at submaximal loads compared to a 1RM during back squat in resistance trained females (Korak, Coons, Caputo, Fuller, & Paquette, 2017). From a practical perspective, people resistance training could avoid lifting heavy loads and still maximize muscle activity of the target muscle. Despite exercise prescription implications, there is limited data describing the effects of a wide variety of loads on lower body muscle activity.

Therefore, the purpose of this study was to identify the loads that produced the greatest amount of muscle activity in the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RM), gluteus maximus (GM), semitendinosus (ST), and bicep femoris (BF) muscles in resistance trained females. It was hypothesized that greater peak muscle activity will occur in the gluteus maximus at loads between 60 - 80% of one-repetition maximum (1RM) compared to loads greater than 80% of 1RM.

Methods

Practical Approach to the Problem

To identify training loads that maximize muscle activity in the VL, VM, RF, GM, ST, and BF, resistance trained females performed 3 repetitions of the back squat at 40%, 60%, and 80% of 1RM on the first testing day and 50%, 70%, and 90% of 1RM on the second testing day. Training load of the lifts was randomly counterbalanced but were chosen to represent a light, medium, and, heavy load on each day. Surface EMG data was collected on the VL, VM, RF, GM, ST, and BF because they are the largest muscle groups used during the squat. All data was normalized to a 1RM squat. Data was analyzed as average peak muscle activity in the ascending and descending phase of each muscle at each intensity.

Subjects

Descriptive statistics for participants are located in Table 1. Twenty apparently healthy low-risk resistance trained females were recruited to participate in the study from the university via word of mouth. Participants were required to have been resistance training at least two times a week for the past three months and were free from lower body orthopedic injury for the last three months. All participants were informed of the benefits and risks of the training protocol, completed the PAR-Q+ pre-health screening, and signed an informed consent document prior to participation. This study was approved by the University's Institutional Review Board prior to data collection.

Experimental Procedures

Participants were required to attend three sessions. The sessions were spaced a minimum of 48 h apart and participants were asked to refrain from lower body resistance

Table 1.

Descriptive characteristics and back squat 1RM of participants (*n* = 20)

Characteristic	M	SD
Age (years)	21.20	1.50
Height (cm)	164.48	13.05
Body Mass (kg)	66.80	17.51
1RM (kg)	85.68	17.73

*1RM = 1 Repetition Maximum

training and alcohol consumption for 48 h prior to each session. During the first session height was assessed to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Germany) and body mass was determined using a digital scale (Tanita Worldwide, Model BF 522, Arlington Heights, Illinois) to the nearest 0.1 kg with participants wearing t-shirts, socks and gym shorts. After measurements were taken, participants prepared for a 1RM test by completing a warmup that consisted of a 3 min row on an ergometer (Concept II) followed by 2 sets of 15 meters of each of the following: high knees, butt kicks, lunges and high leg kicks. After the warm up, participants squatted a weight that they believed they could achieve 15 times. Absolute 1RM was then determined using guidelines from the National Strength and Conditioning Association (2015). All squatting repetitions were performed using a standard Olympic barbell and participants were instructed to squat with the bar at a self-selected high or low bar position and descend until the tops of their thighs were parallel with the ground. A bungee cord was placed at this parallel squat depth and participants were required to touch the bungee with their buttocks on each rep before ascending during all testing procedures.

Upon arrival for the second and third testing session the participants' skin was prepared to reduce signal impedance. This included exfoliation with redux paste and shaving, if necessary. Surface EMG electrodes were attached to the skin using double sided adhesive tape and secured to the skin using adhesive stretch covering. Electrodes were placed on the VL, VM, RF, GM, ST, and BF of the participants' right leg in accordance with guidelines from the Seniam project. Electromyography data was obtained using a wireless surface EMG system (Tringo, Delsys, Natick, MA). Electrogoniometers (Biometrics LTD, Newport, UK) were placed on both knees so that the axis of rotation was centered over the lateral midline of the right knee and the distal arm was aligned with the lateral aspect of the fibula, in accordance with Isear, Erickson, and Worrell (1997). The electrogoniometers were used monitor the joint angle of the participants and differentiate between the descending and ascending phases of the lift.

After surface electrodes were affixed participants completed the same warm-up as used in in first testing session and then repeated their 1RM attempt. Electromyography data was collected during the 1RM to be used for normalization. After completion of the 1RM, participants rested for 5 minutes to minimize any fatiguing effects from the 1RM. After a five-minute rest period the bar was loaded with loads 40%, 60%, and 80% of 1RM during session two and loads of 50%, 70% and 90% of 1RM during session three. Loads were randomized within each session to minimize sampling error from any effects of fatigue. Participants then performed three repetitions at each load using a two second eccentric phase and one second concentric phase with 3 minutes of rest in between each load.

Data Processing

All EMG data was normalized to the 1RM data collected for each participant during each individual training session to represent muscle activation of each muscle as a % of peak muscle activity during 1RM. A band-pass filter was applied to the EMG signal with cut of frequencies of 20 and 450 Hz and data signals were full-wave rectified and smoothed using a root-mean-square (RMS) procedure. Goniometer data was analyzed using a time-shift calculation script set to 0 seconds. For peak amplitude analysis, the peak amplitude for each repetition was used to calculate the average peak amplitude for each muscle under each load to be used in the statistical analysis. Each repetition was divided into an ascending and descending phase so that a peak amplitude for each muscle is available for both phases of the back squat. All data processing was performed using EMGworksanaylsis software (Delsys, Model SC-S08-4.5.3, Natick, MA) and Microsoft excel (2016).

Statistical Analyses

Twelve separate one-way repeated-measures ANOVAS with relative load as the within subject factor (40%, 50%, 60%, 70%, 80%, 90% of 1RM) were run for the VL, VM, RF, GM, BF, and ST (ascending and descending phases) to determine if there were any significant differences in peak muscle activity at the six different intensities. When sphericity was violated Hyunh-Feldt adjustment was applied. Effect sizes were calculated using eta squared (η^2) and post hoc comparisons were conducted using a bonferroni correction. The alpha level was set at .05 for all statistical procedures.

