

ELECTROMYOGRAPHIC ANALYSIS OF CONVENTIONAL AND
RUBBER-BASED BAND SQUATS

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ELECTROMYOGRAPHIC ANALYSIS OF CONVENTIONAL AND
RUBBER-BASED BAND SQUATS

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Life is a storm, my young friend. You will bask in the sunlight one moment, be shattered on the rocks the next. What makes you a man is what you do when that storm comes. You must look into that storm and shout as you did in Rome.
Do your worst, for I will do mine!

-
- Edmond Dantes in The Count of Monte Cristo

DEDICATION

I would like to dedicate this thesis to my parents, Grant and Beth Palmer. Their support and love throughout my education has provided me the extra motivation and incentive to work hard and do my best in everything that I do.

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	vii
LIST OF TABLES.....	x
ABSTRACT.....	xi
CHAPTER	
1. ELECTROMYOGRAPHIC ANALYSIS OF CONVENTIONAL AND RUBBER-BASED BAND SQUATS	1
2. LITERATURE REVIEW	10
3. METHODOLOGY	33
4. RESULTS	42
5. DISCUSSION AND CONCLUSIONS	48
APPENDIX A: Consent Form to Participate in Research.....	59
APPENDIX B: Medical Health Questionnaire Form	63
REFERENCES	65

LIST OF TABLES

Table	Page
1. Mean \pm SD for Age, Height, Weight, and Training Experience with the Squat Exercise.....	33
2. Mean Vastus Lateralis I-EMG for Type of Contraction and Percent Interval of Displacement.....	43
3. Mean Vastus Lateralis I-EMG for Band Configuration and Percent Interval of Displacement.....	43
4. Mean \pm SD 1RM Values (lbs) for the NB, BB, TB, and BB (Without Bands (Bar Plus Weighted-Plates)) Configurations.....	47
5. Correlations between the 1RMs on the NB, BB, and TB Configurations	47

ABSTRACT

ELECTROMYOGRAPHIC ANALYSIS OF CONVENTIONAL AND RUBBER-BASED BAND SQUATS

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Purpose: The purpose of this study was to analyze mean I-EMG activity of the vastus lateralis and the hamstrings group during the back squat exercise using three different types of resistances. **Subjects:** Twenty-two healthy, physically active collegiate males with at least 6 months of resistance training experience using the back squat exercise served as subjects for this study. **Measurements:** To evaluate maximal strength on the squat exercise, 3 1RMs were required from every subject, one for each resistance condition. The purpose of this initial testing was to assign an appropriate external load relative to each subject's one-repetition maximum (1RM) for the No Band (NB), Bottom Band (BB), and Top Band (TB) conditions. EMG testing was then conducted using a 2-channel electromyography (EMG) system that analyzed muscle activity from the vastus lateralis and the hamstrings during the squat exercise for each

resistance condition. Mean integrated-EMG values were then collected for the 90 and 10% intervals for each phase and expressed as mean arbitrary units. **Results:** There was a significantly greater 1RM for the BB condition compared to either the TB or NB conditions. Also, there was a significantly greater 1RM for the TB condition compared to the NB condition. For the vastus lateralis, repeated measures ANOVA indicated a significantly lower mean I-EMG output in the eccentric versus concentric contractions. Also, a significantly lower vastus lateralis mean I-EMG output was observed at the 90% interval of displacement compared to the 10% interval of displacement. Post-hoc analysis indicated that at the 90% interval of displacement there was a significantly lower vastus lateralis mean I-EMG output in the NB condition than both the BB and TB conditions. At the 10% interval of displacement for the vastus lateralis, no significant differences among any of the band configurations were observed. For the hamstrings muscle group, repeated measures ANOVA again indicated a significantly lower mean I-EMG output for eccentric versus concentric contractions. A significantly higher mean hamstring I-EMG output was observed at 90% compared to 10% intervals of displacement. Post-hoc analysis indicated for the hamstrings group that at the 90% interval of displacement, no significant differences among band conditions were observed. In contrast, at the 10% interval of displacement there was a significantly higher mean hamstring I-EMG output in the NB condition than the BB condition.

Conclusion: These results indicate that during a given repetition of the squat exercise, greater overall muscle activity can be obtained by performing BB or TB squats as opposed to a conventional squat without bands (NB). A greater amount of muscle

stimulation per repetition could ultimately enhance greater strength adaptations to occur over time during training.

CHAPTER 1

ELECTROMYOGRAPHIC ANALYSIS OF CONVENTIONAL AND RUBBER-BASED BAND SQUATS

Conventional training using free-weight resistance has been reported as being one of the most productive ways for athletes and active individuals to gain strength and power (14, 16, 21). A major problem, however, with this method of training is that the external resistance provided by the weighted plates remains constant throughout the entire range of motion (ROM) (1, 4, 5, 6, 14, 15, 16). Even though the load being lifted is held constant, the force and torque applied by the active muscles at varying joint angles fluctuates due to changes in leverage or mechanical advantage throughout the lift (4, 5, 6). Therefore, in structural exercises that have ascending strength curves, the torque created by the external resistance does not match the muscle's capability for maximal strength, creating a large unwanted resistance at the bottom and a less than adequate resistance at the top of the ROM (1, 16). Because the body's ability to produce torque is least at the bottom portion of the lift where resistive torque is greatest, this limits the maximal amount of external load capable of being lifted, and as a result overload at the top of the ROM cannot be achieved (12, 14, 16, 17). Overload is an essential component for gaining strength, and without an adequate amount of resistance throughout the entire lift, muscle stimulation and strength adaptations will not reach their full potential (3, 12,

14, 16, 17). Due to resistive torque decreasing and leverage increasing as the barbell ascends towards the top of the ROM, the number of motor units needed to generate enough force to move the external load is minimized resulting in less than maximal effort by the active muscles to complete the lift (1, 9, 16). Because of this decrease in muscle force at the latter portion of an ascending strength exercise, deceleration also occurs, based upon Newton's Second Law of Motion ($F = M \times A$) (25). A deceleration at the conclusion of a lift could prove to be a negative training effect when most sports and daily activities emphasize acceleration during all portions of a ROM (2, 3, 5, 7, 14, 15, 16, 17).

To counter this problem of decreasing muscle force and acceleration at the top portion of the lift, an alternative method of training for gaining strength and power has been established through variable or accommodating resistances in the form of bands or chains (7, 9, 14, 16, 25). By simply attaching either bands or chains to the barbell being lifted a lifter can experience resistance that decreases eccentrically and increases concentrically, matching a structural lift's ascending strength curve (14-18).

An additional effect when using bands during an exercise such as the squat is an increase in eccentric velocity due to an increase in stretch provided by the bands at the top of the lift (1, 7, 9, 11, 16, 19, 25). To counteract this downward pull by the bands, it has been theorized that a greater force must be applied by the active muscles to slow the barbell down (1, 7, 9, 11, 16, 19, 25). A greater force exerted by the muscles at this juncture of the lift can in turn result in greater acceleration as the lifter rises

concentrically from a point of minimal leverage to the top portion of the ROM where leverage is increased (1, 7, 9, 25).

Most cross-sectional and longitudinal studies involving bands and chains have reported beneficial adaptations, such as increases in velocity, rate of force development (RFD), ground reaction forces (GRFs), muscle activity, strength, power, and perceptual exertion, to occur when these apparatuses are combined with free-weights to form a combination of resistances (1, 2, 5, 6, 9, 19, 25, 27). It has often been reported that by combining free-weights with chains or bands, an adequate amount of overall resistance can be applied throughout the ROM of an ascending strength curve lift to address the detriments of conventional training more effectively (1, 5, 18, 19, 25, 27).

A relatively new variable resistance technique, using bands that are tied to the top of the power rack, has gained some recent attention through various articles (12, 16, 23, 24). Although anecdotal, these reports have claimed that this ‘heightened’ or ‘lightened’ method of accommodating resistance provides assistance to the lifter promoting greater power output, RFD, velocity, and acceleration. Kilgallon et al. (12), reported in a recent article that this method has not only shown improvements in young athletes’ abilities to accelerate at extreme velocities, but also has been identified to decrease the probability of injury in novice lifters. McMaster et al. (16) stated that this form of variable resistance provides a degree of unloading in which the external resistance decreases at the bottom portion of a bench press or squat exercise matching the ascending strength of the lifter. Simmons (24) claimed that the ‘lightened’ method can improve a lifter’s explosive strength by utilizing the stretch shortening cycle in which muscle force potentiation is increased. No studies to date, however, have investigated these claims and their effect on

muscle stimulation. Therefore, the purpose of this study is to analyze the muscle activity of the vastus lateralis and the hamstrings group during the back squat exercise using electromyography under three different resistive conditions: conventional free-weights with no bands attached (NB), variable resistance using bands attached at the base of the power rack (BB), and variable resistance using bands attached at the top of the power rack (TB). A secondary purpose of this study will be to assess the validity of the BB and TB resistance conditions as measurements of muscular strength.

Purpose

The purpose of this study is to analyze mean I-EMG activity of the vastus lateralis and the hamstrings group during the back squat exercise using three different types of resistances. The first type of resistance condition is the conventional method using only free-weights (NB). The second and third types of resistance configurations will combine free-weights with the use of variable resistance methods via the attachment of rubber bands to the barbell that is being lifted (BB and TB).

A secondary purpose of this study will be to determine if 1-repetition maximums taken during the squat exercise using bands combined with free-weights can serve as valid measurements of muscular strength.

Hypotheses

It is hypothesized that:

1. Greater muscle activity will occur at the top of the lift during the back squat exercise for the BB and TB resistance conditions compared to the NB resistance condition.
2. The 1RMs collected from the subjects on the BB and TB resistance conditions will serve as valid assessments of muscular strength.

Delimitations

The delimitations for this study are:

1. The sample size. 22 subjects will be selected for this study.
2. The sample population. All subjects will be physically active collegiate males who will have at least 6 months prior experience with resistance training including the back squat exercise.

Operational Definitions

1. Variable resistance training: method of training in which the external load decreases at the bottom portion and increases at the top portion of an ascending strength curve exercise by attaching apparatuses such as bands or chains to the barbell that is being lifted.
2. Bands: rubber-based product that provides a type of variable resistance through an increase and decrease in stretch or deformation.

3. Chains: a collection of steel links attached together that provides another type of variable resistance through an increase and decrease in the amount of links collected on the floor.
4. Conventional resistance training: method of training in which the external load remains constant throughout the entire range of motion by placing only free-weights on the barbell that is being lifted.

Significance of the Study

Coaches and personal trainers are always looking for new and innovative ways to train their athletes and clientele (6, 27). Although conventional resistance training using only free-weights has been one of the most popular methods for gaining strength and power, it has been criticized in recent studies for not providing an adequate external load at the top portion of an ascending strength exercise (12, 14, 16, 17). Without an overload occurring at this part of the ROM, beneficial adaptations towards force production and acceleration fall short of reaching their full potential (3, 12, 14, 16, 17). Conventional training using only free-weights provides the most resistance torque at the bottom portion of an ascending strength curve lift where the active muscles are least capable of applying a torque to counter that created by the resistance (1, 2, 15, 20). This limits the overall amount of external resistance that can be successfully lifted preventing maximal resistance from occurring at different positions within the ROM where the muscles are more inclined to lift a heavier load (1, 2, 15, 20). The failure of conventional training to provide an adequate amount of resistance to all areas of a ROM could ultimately limit the potential for maximal strength gains to occur over a given training period (3, 12, 14, 16,

17). To counteract these detriments, variable resistance training using bands or chains, has gained recent popularity across the globe because it allows for the external load to vary based upon the displacement of the barbell during an ascending strength exercise (14-18). Therefore, as the barbell is lowered eccentrically the resistance decreases where strength capabilities are at a minimum (14-18). As the barbell is raised concentrically, the resistance increases where strength capabilities are at their peak (14-18). This allows for a more adequate resistance throughout a complete ROM (14-18).

The two most common variable resistance methods that have been studied in recent literature use apparatuses in the form of bands or chains (1, 2, 5-9, 11, 14, 15, 17-20, 25, 27). These devices, which are attached to the barbell, oftentimes are combined with free-weights to form a combination of resistances (1, 2, 5, 6, 8, 9, 11, 18, 19, 25, 27). This allows for an adequate amount of external resistance throughout the ROM (1, 2, 5, 6, 8, 9, 11, 18, 19, 25, 27).

Bands are usually tied to the bottom of the power rack where the given lift is to be performed (1, 8, 9, 11, 16, 19, 20, 22-27). These bands provide a varying amount of resistance depending upon the amount of stretch or deformation that occurs throughout the lift (1, 8, 9, 11, 16, 17, 19, 20, 22-27). Band deformation is at its peak when the barbell is at the top portion of the lift, which is where the greatest amount of resistance is present (1, 8, 9, 11, 16, 19, 20, 22-27). At the bottom portion of the lift, band deformation is at a minimum which results in a minimal amount of resistance (1, 8, 9, 11, 16, 19, 20, 22-27).

Chains provide an additional amount of resistance to the barbell based upon the downward pull of gravity (16, 17). As the barbell descends eccentrically, the chain links

unfurl onto the floor, decreasing the amount of additional weight (2, 4, 5, 6, 8, 9, 14-18, 22, 23, 26). As the barbell ascends concentrically, the chain links come back off of the floor, increasing the external load (2, 4, 5, 6, 8, 9, 14-18, 22, 23, 26).

A relatively new form of variable resistance using bands tied above the lifter's head towards the top of the power rack has been developed to provide assistance to the barbell that's being lifted (12, 16, 23, 24). Therefore, instead of the bands pulling down on the barbell increasing the amount of resistance during ascension, these bands pull up on the barbell decreasing the external load (12, 16, 23, 24). Because the bands provide assistance, a greater amount of resistance can be applied to the barbell via weighted-plates (24). This allows for a unique overload, which has been claimed by recent anecdotal reports to have enhanced effects in increasing force output, velocity, and acceleration (12, 16, 23, 24). Despite these anecdotal claims in favor of this type of variable resistance, no studies have been conducted examining these proposed benefits and their effect on muscle stimulation. Therefore, one of the unique attributes to this study will be the analysis of muscle activity that occurs during the squat exercise with the additional attachment of bands tied towards the top of the power rack and to the barbell that is being lifted. If significantly greater muscle activity is found, this method of variable resistance could prove to be an acceptable alternative for gaining strength and power during training (12, 16, 23, 24).

Most researchers who have conducted studies in the past comparing the effects of variable resistances to dynamic constant external resistances have equalized the external load during testing (1, 2, 5, 6, 7, 8, 9, 11, 19, 25, 27). Despite being popular, this method of external load selection does not take into account the reported advantage of being able

to lift a greater amount of overall resistance with the addition of bands or chains versus the maximal resistance able to be lifted with only free-weights (8, 14, 15). Therefore, in order to prescribe an appropriate load during testing, this study will use relative loads based upon each subject's maximal strength on the varying types of resistance conditions being used (14, 15). These relative loads should provide an adequate amount of resistance to elicit the full effects of combining bands with free-weights (14).

The most appropriate method for evaluating improvements in muscular strength when training with a combination of free-weights plus bands is by using bands combined with free-weights during assessment (15). This guarantees a high transfer of specificity which represents the correlation between training and performance (3, 15). The most popular method for assessing muscular strength during the bench press and squat exercises is the conventional 1RM using only free-weights (15). However, because this study will be evaluating muscular strength based upon 1RM tests using bands combined with free-weights, it's imperative that these variable resistance methods are validated as accurate assessments (15). To date, no prior study has examined the validity of 1RM tests using BB and TB resistance conditions as viable measurements for muscular strength. Therefore, a secondary purpose of this study will be to assess the correlations between the NB 1RM and the BB and TB 1RMs. If significance is found, these variable resistances could serve as two alternative methods for assessing muscular strength during the squat exercise.

CHAPTER 2

LITERATURE REVIEW

Variable resistance techniques designed to increase strength and power have recently gained notoriety as being alternative methods to conventional training using only free-weights (1, 2, 4, 5, 6, 7, 8, 9, 12, 14-27). By applying bands or chains to the barbell that's being lifted during an ascending strength curve exercise such as the squat, bench press, or deadlift, a variable resistance is created where greater resistance is at the top of the lift and less resistance is at the bottom matching the body's ability to apply maximal force (14-18). Anecdotal reports claim that using chains or bands in addition to free-weights can increase strength, power, force, muscle activity, velocity, and acceleration at a greater rate than traditional weight training using only dynamic constant external resistance (22, 23, 24, 26). Despite these overwhelming reports in favor of bands or chains, empirical studies have shown mixed results (1, 2, 5-9, 11, 14, 15, 17-21, 25, 27).

This chapter goes into detail on a number of different variables that have been studied in recent articles and publications pertaining to variable resistance methods using bands or chains (1, 2, 5-9, 11, 14, 15, 17-21, 25, 27). The following variables will be reviewed: force, the composition and tension quantification of bands, mechanical

advantage, the stretch-shortening cycle, acceleration and deceleration, the length-tension relationship, electromyography, injury and stress, absolute and relative loads, partner-assisted spotting and band assistance, perceptual influence, instability, and validity (1, 2, 5-9, 11, 14, 15, 17-21, 25, 27).

Force

Force is created and applied through an intricate system of muscles, bones, and connective tissues to generate movement (3). Force is initially produced by the smallest contractile unit of muscle known as the sarcomere (3). Located inside the sarcomere are myofilaments which consist of actin and myosin (3). Myosin filaments, or thick filaments, have globular heads that protrude outside of the filament and are designed to attach to actin in order to create force (3). This attachment of myosin to actin is known as the power stroke (3). Before this can take place; however, an action potential first must be generated by the nerve that innervates the muscle (3, 13). A nerve and the muscle fibers it innervates is called a motor unit (3, 13). Once a large enough action potential has been created, depolarization of the muscle fibers occurs, and the neurotransmitter, acetylcholine, is released at the neuromuscular junction (3, 13). With this action potential comes the release of calcium from the sarcoplasmic reticulum located next to the transverse tubules (3). The calcium stimulates troponin and tropomyosin, which are two proteins found on and along the double helix formation of the actin filament, respectively (3). This opens the active sites of the actin filament for the myosin heads to form cross-bridges and attach (3, 13). According to the Sliding Filament Theory, Z-lines, located on the outskirts of the sarcomere where actin filaments

are found, enclose or 'slide,' when calcium is released, towards the interior of the sarcomere where a heavy concentration of myosin filaments are housed (3). Once this happens, myosin attaches to actin, and force is created via muscular twitch (3). As long as calcium is present within the sarcomere, force will continue to be generated through this small but crucial unit of muscle (3).

Once force is created by the sarcomere, it is transferred, along with the forces created by other sarcomeres, from the muscle to the bone via a series of connective tissues including fascia, ligaments, cartilage, and tendons (3). The force that is transferred to the bone can ultimately cause dynamic movement to occur about a joint (3). This system is vital not only for daily activities, but also for exercise and lifting weights, which can bring about beneficial adaptations towards an athlete's muscular strength (3).

In order for a substantial amount of force to be created during weight training, force output can be increased in one of two ways (3):

1. By increasing rate coding or the frequency by which a muscle fiber is innervated by its corresponding motor neuron
2. By increasing motor unit recruitment, which is the number of motor units that are activated for a given exercise or task

The more frequent a muscle fiber is stimulated the greater the force that is to be produced (3). A single stimulation causes a single muscle twitch which amounts to a limited force output (3). However, if another stimulation of the muscle fiber occurs before the muscle fiber can completely relax from the previous stimulation the two resulting muscular twitches will summate and produce an increased amount of force or tension (3). If the

stimulations become frequent enough, unfused, and finally fused tetanus will occur generating peak force capabilities of that particular muscle fiber within a motor unit (3).

Another way to generate a greater overall force is by recruiting more motor units (3). Novice weightlifters who are in their first 6 to 8 weeks of training, can expect initial strength gains to occur as a result of neural adaptations (3). These adaptations include recruiting more motor units to lift a given load (3). Force capabilities will not only increase due to an increase in recruitment, but also due to the acquisition of recruiting larger motor units that constitute Type II or fast-twitch muscle fibers (3). Fast-twitch muscle fibers are capable of generating greater amounts of force than type I or slow-twitch fibers, which is essential for strength gain (3).

GRFs and RFD have been stated by recent studies to be enhanced when using variable resistance methods such as chains or bands as opposed to conventional training using only free-weights (11, 25, 27). Israel et al. (11) reported that force output was increased during the latter concentric and earlier eccentric phases due to an increase in resistance provided by the deformation of the bands. Stevenson et al. (25) found that RFD during the latter half of the concentric phase for the band condition was significantly higher compared to the NB experimental condition. Wallace et al. (27) discovered that peak force was significantly higher for BB conditions that constituted a total band resistance of 20% and 35% of the overall 85% 1RM load.

The Composition and Tension Quantification of Bands

Most bands are comprised of a hydrocarbon polymer-type material that displays viscoelastic properties that reflect both nonlinear and linear changes in tension due to

changes in stretch or deformation (16, 17). Therefore, unlike chains which alter the external resistance in only a linear fashion due to identically-weighted chain links, rubber-based bands increase and decrease tension based in a curvilinear fashion during deformation (16, 17). Because bands are viscoelastic, there are several factors that affect the rate and amount of tension supplied (16, 17). These include the density, width, thickness, cross-sectional area, resting length, and changes in deformation of the respective band (16, 17). If any one of these material variables were to be altered, a change in the tension-deformation relationship would also likely occur (16, 17).