Results

Descending Phase

Relative load was found to have a significant effect on muscle activity in the GM, F (3.6, 67.8) = 13.11, MSE = 0.02, $p < 0.001$, $\eta^2 = 0.35$; RF, F (2.7, 51.2) = 8.78, MSE = 0.03, $p < 0.001$, $\eta^2 = 0.140$; and VL, F (1.8, 34.1) = 8.39, MSE = 0.07 $p = 0.002$, $\eta^2 = 0.28$. For the GM and VL the greatest average peak muscle activity was produced at 90% of 1RM and which pairwise comparisons revealed was greater than 40% ($p < 0.001$, $p = 0.004$), 50% ($p = 0.001$, p < 0.001), 60% ($p = 0.015$, $p = 0.03$), and 70% ($p = 0.001$, $p = 0.07$) of 1RM, but was not greater than 80% of 1RM. For the RF, 90% of 1RM produced the greatest average peak muscle activity and pairwise comparisons showed this was greater than 40% ($p = 0.001$) and 50% ($p < 0.001$) of 1RM, but was not greater than

60%, 70%, and 80% of 1RM. Relative load had no significant effects on muscle activity in the BF, VM and ST during the descending phase.

Ascending Phase

Relative load was found to have a significant effect on muscle activity in the VL, F (2.0, 38.9) = 6.32, MSE = 0.09 $p = 0.004$, $\eta^2 = 0.22$; RF, F (3.4, 65.1) = 7.00, MSE = 0.04, $p < 0.001$, $\eta^2 = 0.25$; GM, F (2.3, 43.1) = 9.02, MSE = 0.11, $p < 0.001$, $\eta^2 = 0.29$; BF, F (2.7, 51.6) = 9.91, MSE = 0.11, $p < 0.001$, $\eta^2 = 0.32$; and ST, F (3.2, 60.2) = 9.97, MSE = 0.09, $p < 0.001$, $\eta^2 = 0.33$. For the GM, BF, and ST it was revealed that 90% of 1RM produced the greatest average peak muscle activity and pairwise comparisons showed that 90% of 1RM produced significantly greater muscle activity than 40% (p = 0.012, p < 0.001, p = 0.003), 50% (p < 0.001, p < 0.001, p < 0.001), 60% (p = 0.031, p = 0.012, p = 0.006), and 70% (p < 0.001 , p = 0.001, p = 0.007) of 1RM, but was not greater than 80% of 1RM. For the RF, 90% of 1RM produced the greatest average peak muscle activity and pairwise comparisons revealed that 90% of 1RM produced significantly greater muscle activity than 40% (p = 0.012) and 50% (p = 0.005) of 1RM, but not greater than 50%, 60%, 70%, and 80% of 1RM. For the VL it was revealed that 90% of 1RM produced the greatest average peak muscle activity and pairwise comparisons showed that 90% of 1RM produced significantly greater muscle activity than 40% (p = 0.012), 50% (p < 0.001), and 70% (p = .012) of 1RM, but was not greater than 60%, and 80% of 1RM. Relative load had no significant effects on muscle activity in the VM during the ascending phase. Group means and standard deviations for all six muscles in both the ascending and descending phases can be found in Table 2.

Table 2.

Normalized muscle activity in females at varying percentages of one-repetition maximum.

% of 1RM	40%		50%		60%		70%		80%		90%	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
VL DSC*	0.59	0.20	0.67	0.14	0.68	0.21	0.78	0.18	0.78	0.27	0.89	0.24
ASC*	0.64	0.21	0.73	0.22	0.70	0.25	0.80	0.20	0.85	0.33	0.94	0.30
RF DSC*	0.66	0.16	0.70	0.21	0.75	0.15	0.80	0.25	0.81	0.19	0.90	0.22
ASC*	0.67	0.17	0.72	0.17	0.74	0.20	0.82	0.21	0.84	0.14	0.92	0.19
VM DSC	0.61	0.11	0.66	0.16	0.75	0.21	0.76	0.27	1.11	1.70	0.82	0.32
ASC	0.75	0.17	0.76	0.17	0.76	0.21	0.92	0.33	1.03	1.06	0.99	0.44
GM DSC*	0.25	0.13	0.34	0.16	0.37	0.16	0.39	0.16	0.45	0.24	0.52	0.20
ASC*	0.69	0.35	0.71	0.21	0.76	0.27	0.84	0.20	1.01	0.41	1.03	0.21
BF DSC	0.41	0.20	0.43	0.21	0.45	0.18	0.46	0.19	0.47	0.21	0.61	0.31
ASC*	0.53	0.18	0.59	0.24	0.68	0.25	0.79	0.29	0.86	0.41	0.99	0.34
ST DSC	0.60	0.72	0.72	1.45	0.47	0.27	1.61	5.11	0.55	0.46	0.67	0.47
ASC*	0.55	0.29	0.59	0.21	0.61	0.22	0.80	0.24	0.71	0.27	0.99	0.26

*Denotes that relative load had an effect on muscle activity of the muscle during that set; $p < .05$ *VL* vastus lateralis, *RF* rectus femoris, *VM* vastus medialis, *GM* gluteus maximus, *BF* biceps femoris, *ST* semitendinosus, DSC descending phase, ASC ascending phase; % of 1RM = percentage of one-repetition maximum.

Discussion

To the authors' knowledge only one other study has assessed the muscle activity changes during the back squat under a wide variety of loads. However that study performed all sets on the same day, used unnormalized EMG data and focused on the impact that velocity of lift may have on muscle activity (Tillaar, Andersen, & Saeterbakken, 2019). The purpose of the current study was to identify the loads that produced the greatest amount of muscle activity in the VL, VM, RM, GM, ST, and BF muscles. During the descending phase of the squat the GM and VL produced significantly greater amounts of muscle activity at 90% of 1RM than 40%, 50%, 60%, and 70% of 1RM ($p < 0.05$). In both the ascending and descending phase, the RF produced the greatest muscle activity at 90% of 1RM but this was only greater than 40% and 50% of 1RM ($p < 0.05$). During the ascending phase the GM, BF, and ST produced the greatest amount of muscle activity at 90% of 1RM which was greater than 40%, 50%, 60%, and 70% of 1RM ($p < 0.05$). The VL produced the greatest amount of muscle activity at 90% of 1RM which was greater than 40%, 50%, and 70% of 1RM ($p < 0.05$). Despite the fact that every other muscle was affected by relative load ($p < 0.05$), the VM was not and produced its' greatest muscle activity at 80% of 1RM. The GM did produce the greatest amount of muscle activity during the ascending phase of the 80% and 90% of 1RM (ratios of 1.01 and 1.03, respectively), partially supporting the hypothesis that the GM would generate the greatest muscle activity at loads between 60-80% of 1RM.