Due to the complexity of the make-up of bands, it is oftentimes a limitation for practitioners to accurately quantify the amount and rate of tension supplied by rubber-based bands under different deformations and likewise select the appropriate load for training (16, 17, 20). Despite this limitation, there have recently been two peer-reviewed studies that have successfully formulated equations to predict the amount of tension provided by a variety of different-sized bands based on deformation (17, 20). Because tension is dependent upon deformation, if the amount of stretch is known, then tension can be easily predicted based upon the equations that were developed (17, 20). Shoepe et al. (20) took a conservative approach for testing the different loads supplied by different-sized bands using various-weighted dumbbells and a scale. McMaster et al. (17) used a complex procedure of measuring the various tensions provided by the bands at different deformations using both a force plate and a load cell. Strength coaches and personal trainers can mimic any one of these authors' procedures to successfully develop their own set of equations to predict tension, in order to prescribe appropriate intensities for their clientele when using bands during training (17, 20). With knowledge of the

approximate amount of tension supplied by the bands being used, these practitioners can assign a relative load for their athletes and clients to use during training based on maximal strength (14). Therefore, once 1RM strength using variable resistance has been determined, a strength coach or personal trainer need only to select the relative intensity to be used during training, exactly as if they were assigning a load constituted solely by free-weights (14). This technique of selecting the appropriate load when using variable resistance is easy and practical in that it only requires 1RM testing to determine the resistance used during training (14). In addition, training with an external load relative to maximal strength achieved during 1RM testing, has been reported to enhance transfer specificity (15). Transfer specificity is the ability to successfully transfer adaptations gained during training to testing or performance (3, 15).

Mechanical Advantage

When muscles exert force, which is transferred to the bones via connective tissues, the bony limbs onto which the force is applied works as a lever system about a joint for which movement can occur (3). During exercise in which the body is in constant motion, leverage is changing due to the increases and decreases in moment arm distance (3). A moment arm is the horizontal distance between the applied force and the joint on which the force acts (3). Leverage is oftentimes affiliated with the moment arm distance of the muscle compared to the arm of the resistance (3). In fact, by dividing the muscle arm by the resistance arm, mechanical advantage can be calculated (3). A mechanical advantage of more than 1 represents an advantage towards the force capabilities of the muscle (3). A mechanical advantage of less than 1 represents a

disadvantage towards the muscle compared to that of the resistance (3). The ancient Greek scientist Archimedes once said, ‘Give me a lever long enough, and I can move the world.’ Unfortunately for humans, most of the muscles, bones, and joints that make up the body’s lever system are at a mechanical disadvantage, in which the moment arm of the resistance is greater than the moment arm of the muscle (3). Despite this lack of leverage, the human body is still capable of moving huge external loads by generating large forces produced by the muscles (3).

Torque, which is calculated by multiplying the moment arm by the corresponding force, is critical for movement about a joint to occur (3). There are two types of torque that are produced: muscle torque and resistance torque (3). During a concentric action in which the barbell is moved up towards the top of the ROM during an ascending strength lift, the force produced by the muscles is greater than the force generated by the external resistance (3). Therefore, muscle torque would be greater than resistance torque (3). The exact opposite would be true during an eccentric action in which the barbell descends downward (3). In this case, the resistance torque would be greater than the muscle torque (3). During an isometric action in which no movement is occurring, muscle torque and resistance torque would be the same (3).

The squat exercise has an ascending strength curve, in which muscular strength capability or leverage is least at the bottom portion of the lift and is greatest at the top (5, 12, 14, 15, 16, 18, 19). This is due to a lengthening and shortening of the moment arms of the muscle and resistance (3). At the bottom portion of the squat, the resistance arm is much longer than the muscle arm about a given joint (3). Therefore, mechanical advantage at the bottom of the ROM is relatively low, causing the muscles to have to

generate a large amount of force in order to compensate for a lack of leverage (3). As the lifter rises concentrically, both of the moment arms decrease (3). However, because the resistance arm decreases at a faster rate than the muscle arm about a given joint, mechanical advantage is enhanced (3). A limitation of dynamic constant external resistance at this juncture of the lift is that while the load remains the same, the strength capabilities of the muscles increase (4, 5, 6). This provides an inadequate external load at the top of the ROM resulting in the force generated by the muscles to be less than maximal in order to continue to move the barbell (3, 12, 14, 16, 17). With the muscles having to produce less effort to complete the lift, strength adaptations during training are limited (3, 12, 14, 16, 17).

In order to reap the benefits of an increase in mechanical advantage at the top of the ROM, variable resistance, using bands or chains, was created to provide an accommodating resistance to the ascending strength curve, in which resistance decreases at the bottom portion of the lift where mechanical advantage is least and increases at the top portion of the ROM where mechanical advantage is greatest (14-18). Therefore, instead of the force generated by the muscles decreasing at the top of the lift, force actually increases or is sustained when using variable resistance because the muscles have to compensate for the increased external load (7, 9, 14, 16, 25).

Stretch-Shortening Cycle

The stretch-shortening cycle (SSC) combines the natural elasticity of tendons with muscle spindle activity to create a potentiation or force increase to occur during a concentric phase of movement (2, 3). This force increase is stimulated by a quick

eccentric phase followed by a short transition period into the corresponding concentric activity (3). The SSC is often discussed as a means for increasing force output in powerful activities such as plyometrics and vertical jumping (3). Recently, however, the SSC has been found to be a contributing factor for increasing RFD and velocity during the concentric phase of an ascending strength exercise when using variable resistance in the form of chains or bands (2, 11, 19, 25).

Elasticity is the ability of an object, after it is stretched, to be able to resume back to its normal resting length or shape (3). The series-elastic component (SEC) of the SSC takes advantage of the elastic abilities of the tendons to increase force output during the concentric phase of a lift (3). During the squat, as the lifter descends eccentrically, both the muscles and tendons stretch or lengthen causing elastic energy to increase (3). If this eccentric action is completed in a quick enough manner, the elastic energy built up by the tendons summate with the force generated by the muscles to create an even larger force output during the following concentric phase (3).

The SSC is also comprised of the stretch reflex which uses muscle spindle activity to increase force output during a concentric motion (3). Muscle spindles are proprioceptors located inside the intrafusal portion of a muscle (3). These spindles detect changes in tension occurring within the muscle due to the external load and provide afferent feedback to the central nervous system to allow for an adequate amount of motor units to be recruited in order to generate the necessary force output to concentrically lift the given resistance (2, 3). Using variable resistance in the form of bands or chains, muscle spindles have also been reported to elicit a within-repetition post-activation potentiation due to the increased resistance at the top of the lift which causes a greater

number of motor units to be recruited along with an increased rate of firing (2). This causes an increase in force generation and according to Baker and Newton (2) an increase in lifting velocity as well (3). Similar to the SEC, if the eccentric phase is performed quickly enough the resulting force output during the concentric phase will be enhanced because of the increased tension detected by the muscle spindles prior to the movement (3).

With the addition of bands to the squat exercise (BB configuration), it has been reported that greater eccentric velocities can occur compared to traditional lifting techniques using only free-weights (2, 7, 11, 19, 25). With an increase in velocity during this phase of movement combined with a lighter load at the bottom portion of the lift provided by a lack of deformation from the bands, the transition between the eccentric and concentric phases can serve as a catalyst for an enhanced SSC effect (2). Baker and Newton (2) reported an increase in velocity during the concentric phase of the bench press exercise when attaching chains to the barbell due to what they believed to be a more rapid SSC transition. Israel et al. (11) showed greater movement velocities, force output, power, and EMG activity due to a possible SSC effect for the beginning of the eccentric and at the end of the concentric phases of the squat exercise with the addition of bands. Rhea et al. (19) observed significant increases in power and strength for the band experimental training group in the squat exercise because of the increased elasticity of the muscles resulting in an enhancement of the SSC.

Acceleration and Deceleration

Acceleration is a vital component for success in all sports that require quick explosive movements (2, 3, 5, 7, 14, 15, 16, 17). If the equation, according to Newton's 2nd Law of Motion, is manipulated, $\text{Acceleration} = \text{Force} \div \text{Mass}$ (3, 25). Therefore, acceleration can either be increased by an increase in force or a decrease in mass (3, 25). Conventional training with free-weights uses dynamic constant external resistance in which the load remains the same throughout the ROM (1, 4, 5, 6, 14, 15, 16). It has been stated that this method of training provides an inadequate amount of resistance at the top portion of an ascending strength lift due to an increase in the body's leverage and mechanical advantage, where the active muscles are capable of producing greater amounts of force (1, 16). Because of the lack of resistive torque experienced at this part of the ROM, the force generated by the muscles is compensated and deceleration occurs (1, 2, 3, 5, 7, 9, 14, 15, 16, 17). Variable resistance methods using bands or chains have been shown in recent studies to have solved this problem of deceleration by increasing the external load at the top portion of the respective structural lift (7, 9, 14, 16, 25). This increase in resistance forces the active muscles to enhance force output and to continue to accelerate the barbell concentrically in order to complete the lift (1, 2, 7, 9, 25).

As the lifter descends eccentrically during a structural lift, force output increases in order to decelerate the bar at the bottom part of the ROM so a successful transition can be made between the eccentric and concentric phases of movement (1, 3, 7, 9, 11, 16, 19, 25). Recent studies have claimed that when performing the squat exercise using bands, eccentric velocity is increased due to the increased magnitude in tension provided by the bands at the top of the lift (1, 7, 9, 11, 16, 19, 25). This increase in velocity, results in an

increase in force output by the muscles in order to decelerate the barbell for the upcoming transition phase (1, 7, 9, 11, 16, 19, 25). The addition of bands also provides a decrease in resistance at the bottom portion of the lift, therefore, both force output and acceleration are enhanced with a corresponding decrease in resistive mass (12, 25).

It has been reported that because of an increase in external load, deceleration occurs at the top portion of an ascending strength lift when bands or chains are used in addition to free-weights (15, 20). The mass of the external load is inversely related to the acceleration of the barbell that's being lifted (3, 15, 25). So with an increase in mass towards the top of the lift, comes a deceleration (3, 15, 25). These claims of deceleration when using variable resistance contradict the results found by previous studies (2, 7, 9, 25). This is due to external load selection, in which the studies who reported favorable results towards acceleration and velocity matched the external load experienced between the different resistance conditions being tested. Baker and Newton (2) for example, manipulated the resistance provided by the chains in combination with free-weights to equal the same total resistance when free-weights were used without the chains at the top portion of the bench press. This selection of the external load actually caused the mass of the barbell with chains to be less than the mass of the barbell without chains through a majority of the bottom half of the lift. Therefore, it would be expected that a greater velocity and acceleration would occur when chains were added because the external mass was decreased (3). The deceleration that is reported to occur when using variable resistances is unlike the deceleration that occurs when using dynamic constant external resistance, in which force output generated by the muscles decreases due to neural inhibition which also causes a decrease in barbell velocity (20). Ballistic training

exercises such as jump squats and bench throws have also been established to overcome the neural inhibition that occurs during conventional training techniques (2, 7). By making a conscious effort to continue to accelerate the barbell through the ROM, a lifter can achieve acceleration for a longer period of time, which can be beneficial during training for athletes competing in sports such as basketball and volleyball which require explosive movements like vertical jumping (2, 7).

Length-Tension Relationship

A given muscle is capable of producing more force if it is at or close to normal resting length (3). At resting length the key myofilaments for contraction, myosin and actin, are at an optimal position for the greatest number of cross-bridge attachments to occur in order to generate force (3). The resting length is maximized at the top portion of a given ascending strength curve lift, therefore, tension or force output created by the muscles peaks at this point of the ROM (9, 11, 16, 17, 19). Near the bottom of the lift, the length of the active muscles are stretched or lengthened to a degree beyond maximal force capabilities which is reflected by the actin and myosin filaments being too far apart for optimal cross-bridging to occur (9, 11, 16, 17, 19). So during the squat or bench press exercises, as the barbell rises concentrically, not only is mechanical advantage increasing but so is the tension capabilities of the active muscles as their length resumes to their normal resting deformation (9, 11, 16, 17, 19).

Electromyography

For muscle contraction to occur within a motor unit, the motor neuron must first activate the respective muscle fibers it innervates (3, 13). Once an efferent signal from the motor neuron has been sent, neuromuscular transmitters are released at the motor endplates or junctions between the neuron and the muscle fibers (3, 13). If a large enough stimulus accumulates outside of the muscle cells, an action potential is created via the depolarization-repolarization of sodium ions (13). This influx causes the action potential to be released throughout the entire motor unit through an intricate system of transverse tubules (13). Calcium is then submitted from the sarcoplasmic reticulum and binds with troponin and tropomyosin proteins located on the actin filament (3, 13). This causes active actin sites to be exposed promoting myosin heads to cross-bridge with actin ultimately generating force output by the muscle cells (3, 13). Electromyography, or EMG, is the study of muscle function based upon the assessment of these electrical signals stimulated by muscle activity (13).

The action of the depolarization-repolarization cycle creates an electrical dipole or depolarization wave that travels along the respective muscle fiber(s) that was innervated (13). By appropriately attaching two electrodes 1 – 2 cm apart onto the surface of the skin of a corresponding active muscle, EMG software can accurately quantify the degree by which the muscle fiber(s) was stimulated (13). This is due to the detection by the electrodes of the electrical dipole that travels along the active muscle fibers which creates a bipolar signal that's enhanced by differential amplification technology (13). The raw EMG data that is observed by the computer is symmetrical in that corresponding negative and positive amplitudes above baseline are equal (13). Before the data can be viewed on

a computer, the analog voltage must first be converted to a digital signal (7, 8, 10, 11, 13). Amplitude can range between +/- 5000 microvolts at a typical frequency ranging between 6 and 500 Hz, where usually the highest EMG electrical signal is found to be between 20 and 150 Hz (13). Most research studies using EMG report digital signals that are rectified and smoothed using a moving average or root mean square, which allows for all negative amplitudes to be transformed into positive amplitudes (13). This provides the opportunity for basic statistics to be collected including mean and peak EMG signal values (13).

EMG technology uses amplifiers to not only amplify the electrical signal stimulated by muscle activity, but also to negate any external interference or artifacts that might disrupt the digital reading by the computer (13). The frequency range of a typical EMG amplifier has a bandpass setting of 10 Hz highpass to 500 Hz lowpass (13). This allows for an accurate signal to be reported because most EMG signal power is between 10 and 250 Hz which appropriately falls between the range of amplification (13).

EMG signal stimulation is affected by two contributing factors that are also responsible for increasing muscle force: motor unit recruitment and the frequency to which the muscle fibers are stimulated (13). By increasing one or both of these variables, the EMG signal is also likely to be enhanced (13). Therefore, it can be said that EMG activity and the force generated by the muscles are positively correlated (13).

Recent studies have compared EMG signals between experimental conditions that use variable resistance apparatuses, such as bands or chains, to conditions that only use conventional resistance via weighted plates (7, 8, 11). Despite overwhelming anecdotal support that adding bands or chains to the barbell that's being lifted increases muscle

activity, the empirical data recovered by the following studies show mixed results (7, 8, 11). Ebben and Jensen (8) found no significant differences in EMG signals during the squat exercise amongst 3 experimental conditions that compared resistances using only free-weights to variable resistances using free-weights plus bands, and free-weights plus chains. Cronin et al. (7) reported EMG activity of the vastus lateralis muscle during 3 experimental conditions using a supine squat machine. The first condition was a traditional squat. The second and third conditions were both jump squats comparing one condition with bands to the other without bands. Cronin and associates discovered that EMG activity was significantly enhanced during the latter 30% of the eccentric movement for the ballistic condition that used bands compared to the other two conditions that did not use bands. This increase in muscle activity during the final portion of the eccentric phase was thought to be caused by an increase in braking force by the muscles to decelerate the barbell that was being pulled down by the bands. Israel et al. (11) also analyzed EMG activity of the vastus lateralis muscle comparing the squat with bands to the squat without bands. This study reported significantly greater muscle activity for the band condition during the initial eccentric phase and during the latter concentric phase of motion due to greater resistance afforded by the bands at these portions of the lift.

Injury and Stress

Not only is weight training beneficial for increasing variables such as power and strength, it's also important for decreasing the chance of being injured while playing a respective sport (3). Athletic activities require huge amounts of compressive forces and

stresses to be placed upon the joints, muscles, bones and connective tissues, which sometimes can result in traumatic injuries (3, 12, 14, 15, 16, 17, 19, 20). Injuries in sports can oftentimes sideline players for anywhere from several weeks to months at a time, ultimately preventing an athlete from having success in their respective athletic event (3). Weight training has been proven to increase muscle size, bone diameter, and connective tissue strength, which allows for greater stresses to be placed upon these adaptive regions without injury occurring (3).

In some situations, however, athletes who have already suffered an injury are passive when it comes to resistance training in fear of placing too much stress on the tissue that was previously hurt (14, 15). Based upon leverage and mechanical advantage, the area where the most resistive torque occurs is at the bottom portion of an ascending strength curve lift (12, 14, 16, 17). Therefore, in order to ascend concentrically from this point of minimal leverage, huge amounts of force must be generated by the muscles, which places great loads of stress upon the corresponding bones and connective tissues (12, 14, 16, 17). To eliminate this area of increased stress, recent studies have reported the benefits of variable resistance training using bands or chains on decreasing the amount of resistance at the bottom portion of the lift (12, 14). By decreasing resistance at this part of the ROM, the extreme stresses that normally occur at this juncture of the lift when performing conventional training with only free-weights, are minimized (12, 14).

Kilgallon et al. (12) claimed that performing jump squats with bands tied to the top of a power rack, provide an unloading effect upon the barbell which can decrease the amount of stress experienced by the lifter at the bottom portion of the ROM. McCurdy et al. (14) performed a study on the effects of stress and soreness when comparing two

training groups of college baseball players performing the bench press exercise: one group used chains attached to the barbell while the other group used only free-weights. Results showed that although insignificant, the group that did not use chains had mean perceived levels of pain that were nearly 3 times as high as the group that performed the bench press with the chains.

Absolute and Relative Loads

Recent articles have reported that because variable resistance methods using chains or bands decreases the resistance at the bottom portion of an ascending strength curve lift where leverage is at a minimal, a greater absolute load or resistance is capable of being lifted (1, 2, 8, 15, 16, 20). This bottom part of the ROM is also known as the sticking point, and it's the limiting factor to the maximal amount of external resistance lifted during a given exercise when only free-weights are used to supply the load (1, 2, 15, 20). By applying chains or bands to the barbell that's being lifted, the sticking point which normally occurs close to the juncture between the eccentric and concentric phases of movement is actually shifted up towards the top of the lift where mechanical advantage is increased (8, 16). At this point strength capabilities also increase in which more force is capable of being generated by the active muscles (8, 16). Therefore, a greater overall amount of resistance can be lifted (8, 16).

With the advantage of being able to lift a greater absolute load via variable resistance, it's surprising that the majority of studies that have compared the effects of variable resistance to dynamic constant external resistance have used absolute loads that were the same (1, 2, 5, 6, 7, 8, 9, 11, 19, 25, 27). This somewhat negates the concept of

being able to lift heavier loads using chains or bands (8). Despite being unpopular, comparisons using different absolute loads between variable and constant resistances can be made as long as the relative load between the resistances is kept the same based upon each subject's 1RM (14, 15). Therefore, instead of equalizing the absolute load used during testing purposes, the practitioner would equalize the relative load based upon the subject's 1RM on the type of resistance used (14, 15). By using this method of external load selection when comparing both variable and constant resistance techniques, a maximal overload is guaranteed of being established at the top of any ascending strength lift when the addition of bands or chains are attached to the barbell (14). Overload is an essential component of all training programs that are designed to increase muscular strength (3, 12, 14, 16, 17).

Partner-Assisted Spotting and Band Assistance

Articles that have alluded to the variable resistance technique of attaching bands above the lifter, usually at the top of a power rack, have claimed that this method supplies assistance to the barbell that's being lifted during an ascending strength curve exercise (12, 16, 23, 24). A benefit to this form of assistance compared to partner-assisted spotting is that the assistance provided by the bands is consistent over every repetition during a given set as long as the lifter maintains the same ROM for every repetition performed (17, 20). In other words, a given deformation of a band will provide the same assistance/resistance to the barbell based upon the tension-deformation relationship (17, 20).

Partner-assisted spotting is another technique that provides assistance to the barbell being lifted; however, this method provides assistance that is variable based upon human inconsistencies (3). It is known that humans cannot reproduce the exact same force output generated by a muscle because the recruitment of motor units to produce force for a given activity is constantly changing (3, 13). Spotting another individual is no different in that the force generated by the spotter to assist the lifter is undoubtedly different from repetition to repetition within a given set (3, 13).

For safety reasons alone, a spotter is absolutely necessary when performing a structural ascending strength curve exercise such as a bench press or squat, even if bands are attached above the lifter's head to provide assistance to the barbell being lifted (3). However, the amount of assistance provided by partner-assisted spotting can be minimized during this form of variable resistance training because assistance is already coming from the bands themselves (12, 16, 23, 24).

Perceptual Influence

There have been a few recent studies that have reported the psychological benefits of lifting with variable resistance in the form of bands or chains. Despite not reporting any significant physiological results, Ebben and Jensen (8) did state that their subjects all claimed to have felt a difference when squatting a barbell with either bands or chains attached versus lifting a barbell with only free-weights. Both Berning et al. (5) and Coker et al. (6) investigated further the psychological effects of Olympic weightlifting with chains attached to the sides of the barbell that was being lifted. These studies reported not only that all of their subjects claimed to have felt a difference, but also that

using variable resistance in the form of chains was much harder. Similar to Ebben and Jensen (8), these articles reported no significant physiological results, but because of the perceptual influence these authors found amongst their subjects when lifting with chains, Berning et al. (5) and Coker et al. (6) elaborated that these psychological effects could promote greater work ethics during training resulting in enhancements in strength, power, and performance.

Instability

The increased demand upon the lifter during the squat or bench press exercises to control the external load throughout the ROM requires a great amount of synchronization between the agonists and synergists muscles (3, 14, 15). It has been reported that a degree of instability is provided when using dynamic constant external resistance, which could result in additional muscle recruitment in order to balance the load being lifted (3, 14, 15). Over time this increased neuromuscular stimulus could enhance strength adaptations, which also has the potential to positively affect performance (14, 15). With the addition of chains attached to the barbell, it has been claimed that an even greater degree of instability can result due to the loading and unloading of the chains from on and off the floor, respectively (4, 5, 6, 14, 15). Forcing the muscles to have to counteract this unstable load could enhance adaptations even more in favor of strength and performance (4, 5, 6, 14, 15). However, sometimes too much of a good thing can be detrimental when too much instability experienced by the lifter can negatively affect force output and strength gains (14, 15). Therefore, there comes a fine line for practitioners when prescribing training programs using chains and free-weights on what is defined as too

much or too less instability (14, 15). Although there have been no reports, it could also be argued that a high degree of instability occurs with the addition of bands, due to a constant increase and decrease in resistance throughout a repetition. Because of a lack of evidence; however, this claim is currently a mere speculation.