Henneman, Somjen, and Carpenter (1965) were among the first to observe the orderly recruitment of motor units where smaller motor units were recruited before larger ones during muscle contraction. Others have since observed that as force production increases and larger motor units are recruited there is a subsequent increase in muscle activity (Conwit, Stashuk, Tracy, McHugh, Brown, & Metter, 1999; Häkkinen, Kraemer, Newton, & Alen, 2001; Newton et al., 1997). In the current study there was an upward trend in average peak muscle activity for the VL, RF, and BF as load increased from 40-90% of 1RM, indicating that larger motor units were recruited to complete the back squat as relative load increased (see Figures 1 and 2). The findings for these muscles are consistent with an orderly nesting of motor unit recruitment where lower threshold, smaller motor units are recruited before higher threshold, larger motor units as described by Deluca and Erim (1994). For these muscles, production of maximal muscle activity may require training at near maximal loads during the back squat. However, the VM and GM deviated from this pattern, suggesting that maximizing motor unit recruitment and muscle activity for these muscles may not require training at maximal loads.

The VM is a quadriceps muscle that assists in stabilization of the knee and patellofemoral joint (Lin, Wang, Koh, Hendrix, & Zhang, 2004). The squat is a dynamic movement that requires knee joint stabilization; therefore, increased muscle activity in the VM would be expected as relative load increases. Contrarily, in the present study the VM was the only muscle tested which relative load had no significant effect on muscle activity during either squat phase. Also, an interesting finding was that the VM produced greater muscle activity at 80% of 1RM than at 1RM in both the ascending and descending phases of the squat. These results are similar to that of Gonzalez et al. (2017) who reported no difference in muscle activity of the VM in the leg press when tested at light (70% of 1RM) and heavy (90% of 1RM) load. The current study also saw no difference between 70% and 90% of 1RM, and the muscle activity at both of these loads

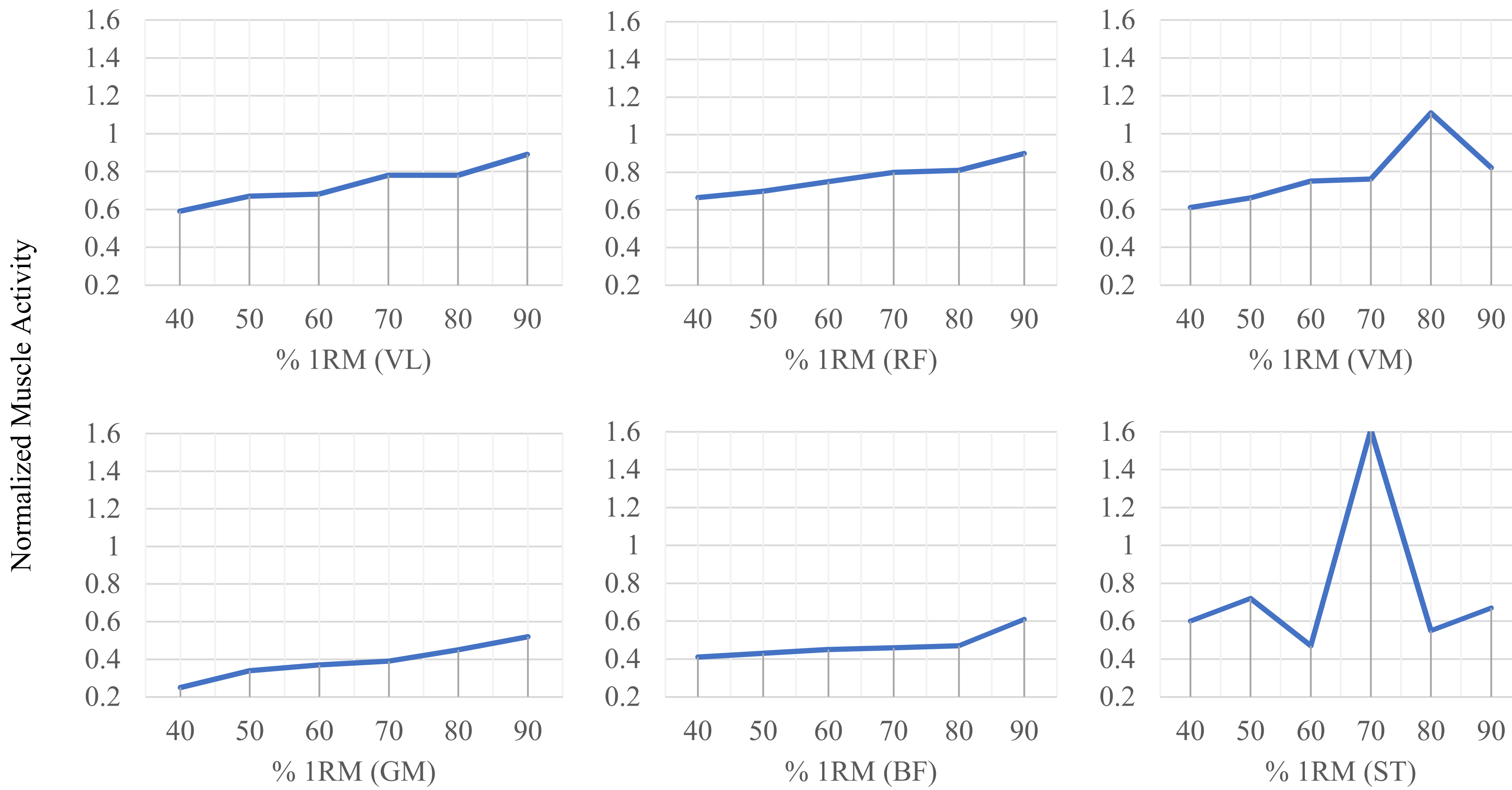

Figure 1. Normalized muscle activity during the descending phase in the Vastus Lateralis (VL), Rectus Femoris (RF) and Vastus Medialis (VM), Gluteus Maximus (GM), Biceps Femoris (BF), and Semitendinosus (ST)at 40%, 50, 60%, 70%, 80%, and 90% of one-repetition maximum (1RM).