Validity

The 1RM using dynamic constant external resistance is the most commonly used test to evaluate muscular strength during the squat and bench press exercises; however, with recent reports claiming that this form of resistance causes muscle force output and acceleration of the barbell to decrease, the assessment of alternative methods for measuring maximal strength is crucial (15). These other methods include variable resistances in the form of bands or chains, which have gained notoriety as being a solution to the negative drawbacks of lifting with a constant external load (7, 9, 14, 16, 25). McCurdy et al. (15) formulated a study using men and women collegiate basketball players to evaluate the validity of the bench press exercise with the addition of chains. A significant correlation was found between the bench press with chains and the bench press without chains, which validates the 1RM with the addition of chains as an acceptable method for testing muscular strength during the bench press exercise. No prior studies, however, have tested the 1RM as a valid assessment when free-weights are combined with the addition of bands. In the future if a significant correlation were to be found between a resistance condition with bands and a resistance condition without bands, not only would this solidify the validity of an alternative method of resistance, but it would also allow future practitioners the ability to prescribe appropriate external loads

during training relative to the corresponding 1RM test (15). This concept of testing under the same resistance condition as training is often referred to as transfer specificity (4, 9, 14, 15). Whether the goal of training is to increase strength or performance, practitioners should always try to maximize transfer specificity so the adaptations achieved during training are meaningful and can be tested to their full potential (4, 9, 14, 15).

CHAPTER 3

METHODOLOGY

Subjects

Twenty-two physically active collegiate males volunteered to participate in this study. Table 1 shows the descriptive data for the subjects. Each of these participants had at least 6 months of resistance training experience using the back squat exercise (27). All subjects read and signed an institution-approved informed-consent form before participating in this study.

Table 1. Mean \pm SD for Age, Height, Weight, and Training Experience with the Squat Exercise.

Subjects (n)	22
Age (y)	22.4 \pm 2.6
Height (in)	70.0 \pm 3.8
Weight (lbs)	191.3 \pm 41.7
Training Experience w/ Squat (y)	8.9 \pm 2.8

Tests or Instruments

Initial testing was conducted on the squat exercise in order to assess each subject's maximal strength. To evaluate maximal strength, 3 1RMs were required from every subject, one for each resistance condition. The purpose of this initial testing was to assign an appropriate external load relative to each subject's 1RM for the NB, BB, and TB conditions. These external loads were the designated resistances when analyzing muscle activity using electromyography. A secondary purpose to this initial testing was to assess the validity of 1RM tests using bands combined with free-weights as measurements for maximal strength (15). To eliminate fatigue as a limiting factor to muscular strength, every subject during initial 1RM testing was given a minimum of 2 days of rest in between each 1RM test.

Following initial 1RM testing, muscle activity using electromyography was collected and analyzed for each subject under all 3 resistance conditions. 1 set of 3 repetitions was performed on the squat exercise for each resistance method. The third repetition of each set for every subject was used for electromyographic data collection (8). These data were collected during a single testing session with the order of testing randomized for each subject (8).

Raw EMG data were recorded with a band-width setting of 10 Hz to 500 Hz using surface electrodes. The surface electrodes (BIOPAC EL503 1 cm diameter) were connected to an amplifier and continuously streamed through an analog to digital converter using a BIOPAC 2-Channel Electromyography Telemetry System (BIOPAC Systems Inc., Goleta, CA) to a compatible computer and diskette. All data were saved to

the computer using a BIOPAC MP 100 system and AcqKnowledge data acquisition software (BIOPAC Systems Inc., Goleta, CA). Raw signal data were smoothed using root mean square (RMS) for the duration of a complete repetition on the squat exercise. The eccentric and concentric phases of movement were indicated on the computer using manual markers.

The bands (EFS Pro Stretch Strong Band 2 -1/2'') that were used during this study were purchased online through eliteFTS. These bands were selected because a prior study conducted by Shoepe et al. (20) used the same bands manufactured through the same online company. Shoepe et al. (20) developed a set of prediction equations to estimate the tension provided by the bands based upon the amount of deformation. Therefore, instead of this study having to establish its own set of prediction equations to estimate tension, the equations constructed by Shoepe et al. (20) were used to predict the amount of resistance or assistance that's provided by the bands contributing to the external load being lifted.

PROCEDURES

Initial 1RM Testing

A single practice session prior to initial 1RM testing was allotted in order for the subjects to become accustomed to the different resistance conditions on the squat exercise. Light to moderate external loads were used during this session to prepare the subjects for their upcoming 1RM tests. Barbell heights at the extremes of both the bottom and top portions of each subject's ROM were also measured prior to 1RM testing in order to estimate the maximal tension provided by the bands during both variable

resistance methods using the following prediction equation developed by Shoepe et al. (20): $y = 44.20 \ln(x) - 191.82$; where x was the linear band deformation (cm), and y was the resistance/assistance applied (kg). To account for the unique anthropometric measurements amongst the subjects, the height where the bands were tied was adjusted to provide a similar resistance (BB) and assistance (TB) between participants. This adjustment was based upon the height of the subject. If the subject was shorter than 70 inches, the bands would originate approximately 3 inches lower for both the BB and TB conditions compared to the height of the bands transfixed for the subjects who were 70 inches or taller. Seventy inches served as the cut-off point for this adjustment because this was the average height of the 22 subjects (Table 1).

For initial 1RM testing, every subject performed three 1RM tests. Each test used a different resistance method. The first 1RM test conducted was the NB resistance condition followed by the BB and TB conditions. A 5 – 10 minute warm-up including light dynamic stretching prior to 1RM testing was conducted by each subject. Following this general warm-up, a more specific warm-up consisting of 3 sets of 3 – 5 repetitions on the squat exercise at a light to moderate external load, was required by the principal investigator for every subject followed by the first 1RM attempts in successful trials. These warm-up sets on the squat exercise used the type of resistance that was used during the 1RM test. A conservative load for each subject's initial 1RM attempt was selected. Because it had been stated by previous research that maximal strength using variable resistance methods was likely to be greater than maximal strength using conventional resistance, an initial 1RM load of 105% was assigned for both BB and TB conditions based upon subjects' NB 1RM (15). Based upon the perceived difficulty of the subject to

lift the designated external load, the following load for the next 1RM attempt was chosen. To increase or decrease the resistance between trials, free-weights in the form of weighted plates were added or subtracted to and from the barbell, respectively. After a successful attempt, if the subject was perceived to have easily lifted the external load, an increase in resistance of 30 – 40 lbs was added for the following 1RM attempt (3). If the subject was successful in completing the trial, but was perceived to have struggled lifting the external load, approximately 10 – 20 lbs was added for the next 1RM trial. During an unsuccessful 1RM trial, the external load was reduced 15 – 20 lbs for a final attempt (3). Five minutes of rest was allowed between attempts to provide for complete recovery. After 1RM testing was completed, a cool-down consisting of light dynamic stretching took place, which was led by the investigator.

During all 1RM testing despite the type of resistance used, subjects were instructed to keep their feet positioned slightly wider than shoulder width and to reach a depth where the hip joint was parallel to the knee. A 1RM attempt that was not performed to proper depth was considered unsuccessful. Stance width was monitored and adjusted if it was too wide or narrow. Support belts were allowed to provide support and safety to each subject. At least one spotter was required at all times during testing to prevent injury to the subject by providing adequate assistance if needed during a failed 1RM attempt. All squats were performed inside a power rack. The principle investigator was a certified strength and conditioning specialist, who provided the necessary instruction for every subject in order to maintain a safe environment. No serious accidents involving any of the subjects occurred during the duration of this study.

Electromyography Testing

EMG testing began once each subject had obtained a 1RM on the 3 types of band conditions. The 2 muscle groups that were analyzed using EMG testing were the vastus lateralis of the quadriceps group and the hamstrings group. According to the study conducted by Ebben and Jensen (8), electrodes placed on the mid-posterior surface of the femur are adequate to represent muscle activation of the entire hamstrings muscle group. Three surface electrodes were placed onto the skin of the right leg to measure the muscle activity of the vastus lateralis. One electrode was placed 5 cm superior to the patella and at an oblique angle just lateral to the midline (10). The second electrode was placed 2 cm distal to the 1st electrode, and the ground electrode was placed onto the lateral condyle of the tibia (8). For the hamstrings, 1 electrode was placed in the center of the thigh midway between the gluteal fold and the back of the knee (8). The second electrode was placed 2 cm distal to and in the same longitudinal axis as the first electrode (8). The ground electrode was placed onto the lateral condyle of the femur (8). These sites were marked with a pen for each subject. Before the surface electrodes could be placed onto the skin; however, proper skin preparation was needed. Subjects were required to shave over each marked site. After shaving, subjects performed the same general and specific warm-ups that were conducted before 1RM testing. Following the warm-up, alcohol wipes were used to clean and remove dead skin from the surface before electrode placement (10). Before testing, the electromyography telemetry system was checked thoroughly in order to ensure that the device was in proper working condition.

Following the placement of the electrodes and connection to the computer, the subject was tested on the squat exercise inside a power rack for each resistance method.

Using the same procedures as during 1RM testing, subjects were monitored by the principal investigator throughout each EMG trial to ensure proper technique was being maintained for every repetition. At least one spotter was required at all times during testing. Eighty percent of the 1RM, based upon the subject's maximal strength using the measured NB, BB, and TB resistances, was used as the external load during EMG testing. One set of 3 repetitions was performed by every subject for each band configuration, where only the 3rd repetition was used for EMG data collection (8). Five minutes of rest were given to all subjects in between tests. Subjects were instructed to perform every repetition for each trial at a voluntary contraction speed similar to that which is normally conducted when performing a set during training.

Statistical Analysis

To compare EMG activity amongst the 3 resistance conditions throughout the entire ROM, both the eccentric and concentric phases of movement were each broken down into ten 10% intervals of displacement (7). Mean integrated-EMG values were calculated for only the ninety and ten percent intervals and expressed as mean arbitrary units.

The dependent variables in this study are the mean I-EMG values recorded for the 1) vastus lateralis and 2) hamstring muscle groups during each exercise test trial. These muscle groups were analyzed as separate dependent variables due to the very large difference in scale between them. The independent variables in this study are:

1. the type of contraction during each squat exercise: concentric versus eccentric motions.

2. the percent interval of displacement during each squat exercise: ninety percent versus ten percent. For the purpose of this study, only the ninety percent (top of the lift) and ten percent (bottom of the lift) intervals of displacement were analyzed in order to compare the percentages of displacement for each lift at which either the BB or TB configuration might have the greatest influence on resistance and EMG output.
3. the type of rubber band configuration used during each squat exercise: bands attached at the top of the power rack (TB), bands attached at the bottom of the power rack (BB), and the control condition, no use of rubber bands at all (NB).

Repeated measures ANOVA was used to detect differences in vastus lateralis or hamstring mean I-EMG output among the three repeated (within-subjects) independent variables. In this analysis, band type (TB, BB, or NB) was nested within intervals of displacement (90% or 10%), which was nested within types of contraction (concentric or eccentric). For each statistical test, an alpha level of .05 was used to determine significant differences across trials. For any significant effect or interaction, paired t-tests were used to determine individual trial differences. The Bonferroni adjustment was used to correct each post-hoc test for inflation in the overall alpha level. A Microsoft Excel datasheet was used to calculate Pearson's correlation coefficients to determine the validity between the 1RMs for the NB and both the BB and TB conditions.

A preliminary pilot study was conducted in order to determine the test-retest reliability of the EMG measures. The mean vastus lateralis and hamstring I-EMG were measured across three repetitions for each subject for each of the three band configurations, NB, BB, and TB, for both eccentric and concentric contractions. Chronbach Alpha reliability for the average of the three repetitions ranged from .88 to .96

for the vastus lateralis measures, and from .90 to .93 for the hamstring measures. Based on an overall average of .923 for the reliability of three repetitions, Spearman-Brown prediction indicated a reliability of .80 for one repetition only. Consequently, the mean vastus lateralis and hamstring I-EMG recorded for each subject for both eccentric and concentric contractions in this study came from the third repetition during each trial. This procedure was consistent with that used by Ebben and Jensen (8) to measure mean I-EMG data during the squat exercise comparing traditional, chain, and elastic band conditions.

The results of this pilot study were also used to determine the appropriate sample size needed for detecting statistical significance for means with repeated measures. For an average eccentric measure of .166 units and concentric measure of .212 units, with an alpha level of .05 and statistical power equal to .80, a sample of 19 subjects would be necessary across the two intervals of displacement and three band conditions. Consequently, 22 subjects were recruited for measuring mean I-EMG across all trials.

CHAPTER 4

RESULTS

Descriptive values for the mean I-EMG output across types of contraction and percent intervals of displacement from the vastus lateralis muscle are reported in Table 2. Descriptive values for the mean I-EMG output across types of band configurations and percent intervals of displacement from the vastus lateralis muscle are reported in Table 3. For the one-repetition maximum (1RM) lifts, there was a significantly greater 1RM for the BB condition compared to either the TB $t(21)=5.4$, $p<.0001$, or NB condition $t(21)=16.3$, $p<.0001$ (Table 4). The BB 1RM was a predicted value that included the amount of weight coming from the bar and weighted-plates plus the estimated amount of resistance supplied by the bands at the top portion of the ROM where the bands were stretched to their peak. The BB 1RM without the resistance provided by the bands (bar plus weighted plates) is included along with the NB, BB, and TB 1RMs in Table 4. Note that the BB 1RM without the bands was less than the NB 1RM demonstrating that a lighter mean load was used in the form of weighted-plates plus the bar in order to likely compensate for the additional amount of resistance supplied by the bands. There was also a significantly greater 1RM for the TB condition compared to the NB condition $t(21)=15.2$, $p<.0001$ (Table 4).

Table 2. Mean Vastus Lateralis I-EMG for Type of Contraction and Percent Interval of Displacement

	10% (\pm SD)	90% (\pm SD)	Combined Contraction *
Eccentric	25.0 \pm 15.0	8.7 \pm 6.2	16.9 \pm 14.0
Concentric	27.5 \pm 15.7	13.8 \pm 8.6	20.7 \pm 14.4
Combined Interval *	26.2 \pm 15.4	11.3 \pm 7.9	

* Denotes significant difference between the eccentric and concentric phases; also denotes significant difference between the 10% and 90% interval of displacement.

Table 3. Mean Vastus Lateralis I-EMG for Band Configuration and Percent Interval of Displacement

	10% (\pm SD)	90% (\pm SD)	Combined Band Configuration
NB	27.8 \pm 16.5	8.8 \pm 5.1	18.3 \pm 15.4
BB	27.5 \pm 17.7	12.3 \pm 8.2 *	19.9 \pm 15.7
TB	23.4 \pm 11.1	12.6 \pm 9.4 *	18.0 \pm 11.6

* Denotes significant difference between the BB and NB configurations at the 90% interval of displacement; also denotes significant difference between the TB and NB configurations at the 90% interval of displacement.

For the vastus lateralis, repeated measures ANOVA indicated a significantly lower mean I-EMG output $F(1,21)=47.6$, $p<.0001$, in the eccentric (16.9 ± 14.0) versus concentric (20.7 ± 14.4) contractions. Also, a significant lower vastus lateralis mean I-EMG output $F(1,21)=59.5$, $p<.0001$, was observed at the 90% interval of displacement (11.3 ± 7.9) compared to the 10% (26.2 ± 15.4) interval of displacement. In addition, there was also a significant interaction $F(2,42)=3.3$, $p=.048$, between percent interval of displacement and band configuration. This interaction indicated that there were significant vastus lateralis mean I-EMG differences across the types of band configurations, and these differences were not consistent between the 90% and 10% intervals of displacement. The nature of this interaction is demonstrated in Figure 1. Post-hoc analysis indicated that at the 90% interval of displacement there was a significantly lower $t(21)=3.3$, $p=.004$ vastus lateralis mean I-EMG output in the NB condition (8.8 ± 5.1) than the BB condition (12.3 ± 8.2). Also, at the 90% interval of displacement there was a significantly lower $t(21)=3.1$, $p=.005$ vastus lateralis mean I-EMG output in the NB condition (8.8 ± 5.1) than the TB condition (12.6 ± 9.4). No significant difference between the BB and TB conditions $t(21)=0.4$, $p=.708$, was observed at the 90% interval of displacement. In contrast, at the 10% interval of displacement, no significant differences among any of the band conditions were observed. This result indicates that at the top of the squat exercise, both the TB and BB conditions caused greater relative mean I-EMG output in the vastus lateralis muscle group than the NB condition; however, at the bottom of the squat exercise, there were no relative differences in vastus lateralis mean I-EMG output among the band conditions.

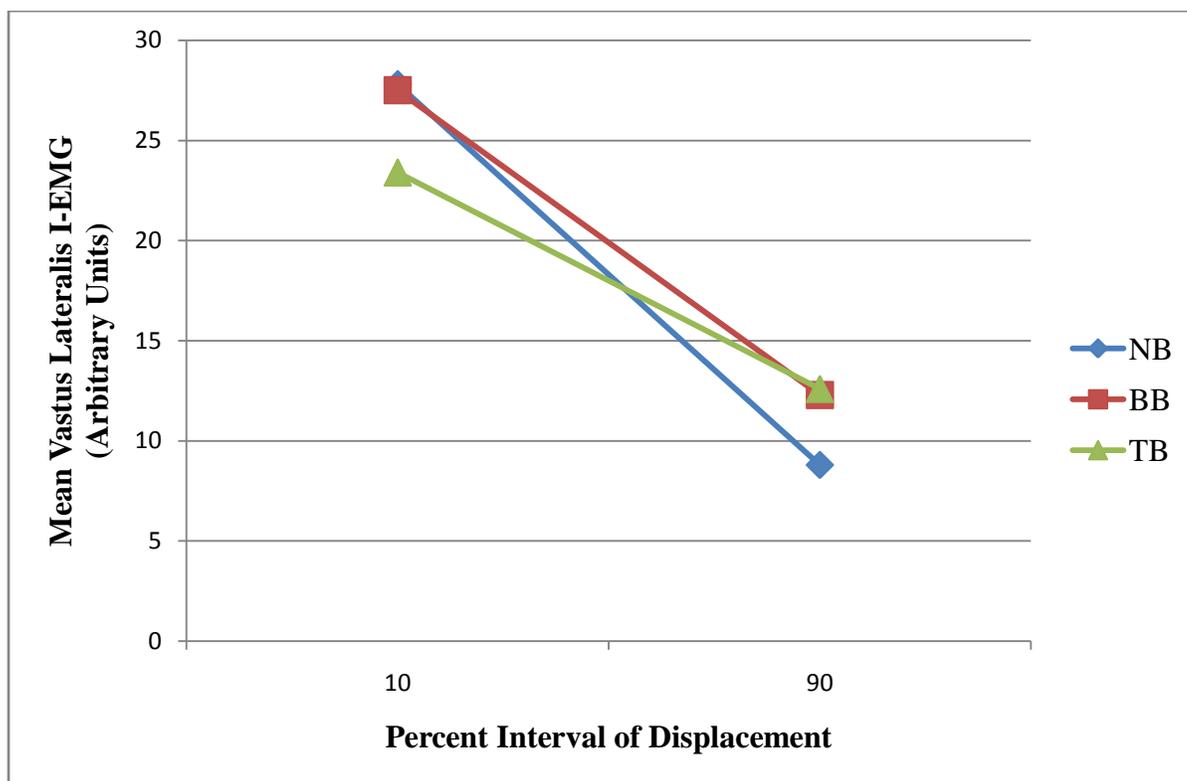


Figure 1. Mean Vastus Lateralis I-EMG for Band Configuration and Percent Interval of Displacement

For the hamstring muscle group, repeated measures ANOVA again indicated a significantly lower mean I-EMG output $F(1,21)=125.3$, $p<.0001$, for eccentric (1.7 ± 1.0) versus concentric (3.7 ± 2.7) contractions. While a significantly lower mean vastus lateralis I-EMG output was observed at 90% compared to 10% of displacement, a significantly higher mean hamstring I-EMG output $F(1,21)=39.6$, $p<.0001$, was observed at 90% (3.7 ± 2.7) compared to 10% (1.8 ± 1.1) of displacement. In addition, there was a significant interaction $F(1,21)=48.2$, $p<.0001$, between type of contraction and interval of displacement. This interaction indicates that the difference in mean hamstring I-EMG

output between 90% and 10% of displacement is not consistent for both eccentric and concentric contractions. Post-hoc analysis indicated that for the eccentric portion of the squat exercise, there is no significant difference $t(21)=1.1$, $p=.275$, in mean hamstring I-EMG output between the 90% and 10% intervals of displacement. In contrast, for the concentric portion of the squat exercise, there is a significantly greater $t(21)=7.8$, $p<.0001$, mean hamstring I-EMG output at 90% of displacement (5.4 ± 2.7) than at 10% of displacement (2.0 ± 1.2).

Similar to the results from the vastus lateralis muscle group, there was also a significant interaction for the hamstrings $F(2,42)=5.0$, $p=.012$, between interval of displacement and band configuration. This interaction indicates that there are significant mean hamstring I-EMG differences across the types of band configurations, and these differences are not consistent between the 90% and 10% intervals of displacement. Post-hoc analysis indicated for the hamstrings that at the 90% interval of displacement, no significant differences among band conditions were observed. In contrast, at the 10% interval of displacement there is a significantly higher $t(21)=3.0$, $p=.007$ mean hamstring I-EMG output in the NB condition (2.0 ± 1.3) than the BB condition (1.6 ± 0.8). No significant differences in mean hamstring I-EMG output between either the NB versus TB conditions, or the BB versus TB conditions, was observed at the 10% interval of displacement. These results indicate that at the top of the squat exercise, there are no relative differences in mean I-EMG output in the hamstrings muscle group among the band conditions; however, at the bottom of the squat exercise, the BB condition causes significantly less relative mean hamstring I-EMG output than the NB condition.