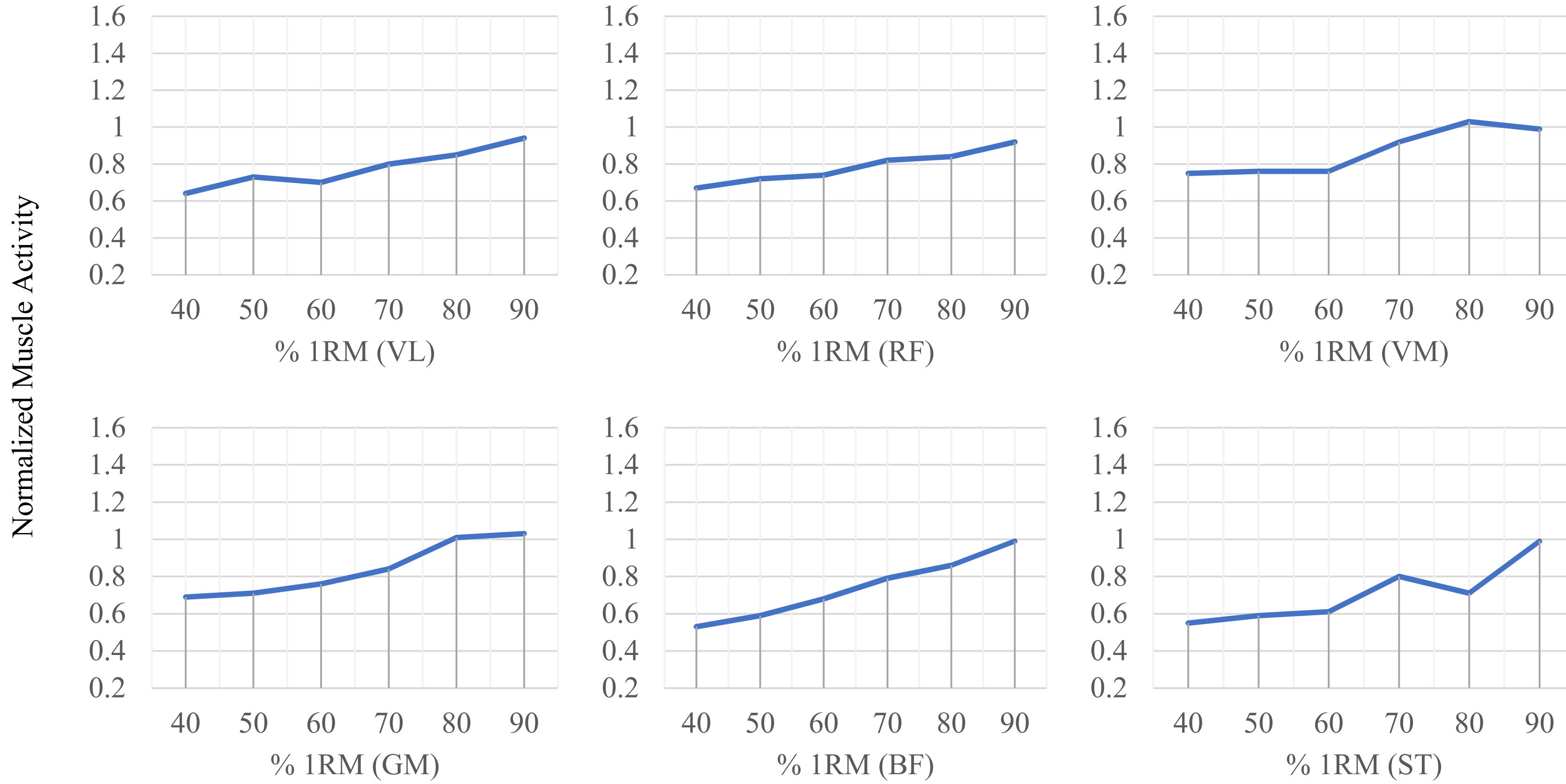

Figure 2. Normalized muscle activity during the ascending phase in the Vastus Lateralis (VL), Rectus Femoris (RF) and Vastus Medialis (VM), Gluteus Maximus (GM), Biceps Femoris (BF), and Semitendinosus (ST)at 40%, 50%, 60%, 70%, 80%, and 90% of one-repetition maximum (1RM)

was lower than that of 80% of 1RM, suggesting that 80% of 1RM is the optimal load to produce maximal muscle activity in the VM.

Similar findings were seen in the GM where greater muscle activity was seen at both 80% and 90% of 1RM when compared to a 1RM. McCaw and Melrose (1999) reported similar results when they measured muscle activity with varying squat stances in high- and low-load conditions, and the GM produced the greatest muscle activity at 75% of 1RM (the high load condition). However, only two loads were tested and 1RM EMG data was not collected, so no comparison could be made between 75% of 1RM and 1RM. Similar to the current study, Korak et al. (2017), reported that 75% of 1RM produced greater muscle activity than at 1RM during the back squat. While 75% of 1RM was the only load tested by Korak et al. (2017), the current study did not see muscle activity rise above 1RM at 70% of 1RM suggesting that a load between 75% of 1RM and 90% of 1RM may be optimal for maximizing muscle activity in the GM during the back squat.

The results from the current study in conjunction with those from Gonzalez et al (2017), McCaw and Melrose (1999), and Korak et al (2017), may suggest that in some muscles, during certain movements, there is point where additional external load does not recruit additional motor units and generate greater muscle activity. This was seen by Kukulka and Clamann (1981) who observed that the biceps brachii and adductor pollicis did not further recruit motor units after 88% and 50% of maximal voluntary contractions, respectively. Results of this nature have largely been reported in isometric and computer generated studies (De Luca & Contessa, 2015; De Luca & Contessa, 2011, Kukulka and Clamann, 1981), though the results from the current study and those of Gonzalez et al.

(2017), McCaw and Melrose (1999), and Korak et al (2017) suggest this may also occur in larger muscles during more complex movement patterns.