Significant correlations were discovered between the NB, BB, and TB 1RMs (Table 5). These results indicate that both the BB and TB resistance conditions can serve as valid assessments of muscular strength on the squat exercise.

Table 4. Mean \pm SD 1RM Values (lbs) for the NB, BB, TB, and BB (Without Bands (Bar Plus Weighted-Plates)) Configurations

NB	317.5 \pm 61.1
BB	393.9 \pm 64.6 **
TB	368.2 \pm 57.8 *
BB (w/o Bands)	300.5 \pm 60.5

** Denotes significant difference between the BB and both the NB and TB resistance conditions. * Denotes significant difference between the TB and the NB resistance condition.

Table 5. Correlations between the 1RMs on the NB, BB, and TB Configurations

	NB	BB	TB
NB	1.0		
BB	0.94*	1.0	
TB	0.97*	0.94*	1.0

* $P \leq 0.05$.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Although significant results were found between the independent variables at various interactions for the hamstring muscle group, these mean I-EMG values are subject for question (3). Significantly greater muscle activity during the concentric phase compared to the eccentric phase can be explained and is supported by the study conducted by Ebben and Jensen (8); however, it is difficult to explain why greater mean hamstring I-EMG was seen in this study at the top of the squat exercise (90%) compared to that of the bottom (10%) during the concentric contraction phase (28). Research has found that greater torque is created at the bottom of the ROM during an ascending strength curve lift, such as the squat exercise, where lower degree angles of flexion occur at the activated joints (3). Greater torque values are synonymous with greater muscle activity which contradicts this study's finding (3).

Wright et al. (28) concluded in his study that EMG activity for the hamstrings was significantly lower during the squat exercise compared to that of the leg curl and stiff-leg deadlift exercises. Unlike the leg curl and stiff-leg deadlift, which are both single-joint exercises, the squat is a multi-joint exercise (28). For the leg curl and stiff-leg deadlift during the concentric phase, the hamstrings serve solely as agonist muscles through

flexion and extension initiated across the knee and hip respectively (28). During the squat exercise, the hamstrings are subject to movement across both the knee and hip joint simultaneously (28). This multi-joint action of the squat causes the hamstrings to serve roles as both agonists and antagonists during the majority of the entire ROM (28). As the lifter descends eccentrically when performing the squat, flexion occurs at both the hip and at the knee (28). The hamstrings are primarily responsible for both extension of the hip and flexion of the knee; therefore, during the eccentric phase, the hamstrings serve as agonists for knee flexion and antagonists for hip flexion (28). The exact opposite is true during the concentric phase, in which the hamstrings serve as the antagonists for knee extension and the agonists for hip extension (28). This trading of roles as agonists and antagonists creates a simultaneous lengthening and shortening of the hamstring muscles throughout the ROM (28). It is because of this simultaneous movement that the hamstrings are relatively inactive during the squat exercise (28). Reciprocal inhibition is another possible explanation as to why muscle stimulation of the hamstrings was relatively low in comparison to stimulation of the vastus lateralis (3). The quadriceps and hamstrings muscle groups serve as antagonists to one another when movement occurs about the knee (3). Therefore, a large amount of muscle activity by the vastus lateralis could have inhibited the hamstrings from eliciting substantial EMG values (3). In fact, based upon the results collected during this study, the average mean vastus lateralis I-EMG values were 9 times greater than the mean hamstring I-EMG values. High variability values amongst the hamstring EMG data could also be another reason as to

why greater muscle activity at the hamstrings occurred at the top portion of the lift (90%) compared to hamstring muscle activity at the bottom (10%).

Wright et al. (28) stated that for the hamstrings during the concentric phase of the squat, a lengthening through 116.1° of movement occurred at the knee with a simultaneous shortening at the hip through 128.6° of movement. This leaves a net ROM of 12.5° of movement involving the hamstrings (28). In other words, once the knee is fully extended, hamstring movement at the hip continues to occur for another 12.5° of movement until the repetition is completed (28). It's interesting to note; however, that this net 12.5° of movement at the end of the squat exercise occurs at relatively the same position where greater mean hamstring I-EMG was found (90%). At this portion of the ROM, the hamstrings' sole responsibility would be to serve as agonist muscles in extending the thigh at the hip (28). Although this movement occurs at the top of the lift where the angle of flexion at the hip joint is relatively high, it's the only part of the ROM where the hamstrings create movement through only a single joint (3, 28). Therefore, higher mean hamstring I-EMG values at this position of the squat (90%) can be justified because movement by the hamstrings occurs only at the hip, which simulates the hamstring activity of the stiff-leg deadlift exercise to where greater EMG was found (28).

Even though in this study significantly greater mean hamstring I-EMG values were found for the NB configuration compared to the BB configuration at the 10% interval of displacement, the relatively small muscle activity at this bottom portion of the lift is likely to have a minimal contribution to a lifter successfully completing the exercise and is likely inconsequential towards training adaptations for strength and power (28).

Ebben and Jensen (8) performed a study comparing mean I-EMG between traditional, chain, and elastic band squats for the quadriceps and hamstring muscle groups. Despite finding no differences between these three types of squats for mean I-EMG activity, these authors concluded that significant differences might have been obtained if an alternative protocol was used in selecting testing loads for each squat condition. Instead of equating the testing loads, they predicted that by examining the differences in mean I-EMG between various absolute loads, significance could possibly be achieved. This study followed the procedures of Ebben and Jensen (8) by selecting different absolute loads for testing between the NB, BB, and TB conditions in an effort to find significant differences in mean I-EMG for the vastus lateralis and hamstring muscles. These absolute loads were selected based upon a relative percentage of 80% of a subject's 1RM on the given squat configuration. It has been suggested by previous research and verified in this study that a greater absolute load is capable of being lifted if a type of variable resistance is used where the resistance is decreased at the bottom and increased at the top portions of the lift (1, 2, 8, 15, 16, 20). It was assumed by this study that if a subject was capable of lifting a greater absolute load using bands, then the absolute load used during training for this type of squat would also be greater based upon that subject's 1RM using either the BB or TB configuration (14, 15). Therefore, even though the resistances for each subject in this study were different between the different squat configurations, this method of selecting testing loads can be justified based upon Ebben and Jensen's (8) suggestion for future research and the proven assumption that one of the major advantages of using variable resistances is the increase in the absolute load capable of being lifted (1, 2, 8, 15, 16, 20).

Similar to Ebben and Jensen's (8) findings, this study also discovered that there was a significant increase in muscle activity for the vastus lateralis and hamstring muscle groups during the concentric contraction phase compared to that of the eccentric phase despite the type of squat configuration used. This is not surprising given that the activated musculature of both the vastus lateralis and the hamstrings must generate a torque greater than that produced by the resistance in order to move the weight up in an ascending fashion (3).

The mean vastus lateralis I-EMG values for the percent intervals of displacement were also proven to be significantly different between the top (90%) and bottom portions (10%) of the lift. It is known when muscles generate force at joints where the angle is relatively minute (i.e. 10%), greater muscular torque is needed to overcome the increasing torque created by the resistance (3). This verifies the results of this study in that greater mean I-EMG for the vastus lateralis was observed at the bottom compared to the top portions of the squat exercise.

When comparing the interaction between the band configurations and the percent intervals of displacements, significantly greater mean vastus lateralis I-EMG was noted for the BB and TB conditions at the top of the lift (90%) compared to the NB condition. This finding supports the research of both Cronin et al. (7) and Israetel et al. (11) whose studies both found significantly greater muscle activity towards the top portions of the squat ROM using the BB configuration. Israetel et al. (11) stated the reason for this increased EMG at this part of the ROM was simply due to the fact that greater resistance was applied to the barbell when the bands were used compared to the NB condition. Similar to the study conducted by Israetel et al. (11), this study also manipulated the load

when using the band conditions that applied a greater resistance at the top of the lift, confirming the increase in mean vastus lateralis I-EMG.

At the bottom portion of the squat exercise (10%), this study observed no significant differences for the vastus lateralis between any of the resistance configurations. The effect of having a greater load when using BB or TB at the top of the lift, might have contributed to this finding (7). As the lifter descends eccentrically to the lower depths of the ROM when using BB or TB, the absolute load decreases to a level typically less than the resistance experienced by the NB (12, 14-18, 23, 24). Even though the NB resistance is greater at this juncture of the squat, no significance was reported between the NB, BB, and TB conditions. This is possibly due to what Cronin et al. (7) alluded to in his explanation that the vastus lateralis muscle is forced to generate a greater braking force at the bottom of the lift to overcome the downward momentum of the increased resistance experienced by the lifter at the top of the squat exercise when using bands versus no bands.

Significant differences were also obtained between the NB, BB, and TB 1RMs. Recent studies have reported that because variable resistance methods using chains or bands decreases the resistance at the bottom portion of an ascending strength curve lift where leverage is at a minimal, a greater absolute load or resistance is capable of being lifted (1, 2, 8, 15, 16, 20). This bottom part of the ROM is also known as the sticking point, and it is the limiting factor to the maximal amount of external resistance lifted during a given exercise when only free-weights are used to supply the load (1, 2, 15, 20). By applying chains or bands to the barbell that is being lifted, the sticking point which normally occurs close to the juncture between the eccentric and concentric phases of

movement is actually shifted up towards the top of the lift where mechanical advantage is increased (8, 16). At this higher position in the ROM, strength capabilities also increase in which more force is capable of being generated by the active muscles (8, 16).

Therefore, a greater overall amount of resistance can be lifted (8, 16). This study verified these findings, as the BB and TB 1RMs were significantly greater than the NB 1RM.

The BB 1RM was also significantly greater than the TB 1RM. This could be attributed to differences in maximal resistance and assistance between the BB and TB configurations, respectively. Although not reported in the results section of this study, using anthropometric statistics acquired from each subject at the beginning of the methodology determined that the average maximal resistance generated by the bands for the BB condition was 93 lbs based upon the average maximal band deformation of 49 inches. This maximal resistance occurred at the top of the lift where the bands were stretched to their peak. The average maximal assistance provided by the bands for the TB condition only accounted for 46 lbs based upon the average maximal band deformation of 38 inches. This maximal assistance occurred at the bottom of the lift where again, the bands were stretched to their peak for a given lifter's ROM. A greater amount of resistance provided by the bands for the BB condition, which accounted for a greater percentage of the overall load that was being lifted, could have been the reason why the mean BB 1RM was higher than the mean TB 1RM. These differences in maximal resistance and assistance between the BB and TB configurations respectively, served as a limitation to this study. Future research may examine the differences in various kinetic and kinematic variables between BB and TB conditions when the maximal resistance and assistance provided by the bands are equal.

To this author's knowledge, no prior empirical studies have investigated the effects of the TB configuration on muscle activity. This relatively new form of variable resistance using bands tied above the lifter's head towards the top of the power rack has been developed to provide assistance to the barbell that is being lifted (12, 16, 23, 24). Therefore, instead of the bands pulling down on the barbell increasing the amount of resistance during ascension (BB configuration), this band configuration pulls up on the barbell decreasing the external load during declension (12, 16, 23, 24). The bands during the TB configuration provide maximal assistance to the barbell at the bottom portion of the ROM where the lifter is most vulnerable to the phenomenon known as the sticking point, which limits the amount of resistance capable of being successfully lifted (1, 2, 12, 15, 16, 20, 23, 24). Due to the support supplied by the bands, this limitation is negated creating the opportunity for a greater amount of resistance to be applied to the barbell via weighted-plates (24). With the TB configuration during an ascending strength curve exercise, as the lifter raises the bar concentrically towards the top portion of the ROM, the bands begin to decrease in stretch (12, 16, 23, 24). This decrease in band deformation at the top of the lift causes the tension created by the bands to also decrease limiting the amount of assistance provided to the lifter (24). Therefore, a greater amount of resistance is gradually loaded onto the barbell due to an increasing lack of support supplied by the bands (12, 16, 23, 24). To counteract this increase in external load, the lifter must generate a greater amount of force in order to continue to move the barbell in an ascending fashion until the repetition is completed (24). Results from this study indicate that the TB 1RM supplied the lifter with an average of approximately 50 more pounds in resistance compared to the NB 1RM at the top portion of the squat exercise. This unique

overload in additional resistance in the form of weighted-plates has been claimed by recent anecdotal reports to have enhanced effects in increasing force output, velocity, and acceleration (12, 16, 23, 24).

The BB configuration has also been reported to elicit an overload towards the top portion of an ascending strength curve exercise; however, unlike the TB condition, this additional resistance is created by the bands (7, 9, 16, 25). As the lifter ascends towards the top of the ROM the bands begin to increase in stretch (7, 9, 16, 25). As the band deformation increases, the amount of tension supplied by the bands also increases creating an additional amount of resistance (7, 9, 16, 25).

In conclusion, this study was able to demonstrate the use of 1RM testing using the BB and TB configurations as acceptable assessments of maximal strength on the squat exercise based on the significant correlations found between the NB, BB, and TB 1RMs. Therefore, in the future coaches and personal trainers can use these resistance conditions as pretests to more accurately prescribe training loads to their respective clientele based upon percentages relative to their actual strength on the band configuration that is used (14, 15). This method of load selection is based upon the concept, transfer of specificity, because testing is condoned under the same resistance condition as training (4, 9, 14, 15). By increasing specificity when using the BB and TB configurations during training, greater improvements can be made towards strength and power due to the similarity between training and performance (3).

This study also showed that greater mean I-EMG for the vastus lateralis can be achieved at the top portion of the ROM (90%) when variable resistance apparatuses in the form of BB or TB configurations are used versus the NB configuration when performing

the squat exercise. No significant differences were reported for the vastus lateralis at the bottom portion (10%) of the squat exercise between any of the band configurations. Thus, according to the findings of this study, during a given repetition of the squat, greater overall muscle activity can be obtained by performing BB or TB squats as opposed to a conventional squat without bands (NB). EMG signal stimulation is affected by two contributing factors that are also responsible for increasing muscle force: motor unit recruitment and the frequency rate of the motor unit (13). By increasing one or both of these variables, the EMG signal is also likely to be enhanced (13). Therefore, the assumption can be made that EMG activity and the force generated by the muscles are positively correlated (13). So, based upon the direct relationship between EMG and force output, it can be said that not only is muscle activity going to be increased, but also force output will likely be enhanced for a given repetition when performing the squat using BB or TB resistance conditions versus the NB configuration. A greater amount of force generated by the muscles could ultimately produce greater strength adaptations over time during training (3, 12, 14, 16, 17).

Using BB or TB configurations during training could help provide variety to an athlete's workout program and prevent plateaus from occurring when making an effort to gain maximal strength (1). By no means is this study stating that only variable resistances in the form of BB or TB should be used when training for strength or power on the squat exercise. A prescribed combination of NB, BB, and TB squats during the course of an athlete's training cycle could likely prove to be the best way to maximize favorable adaptations towards performance. Future studies using BB and TB squats

during training will help shed light on whether these resistance apparatuses can produce significant gains for muscular strength and power.

APPENDIX A

Consent Form to Participate in Research

Electromyographic Analysis of Conventional and Rubber-Based Band Squats

Principal Investigator and Contact Information:

Texas State University – Exercise Science Program

• Ty Palmer, Graduate Student

Phone: 830-459-5850

Email: tp1165@txstate.edu

Introduction

You are being asked to participate in a research study. This form provides you with information regarding the research being conducted. Please read this form and ask any questions you may have regarding participation in this study. Participation is entirely voluntary. You will be tested in the weight room located in the Jowers Center at Texas State University-San Marcos. Read the information below and ask questions about anything you do not understand prior to deciding whether or not to participate.

Purpose

The purpose of this research is to analyze the effects of the lower leg muscles during the squat exercise using conventional and rubber-based band resistances. An alternative purpose is also to examine the validity of rubber-based band resistances as capable methods of assessing muscular strength during the squat exercise.

Procedures

You must first fill out a form about your health history using the Medical Health Questionnaire Form attached to the back of this Consent Form. Participants may choose to not answer any of the Medical Health Questionnaire Form questions if they do not feel comfortable doing so.

Each subject will be instructed to wear athletic clothing including a t-shirt and gym shorts during all testing.

The subjects will be initially tested for their 1RM in the squat for each of the 3 squat conditions. These tests will each take about 30 minutes to complete. These 3 squat conditions are:

1. Conventional resistance using only free-weight.
2. Variable resistance using bands tied at the base of the power rack plus free-weights
3. Variable resistance using bands tied towards the top of the power rack plus free-weights

Prior to completing the 1RM tests, a single practice session will be given in order for the subjects to become use to performing the squat using the different resistance conditions.

The final testing day will include the following procedures which will take about 30 minutes to complete. Before testing, the electromyography telemetry system will be checked thoroughly in order to ensure that the device is in proper working condition.

1. The principal investigator will locate and mark specific areas of the right leg to measure muscle output of the vastus lateralis.
2. Subjects will be given a new shaving implement to remove hair from specific marked spots on the right leg in order to place electromyography leads.
3. Prior to testing, subjects will complete a 5-10 minute warm up performing light dynamic stretching and several warm-up sets on the squat exercise for each resistance condition.
4. After the warm up, subjects will clean with alcohol wipes the surface of the skin previously marked for electromyography leads.
5. Electromyography leads will be placed on the clean surface of the marked skin on the right leg.
6. Subjects will be instructed, by the principal investigator, on how to complete each squat that will be conducted
7. Leads will be hooked up with conduction wires to the BIOPAC 4-Channel Electromyography Telemetry System.
8. Subjects will perform a total of 9 repetitions on the squat exercise, 3 repetitions for each squat condition.
9. Upon test completion, subjects will conduct a cool down consisting of light dynamic stretches.

Potential Risks or Discomforts

The potential risks for this experiment are minimal because the subjects will be supervised by the principal investigator, who is also a certified strength and conditioning specialist, during the duration of the study; however, with any exercise there are potential risks for injury. Subjects will be required to perform the squat exercise with at least one experienced spotter during all testing. Risks will also be minimized by warming up prior to the testing protocol and cooling down after testing.

All squat exercise testing will be conducted in the Jowers Center weight room inside a power rack.

If a medical emergency occurs during testing, emergency services will be contacted. The primary investigator will assist with all emergency situations until EMS arrives on scene. If a minor emergency occurs, the weight room is located next to the Athletic Training Lab with on-site accredited Athletic Trainers available to provide support if needed. The primary investigator also has certification in CPR and has experience working with research conducted by other professors in the Health and Human Performance Department at Texas State University. A subject will be responsible for any medical costs if an injury does occur as a result of participating in this study.

Possible Benefits

The benefits of this investigation will provide you information about:

- Muscle output activity in the leg while performing the squat exercise using 3 different resistance conditions.
- Alternative methods for assessing muscular strength using rubber-based band resistances

Confidentiality

A subject's name, age, height, etc. will be required to participate in this study; however, all data will be kept in the primary investigator's office for 3 years in a locked cabinet in order to preserve the confidentiality of a subject's information. Only the principle investigator and the members of the investigator's thesis committee will have access to the results during or after research. Results from the study may be used for future research. If consent form material is needed for research purposes, subjects will be contacted for additional release of consent of information.

Participation

Participation in the study is completely voluntary and you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed. You may request a copy regarding the results of this study anytime upon completion of the study. Please contact the principal investigator, Ty Palmer at (830) 459-5850 or tp1165@txstate.edu in order to arrange delivery of the results. A minimal percentage of extra credit (less than 5%) in relation to the total points offered in class will be provided to each subject as an incentive. If students do not want to participate in the study as subjects, alternative assignments such as spotting the subjects during lifting or providing subjects with motivation will serve as opportunities for earning extra credit as well. If you have any other questions regarding the research,

research participants' rights, and/or research-related injuries to participants, please contact the IRB chair, Dr. Jon Lasser at (512) 245-3413, lasser@txstate.edu or Ms. Becky Northcut, Compliance Specialist at (512) 245-2102.

Authorization

Texas State University-San Marcos, Department of Health and Human Performance supports the practice of protection for human subjects participating in research and related activities. The consent form is provided so that you can decide whether or not to participate in the present study.

“I have read the above statement and have been fully advised of the procedures to be used in this project. I have been given sufficient opportunity to ask any questions I had concerning the procedures and know that I am free to ask questions as they may arise. I likewise understand that I can withdraw from the study at any time without being subjected to reproach.”

Participant Name Printed (18 years or older)

Phone #

Signature

Date (mm/dd/year)

Principle Investigator Signature

Date (mm/dd/year)

APPENDIX B

Medical Health Questionnaire Form

Name: _____

Age (Years): _____

Height (Feet & Inches): _____

Weight (lbs): _____

Weight Training Experience on the Squat Exercise (Years): _____

Yes		No		Current Activity Level
<input type="radio"/>	<input type="radio"/>	Are you physically active (i.e., do you get at least 30 minutes of physical activity on at least 3 days per week)?		
<input type="radio"/>	<input type="radio"/>	Have you participated in weight training activities for at least once a week for the past 6 months?		
Yes		No		Symptoms – Do you:
<input type="radio"/>	<input type="radio"/>	Experience chest discomfort with exertion?		
<input type="radio"/>	<input type="radio"/>	Experience unreasonable breathlessness or unusual fatigue at rest, with mild exertion, or during usual activities?		
<input type="radio"/>	<input type="radio"/>	Experience dizziness, fainting, or blackouts?		
<input type="radio"/>	<input type="radio"/>	Experience difficulty breathing when lying flat or when asleep?		
<input type="radio"/>	<input type="radio"/>	Experience ankle swelling?		
<input type="radio"/>	<input type="radio"/>	Experience forceful or rapid heart beats?		

<input type="radio"/>	<input type="radio"/>	Experience numbness in legs or arms from time to time?
Yes	No	Other health issues that may warrant physician approval before engaging in physical activity.
<input type="radio"/>	<input type="radio"/>	Have you ever been told not to exercise by a health care provider?
<input type="radio"/>	<input type="radio"/>	Do you have problems with your muscles, bones, or joints?

Please provide an Emergency Contact: **Name:** _____

Phone Number: _____

I certify that the information included on this form is correct.

Date

Signature of Participant

Date

Signature of Primary Investigator

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VITA

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