It is possible that there is no additional increase in muscle activity after a certain point in the GM and VM because several prime movers, synergists, and stabilizing muscles work together to complete a traditional squat. When the GM or VM recruits its full pool of motor units several accessory muscles may be recruited, possibly leveling off or lowering the muscle activity of the prime mover. This is displayed in figure 2 where muscle activity for the GM levels off at 80% of 1RM and synergist muscles like the BF and ST show somewhat sharp increases in muscle activity. Examining these interactions would be complex and require recording of muscle activity in several smaller accessory muscles during dynamic movements. Future studies should investigate the interaction of synergist and stabilizing muscles to prime movers during movements such as the back squat.

Possibly the most interesting finding in this study was the behavior of the motor unit recruitment in the GM, which is the largest muscle in the body and is important in various activities of daily living and athletic performance tasks. Unfortunately, the GM is believed to be a muscle that is often inhibited and weak, resulting in the development of synergistic dominance which places the hamstrings at risk for overuse injuries (Sahrmann, 2005). The back squat is a common exercise used to strengthen and activate the GM to correct synergistic dominance (Clark et al., 2014). In fact, a review article focusing on the role of the GM in training and rehabilitation noted that a full squat produces the greatest amount of muscle activity when compared to other exercises that focus on the GM, however they make no recommendations as to the load which may maximize muscle activity in the GM (Wilson, Ferris, Heckler, Maitland, & Taylor, 2005).

The results from the present study suggest that a load between 80-90% of 1RM produces the greatest amount of muscle activity in the GM during the back squat. Similarly, if the VM is to be targeted in the back squat, 80% of 1RM appears to be the optimal load while other muscles tested in this study (BF, VL, and RF) appear to require high intensities (90% of 1RM) to produce maximal muscle activity. Additionally, it is possible that because training at lighter loads allows for more repetitions to be performed that muscle activity throughout and entire training session would be significantly higher for the GM and VM if a load of 80% of 1RM is used.

One potential limitation to this study was the behavior of the ST during the descending phase of the squat. This high average peak muscle activity was the result of one participant. The possibility of removing this data point was discussed, however it did not meet the criteria for removal. It is possible the high muscle activity was seen in the participant as a result of severe knee valgus during the 70% of 1RM condition. Future research may consider examining the differences in muscle activity in those who display knee valgus during the squat and those who do not.

Practical Applications

For the VL, RF, and BF the results showed an upward trend in muscle activity as relative load was increased. Practitioners should consider using relatively heavy loads to train the VL, RF, and BF in the back squat. The VM was maximally activated at 80% of 1RM, and if this muscle is being targeted during a squat it, appears 80% of 1RM would be the optimal training load. Similarly, if the squat is being used to target the GM, it is recommended that coaches and trainers prescribe a load between 80-90% of 1RM to produce maximal muscle activity.

Chapter III References

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Appendices for Chapter III

Appendix A

IRB

INSTITUTIONAL REVIEW BOARD
Office of Research
Compliance, 010A
Sam Ingram Building,
2269 Middle
Tennessee Blvd
Murfreesboro, TN
37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Wednesday, March 27, 2019

Principal Investigator	**Kelton Mehls** (Student)
Faculty Advisor	John Coons
Co-Investigators	Brandon Grubbs and Sandra Stevens
Investigator Email(s)	kdm7d@mtmail.mtsu.edu; john.coons@mtsu.edu
Department	Exercise Science, Health and Human Performance
Protocol Title	***Muscle performance changes with training load variation in resistance trained females***
Protocol ID	**19-2190**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive* *procedures*. A summary of the IRB action and other particulars in regard to this protocol application is tabulated below:

IRB Action	**APPROVED for ONE YEAR**		
Date of Expiration	**3/31/2020**	Date of Approval	3/27/19
Sample Size	100 (ONE HUNDRED)		
Participant Pool	Primary Classification: **Healthy Adults (18 or older)** Specific Classification: **Female adults**		
Exceptions	1. Collection of contact information including identification number is permitted. 2. Ying Jin (CITI7430853) is permitted to access deidentified raw data for providing help with statistics and modeling. 3. Bailey Hunt (CITI7006898) is permitted to provide overal assitance with electron placement		
Restrictions	**1. Mandatory signed informed consent; the participants must have access to an official copy of the informed consent document signed by the PI.** **2. Data must be deidentified once processed.** **3. Identifiable data must be destroyed as described in the protocol.** **4. Any identifiable data/artifacts that include auido/video data, photographs and handwriting samples must be used only for research purpose and must be destroyed after data processing.** **5. Exclusion criteria as proposed using ACSM PAR Q+) to exclude potentially risky participants is mandatory.**		
Comments	NONE		

This protocol can be continued for up to THREE years (**3/31/2022**) by obtaining a continuation approval prior to **3/312020**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Post-approval Actions

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

Continuing Review (**Follow the Schedule Below:)**

Submit an annual report to request continuing review by the deadline indicated below and please be aware that **REMINDERS WILL NOT BE SENT.**

Reporting Period	Requisition Deadline	IRB Comments
First year report	2/28/2020	The PI requested to end the protocol by March 2020. If not renewed, this protocol will automatically close on the date mentioned in page 1.
Second year report	2/28/2021	NOT COMPLETED
Final report	2/28/2022	NOT COMPLETED

Post-approval Protocol Amendments:

Only two procedural amendment requests will be entertained per year. *In addition, the researchers can request amendments during continuing review. This amendment restriction does not apply to minor changes such as language usage and addition/removal of research personnel. .*

Date	**Amendment(s)**	**IRB Comments**
NONE	NONE.	NONE

Other Post-approval Actions:

Date	**IRB Action(s)**	**IRB Comments**
NONE	NONE.	NONE

Mandatory Data Storage Requirement: All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study has been closed. Subsequent to closing the protocol, the researcher may destroy the data in a manner that maintains confidentiality and anonymity.

IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed

Sincerely,
Institutional Review Board
Middle Tennessee State University

CHAPTER IV: IDENTIFICATION OF OPTIMAL LOAD FOR THE HANG POWER CLEAN IN YOUTH ATHLETES

Introduction

Power sports require athletes to produce large amount of force in a short period of time, making maximal power production is a significant predictor of athletic performance (Haff, Whitley, & Potteiger, 2001). While the best training method to increase maximal power is disputed, it has been suggested that using a load which optimizes peak power (PP) occurs is most effective. (Harris, Cronin, Hopkins, & Hansen, 2008; Wilson, Newton, Murphy, & Humphries, 1993). The National Strength and Conditioning Association (NSCA) notes that a wide range of training loads can maximize PP and that the optimal training load is dependent on the athlete's skill level and the type of lift performed (Haff & Triplett, 2015).

Professional rugby players achieved PP at 80% of one repetition maximum (1RM) during the hang power clean (Kilduff et al., 2007) while recreationally trained rugby players reached PP at lighter loads of 50-59% of 1RM during the jump squat (Baker, Nance, & Moore, 2001). In college level athletes, loads that ranged from 40% to 80% of 1RM were optimal for producing PP during the power clean and its derivative lifts (Comfort, Fletcher, & McMahon, 2012; Comie, Mccaulley, Triplett, & Mcbride, 2007; Kilduff et al., 2007). Although NSCA provides evidence-based training recommendations for PP, more data is needed to enhance exercise prescription so that athlete skill level and lift type are considered when training to maximize power.

Rate of force development (RFD) is also regarded as a valuable predictor of athletic performance (Cronin & Hansen, 2006). To achieve high rates of force production external loads must be moved rapidly. Studies that investigated loading for maximal RFD reported a wide load range, as peak RFD was achieved at approximately 70% of 1RM in the power clean (Comfort et al., 2012), 90% of 1RM in the hang power clean (Kilduff et al., 2007), and 120% of power clean 1RM in the mid-thigh clean pull (Comfort, Udall & Jones, 2012). Load variability in these studies was likely influenced by technical proficiency, strength levels, and training status of the athletes tested (Kawamori et al., 2005; Stone et al., 2003). Most athletic movements occur in under 300ms, which does not afford athletes the time required to reach maximal force production or maximal power (Haff and Tripplett, 2016). Therefore, investigation into training parameters to increase rate of force development are necessary to ensure athletes are prepared for a full range of athletic movements (Haff & Triplett, 2016).

In recent years Olympic lifting has become common practice in many high school weight rooms because it is a safe and effective method for increasing maximal power in youth athletes (Hopkins, Marshall, Batterham, & Hanin, 2009; Channel & Barfield, 2008; Duehring, Feldmann, & Ebben, 2009). Given the evidential differences in PP loads between collegiate and professional athletes, there is value in exploring PP loads in youth athletes. Therefore, the purpose of this study was to determine the training load which optimizes PP output and peak rate of force development in youth athletes during the hang power clean. It was hypothesized that PP would be optimized between 40% - 50% of 1 RM while peak RFD in the first 300ms would be optimized at 60% - 70% of 1 RM.

Methods

Practical Approach to the Problem

This study used a repeated measures design to determine the load which maximized PP and the peak RFD in the first 300ms at a variety of intensities relative to the participants 1RM (30%, 40%, 50%, 60%, 70%, 80%, and 90% of 1RM). These lifts were performed in two testing sessions in a random counterbalanced order. The dependent variables PP and RFD in the first 300ms were recorded using a TENDO unit. These variables were chosen because they have been shown to be strong predictors of athletic performance.

Subjects

Descriptive statistics for participants can be found in Table 1. Sixteen high school male athletes were recruited from a local area high school to participate in the study. All athletes competed in at least one power-based sport during the school year and had been participating in a structured strength and conditioning program for at least the past four weeks. Any athlete that was currently participating in rehabilitation for an injury was excluded from the study. All participants and their parents/legal guardians (when necessary) were informed of the benefits and risks of participation and signed an informed consent document. This study was approved by the University's Institutional Review Board prior to data collection.

Table 1.

Descriptive Characteristics of participants (*n* = 16)

	M	SD
Age (year)	16.94	0.97
Height (cm)	180.08	8.14
Body Mass (kg)	81.06	15.04
1 RM (kg)	70.17	14.41

*1RM = one repetition maximum

Experimental Procedures

Participants were required to attend three testing sessions. The sessions were spaced a minimum of 48 hours apart and participants were asked to refrain strenuous exercise 24 hours prior to testing. During the first session height was assessed to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Germany) and body mass was determined using a digital scale (Tanita Worldwide, Model BF 522, Arlington Heights, Illinois) to the nearest 0.1 kg. After measurements were taken, participants prepared for a 1RM test by completing a dynamic warmup that consisted of two sets of twenty meters of each of the following: high knees, butt kicks, lunges and high leg kicks. After the warmup, participants were permitted to perform a warm-up of two sets of five repetitions in the hang power clean using loads of approximately 50% of their 1RM. The absolute 1RM was then determined using guidelines from the NSCA (2016). The second and third testing session began using the same warm-up conducted during the first training session. After warm-up was complete, all athletes performed 3 repetitions of the hang power clean at loads of 30%, 60%, and 90% in the second testing session and 40%, 50%, 70% and 80% of their 1RM in a random counterbalanced order. Data were recorded using a TENDO barbell linear transducer system. Instantaneous RFD was calculated by dividing change in force by change in time from the raw data output from the TENDO unit. A maximal value was located within the first 300ms to produce peak RFD in the first 300ms. Four minutes of rest was provided between each tested load to negate any effects of fatigue.

Statistical Analysis

Two separate one-way repeated-measures ANOVAs with relative load as the within subject factor (30%, 40%, 50%, 60%, 70%, 80%, 90% of 1RM) were conducted for PP and peak RFD in the first 300ms. Hyunh-Feldt adjustment was applied when sphericity was violated. Effect sizes were calculated using eta squared (η^2) and post hoc comparisons were conducted using a Bonferroni correction. The alpha level was set at .05 for all statistical procedures.

Results

Peak Power

Relative load was found to have a significant effect on PP, F (2.196, 32.945) = 35.662, MSE = 63118.03, $p < 0.001$, $\eta^2 = 0.54$. Pairwise comparisons revealed that 80% of 1RM produced the greatest PP (1536.46 watts) which was significantly greater than 30% ($p < 0.001$), 40% ($p < 0.001$), 50% ($p < 0.001$), and 60% ($p = 0.004$) of 1RM, but not statistically significantly greater than 70% or 90% of 1RM.

Peak Rate of Force Development in the first 300ms

Relative load was found to have a significant effect on peak RFD in the first 300ms, F (6, 90) = 8.425, MSE = 74218764.31, $p < 0.001$, $\eta^2 = 0.27$. Pairwise comparisons revealed that 70% of 1RM produced the greatest peak RFD (11663.672 $N \cdot Sec^{-1}$) which was significantly greater than 30% ($p = 0.026$) and 40% ($p = 0.002$) of 1RM, but not significantly greater than 50%, 60%, 80% or 90% of 1RM. Group means and standard deviations for all variables can be found in Table 2.

Table 2.

Group means for peak power and rate of force

Development in the first 300ms (*n* = 13)

	Peak Power (W)		Peak RFD in first 300ms ($N \cdot Sec^{-1}$)	
Intensity (% of 1RM)	M	SD	M	SD
30%	909.21	418.25	6594.21	3712.40
40%	1074.00	449.76	8004.04	4667.28
50%	1229.52	399.81	9531.20	4534.38
60%	1294.17	467.06	8809.49	5753.91
70%	1526.15	517.26	11663.67	6579.10
80%	1536.46	400.44	11498.78	5996.14
90%	1519.81	393.97	11329.24	4992.50

* 1RM = 1 repetition maximum; RFD = rate of force development; W = watts; $N \cdot Sec^{-1}$ = Newton Seconds

Discussion

While several studies have investigated the relative load that optimizes PP and RFD in a variety of lifts, to our knowledge this is the only study which has assessed these qualities in youth athletes. It was hypothesized that PP would be optimized between 40 - 50% of 1RM while peak RFD in the first 300ms would be optimized between 60 - 70% of 1RM. Peak RFD in the first 300ms occurred at 70% of 1RM, which was significantly greater than 30% and 40% of 1RM ($p < 0.05$). However, PP was optimized at a higher relative load than anticipated, where 80% of 1RM produced the greatest PP which was significantly greater than 30%, 40%, 50%, and 60% of 1RM ($p < 0.05$).

The results for PP from this study are comparable to those of Kilduff et al. (2007) who found that PP in the hang power clean occurred at 80% of 1RM in professional rugby players. Similarly, studies with colligate athletes have shown that PP is maximized 80% of 1RM in the power clean and 70% of 1RM in the hang power clean (Bevan et al., 2010; Comfort et al., 2012). These results have been duplicated in recreationally trained males who maximized peak power at 70% of 1RM in the hang power clean (Kawamori et al., 2005). It should be noted that these studies sampled older, more experienced athletes as opposed to the youth athletes who were tested in the present study. Stone et al. (2003) suggested that strength level is a factor in determining optimal PP load. However, in the present study PP was achieved at 80% of 1RM (1536.46 W), but not different from 70% (1526.15 W) and 90% (1519.81) of 1RM. Our data suggests that youth athletes can train between 70% - 90% of 1RM to maximize PP during the hang power clean. This allows strength and conditioning coaches to prescribe from a load range specific to the hang power clean that optimizes peak power based on the goal of the training session or cycle of periodization.

In the current study peak RFD in the first 300ms was measured because the NSCA suggests that most movements in athletics occur within 300ms (Haff and Tripplet, 2016). Kilduff et al (2007), reported that peak RFD occurred at 90% of 1RM in professional rugby players, while Comfort et al (2012) reported peak RFD at 70% of 1RM in colligate athletes during the power clean. Contrary to the current study, neither of the two aforementioned studies reported that relative load had a significant effect on RFD. The present study indicated that 70% of 1RM produced the greatest peak RFD in the first 300ms of the hang power clean, which was significantly greater than 30% and 40% ($p < 0.05$) of 1RM. These results in conjunction with other studies (Kilduff et al., 2007 and Comfort et al., 2012) suggest that RFD during a clean movement may be maximized at a wide variety of relative intensities thereby allowing coaches to prescribe loads based on a variety of factors such as the goal of the training session or the athletes' comfort level with the lift.

Bhem and Sale (1990) suggested that the intent to produce a contraction quickly contributes to the rate muscle contraction or movement occurs. While athletes' in previous studies and the current study were instructed to perform the movement as fast as possible, it would appear the velocity of lifts at lighter loads was not adequate to overcome the lack of load and maximize power and RFD. The athletes recruited for this study were well-trained athletes who attended private high schools and were taught these lifts by Certified Strength and Conditioning Coaches. For an athlete who is familiar with the lift, it is possible that low relative loads do not elicit as high of PP and RFD because low intensities do not require a great deal of velocity to complete the lift. Instead an experienced athlete may require external stimulus, a relatively heavy load, to complete the lift as rapidly as possible (Angel, 1975).

Additionally, an athlete experienced with the lift may be uncomfortable with low relative load and may slow the lift velocity to ensure they are using proper technique. This may explain why the youth athletes in this study needed loads of at least 70% of 1RM to maximize PP and RFD. Youth athletes appear to be capable of producing similar RFDs at a wide variety of loads, meaning lower loads may be ideal when teaching youth athletes' lifts and focusing on technical proficiency. Both PP and RFD seem to be optimized at approximately 70% - 80% of 1RM in youth athletes in the hang power clean. During times of the year when athletic performance is more important than lifting performance, coaches may consider reducing training loads because they can still achieve high PP and RFD outputs.

It should be noted that only studies which examined power clean movements were incorporated into this discussion and the findings from this study should be applied specifically to youth athletes performing the hang clean movement. A variety of studies have assessed a plethora of lifts and it is widely reported that the lift type, strength level and technical proficiency of the athlete appear to influence the relative load that maximizes PP and RFD (Baker et al., 2001; Comfort et al., 2007; Harris et al., 2008; Kawamori et al., 2006; Stone et al., 2003; Suchomel, Beckham, & Wright, 2015; Thomas et al., 2007). Future studies should examine lifts commonly used with youth athletes during training to determine the optimal loading for PP and RFD. Additionally, studies should work to determine the effect which strength level and technical proficiency has on the relative intensities which optimize PP and RFD.

Practical Applications

The findings of this study indicate that youth athletes are performing the hang power clean a load near 80% of 1RM will produce the greatest PP while a load near 70% of 1RM will produce the greatest RFD. It is important to note that a range of loads produced a similar PP (70% - 90% of 1RM) and peak RFD (50% - 90% of 1RM). Strength and conditioning practitioners should use this knowledge to prescribe loads to maximize PP and RFD based on the goal of each training session.

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Appendices for Chapter IV

Appendix A

IRB

INSTITUTIONAL REVIEW BOARD
Office of Research
Compliance, 010A
Sam Ingram Building,
2269 Middle
Tennessee Blvd
Murfreesboro, TN
37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Thursday, March 21, 2019

Principal Investigator	**Kelton Mehls** (Student)
Faculty Advisor	John Coons
Co-Investigators	Brandon Grubbs and Sandra Stevens
Investigator Email(s)	kdm7d@mtmail.mtsu.edu; john.coons@mtsu.edu
Department	Exercise Science, Health and Human Performance
Protocol Title	***Identification of optimal load for the Hang Power Clean in youth athletes***
Protocol ID	**19-2197**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures*. A summary of the IRB action and other particulars in regard to this protocol application is tabulated below:

IRB Action	**APPROVED for ONE YEAR**

Date of Expiration	**3/31/2020**	Date of Approval	3/21/19
Sample Size	100 (ONE HUNDRED)		
Participant Pool	Primary Classification: **Special Population - Minors (14-18 years of age)** Specific Classification: **Students of Ensworth and Lipscomb Academies**		
Exceptions	1. Combined parental consent/child assent documentation permitted. 2. Contact information including identification number is permitted.		
Restrictions	**1. Mandatory signed parental consent and active child assent; the participants must have access to an official copy of the informed consent document signed by the PI.** **2. Data must be deidentified once processed.** **3. Identifiable data must be destroyed as described in the protocol.** **4. Any identifiable data/artifacts that include auido/video data, photographs and handwriting samples must be used only for research purpose and must be destroyed after data processing.** **5. Research site restriction applies (site information on file)**		
Comments	NONE		

This protocol can be continued for up to THREE years (**3/31/2022**) by obtaining a continuation approval prior to **3/312020**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Post-approval Actions

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

Continuing Review (**Follow the Schedule Below:)**

Submit an annual report to request continuing review by the deadline indicated below and please be aware that **REMINDERS WILL NOT BE SENT.**

Reporting Period	Requisition Deadline	IRB Comments
First year report	1/31/2020	The PI requested to end the protocol by December, 2019. If not renewed, this protocol will automatically close on the date mentioned in page 1.
Second year report	1/31/2021	NOT COMPLETED
Final report	1/31/2022	NOT COMPLETED

Post-approval Protocol Amendments:

Only two procedural amendment requests will be entertained per year. *In addition, the researchers can request amendments during continuing review. This amendment restriction does not apply to minor changes such as language usage and addition/removal of research personnel. .*

Date	**Amendment(s)**	**IRB Comments**
NONE	NONE.	NONE

Other Post-approval Actions:

Date	**IRB Action (s)**	**IRB Comments**
NONE	NONE.	NONE

Mandatory Data Storage Requirement: All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study has been closed. Subsequent to closing the protocol, the researcher may destroy the data in a manner that maintains confidentiality and anonymity.

IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

CHAPTER V: OVERALL CONCLUSIONS

This dissertation focused on enhancing resistance training prescription by investigating optimal loading in the back squat and hang power clean. The first study examined the muscle activity of the VL, RF, VM, GM, BF, and ST muscles in resistance trained females under a variety of training loads. Study two measured PP and peak RFD in the hang power clean in youth athletes in a variety of training loads.

In study one, resistance trained females performed 3 repetitions of the traditional back squat at loads of 40%, 50%, 60%, 70%, 80% and 90% of their 1RM. Muscle activity of the VL, RF, VM, GM, BF, and ST was measured and recorded using a wireless surface EMG unit. Training load was shown to have a significant effect on the VL, BF, and RF where muscle activity tended to increase as more load was applied. Training load also had a significant effect on the GM, however unlike the previously stated muscles the GM produced greater muscle activity at 80% and 90% of 1RM than at 1RM. In the VM, training load had no effect on muscle activity, however it, like the GM, produced a greater amount of muscle activity at 80% of 1RM than at 1RM. These results may be explained by the complex nature of a movement like the squat which requires the interaction of several prime mover, synergist, and stabilizing muscles. As more load is applied to increase the intensity, large muscles like the GM may not be able to recruit more motor units, resulting in the recruitment of several different accessory muscles. When accessory muscles are recruited in this manner, it reduces the demand on muscles like the GM, and appears to decrease the muscle activity at maximal loads. Practitioners can use this information to prescribe training loads which will target specific muscles during the traditional back squat, an exercise frequently used in both resistance training and rehabilitation.

In the second study youth athletes preformed three repetitions of the hang power clean at 30%, 40%, 50%, 60%, 70%, 80%, and 90% of their 1RM. Peak Power and RFD were measured using a Tendon linear barbell transducing system to determine which relative intensity produced the highest peak power and highest rate of force development in 300ms. Training load was shown to have a significant effect on both variables in this study. PP was highest at 80% of 1RM which was significantly greater than 30%, 40%, 50%, and 60% of 1RM, but was not different from 70% of 1RM and 90% of 1RM. This indicates that PP in youth athletes may be optimized at a variety of loads between 70% and 90% of 1RM, and that strength coaches should prescribe loads with this lift dependent on the goal of the training session and where they athlete currently is in a periodization cycle. Training load was also shown to have an effect on RFD in the first 300ms, which was maximized at 80% of 1RM. This was significantly greater than 30% and 40% of 1RM but not greater than the other loads tested in this study, indicating that RFD may be optimized at a wide variety of loads. These results were interesting because the authors believed that younger, less experienced youth athletes would not optimize PP and RFD at high training loads like 80% of 1RM. It is possible that the private school atheltes recruited for this study were well trained which translates into a higher optimal training load for PP and RFD than what would typically be seen in this population. Practitioners should use this information to help them prescribe loads when training to maximize power and RFD while considering other variables such as the goal of the training session and the point which the athlete is in the periodization cycle.

Resistance training is a vital part of enhancing an athlete's abilities and prescription of resistance training requires accounting for several variables including training load. To maximally activate the GM during the back squat, loads between 80% - 90% of 1RM should be prescribed. Similarly, to target the VM during the back squat, a load of 80% of 1RM optimizes muscle activity. When training youth athletes to maximize PP and RFD using the hang power clean, loads of 80% of 1RM optimize these variables. So it should be noted that these may be optimized at a wide variety of loads and strength and conditioning professionals should also consider factors like the goal of the training session and periodization cycle when prescribing loads for these lifts.

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