Does the Use of the Antagonist Facilitated Specialization and Oscillatory Training Methods Reduce Co-Activation and Improve Rate of Force Development to a Greater Extent than Traditional Methods?

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Does the Use of the Antagonist Facilitated Specialization and Oscillatory Training Methods Reduce Co-Activation and Improve Rate of Force Development to a Greater Extent than Traditional Methods?

by

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Abstract

Performance coaches have been concerned with methods of training to improve rate of force development since the realization of its importance in performance. This study examined the effects of the antagonistic facilitated specialized method and oscillatory training method effects to improve rate of force development specific to sport requirements and reduce unnecessary levels of antagonist muscle co-activation. Thirty-two subjects completed an eighteen week training program in which the first fifteen weeks of training were identical between the two training groups. In the final three weeks of the program subjects were split into two groups. One group followed the peaking method as laid out in this study; while the other followed a more typical training method used in today’s coaching methods. The changes in rate of force development were then measured between the two training groups. Neither group showed significant changes in their rate of force development. However, the peaking group did approach statistical significance ($p=0.08$) with their average rate of force production pre and post-training being $1389 \pm 504$ lb/sec. and $1769 \pm 647$ lb/sec., respectively. The power group remained statistically insignificant ($p=0.40$) with an average rate of force production pre and post training being $844 \pm 448$ lb/sec. and $1071 \pm 420$ lb/sec., respectively. Although the results of this study showed no significant improvements in rate of force development due to training, a trend towards significance can be seen in the final jump within the peaking group while the power group did not approach a significant value. This shows some potential for the antagonist facilitated specialized method and the oscillatory method to improve rate of force development to a greater extent than other methods used in a typical strength training model.
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Chapter I: Review of Literature

This review of literature is presented in the following sections: Rate of force development and co-activation; antagonist; transfer of training; why/how co-activation occurs; why reducing co-activation is a goal for athletes; and ways co-activation could be affected.

Rate of Force Development (RFD) and Co-activation

Success in non-team sports ultimately comes down to which athlete can produce the most force in the time allowed during their individual competition event, while also being efficient with their movements \(^1\)\(^-\)\(^7\). The goal of a strength and performance coach at any level should be to get athletes to make the greatest performance gains in the shortest amount of time \(^7\). This is the idea of efficiently applying optimal periodization schemes for athletes.

Individual athletes generate maximal forces based on two elements. The first determining factor is the maximal force capabilities of individual muscles, with the second being the coordination of muscle activity by the central nervous system (CNS) \(^4,8\). The ability of the individual muscles to produce force is determined by specific training methods, while the force produced by the coordination of muscle activity is a learned activation pathway of the muscles for optimal safety of the organism while maintaining maximal force outputs \(^3\).

The ability to produce force rapidly has been coined the rate of force development (RFD) and is actively sought after by every strength and performance coach. The reasoning for placing importance on improving RFD is due to the limited time available for athletes to deliver force in their competition movements \(^2\). The time available for force development in athletic movements is much smaller than the time needed for the body to produce maximal force, which takes up to 0.3-0.4 seconds \(^2,5\). Sprinting is an example of this, the ground contact time in maximal velocity sprinting is typically between 0.08 and 0.12 seconds, which is much less than the 0.3 to 0.4 seconds needed to
produce maximal force \(^{(2,5)}\). Pre-activation plays a role in increasing force production, however maximal force still is not achieved. Pre-activation is especially important to optimize the stretch-shortening cycle. Pre-activation “increases the initial muscle stiffness and thereby improves the ability of the viscoelastic tendons to be stretched and recoil,” which further improves RFD. In order to increase the force produced during sprinting, the ability to produce force rapidly becomes more important than maximal force production. Sprinting is just one example of a movement of sports; however, the majority of maximal velocity movements in sport have a time of less than 0.25 seconds to produce force. It is for this reason every coach is training with the intent to increase RFD.

Rate of force development is influenced by different training methods. Rate of force development can be trained in a biphasic manner with an early phase lasting less than 0.1 seconds and a late phase with times longer than 0.1 seconds \(^{(4,9)}\). The early phase is influenced primarily by neural drive while the late phase is more dependent upon the muscle cross sectional area and maximal force production capabilities \(^{(2,4,9)}\). Another trainable aspect that leads to improvements in RFD can be found in the viscoelastic properties of the muscle and tendon \(^{(2)}\). The proportion of fast and slow twitch fibers is another variable that affects RFD; however, this tends to be more genetically based and not as trainable \(^{(2)}\).

With early and late phases of RFD affected by different processes, it is not surprising that different training methods bring about different adaptations to the two phases. Training programs that place focus on explosive strength, or high velocity movements increases early force development by increasing neural drive \(^{(1,2,4,6,9)}\). It appears that the early phase of force development may also be improved when the intention of training is maximal acceleration, meaning the intended velocity becomes more important than the object velocity \(^{(4,5,9,10)}\). Programs that focus training on high loads lead to improvements in maximal strength and maximal force development. These
adaptations are involved in the late phase, as the movements allow enough time for maximal force to be developed during muscle contraction.

Maximal velocity movements in athletic competitions do not allow enough time to apply maximal force with each contraction. This does not mean that maximal force should be overlooked in the training process. Maximal force has a positive relationship with RFD, meaning as maximal force increases, so does RFD \(^{14}\). This concept justifies the thought process of athletes needing to improve maximal strength. There comes a point, however, when increasing maximal strength will no longer transfer to improved athletic performance. Once this threshold of maximal strength has been reached, the goal of coaches must be to increase the early phase of RFD. The time period of the year also determines a coach’s decision on which phase to train in regards to RFD. As the competition period approaches, focus of training must be shifted to the early phase in order to optimize transfer of training, and ultimately performance.

The second determining factor of force production in athletes is the coordination of the muscle activity, as controlled by the CNS. In order to perform optimally and produce maximal force, precise coordination of the involved muscles is an absolute requirement \(^{11}\). The improvement in this coordination of the nervous system is a learned skill through training \(^{3,12}\). Training with exercises that utilize the same muscle activation systems as seen in competition will lead to increased coordination of the nervous system and increased transfer of training. When all of these nervous system qualities improve, athletes better able coordinate the activation of fibers in single muscles as well as in muscle groups.

The CNS, consisting of the brain and spinal cord, send signals in accordance to the desired action. The brain sends an action potential, or signal, down the spinal cord and through the peripheral nervous system to the desired motor neuron. The peripheral nervous system has many
branches that connect the spinal cord to all parts of the body. In some cases reflexes are used. In these cases the signal originates in the spinal cord. The reflex system is used when rapid reaction is necessary.

A motor unit is composed of a single motor neuron and the muscle fibers it innervates \(^{(10)}\). Different motor units vary greatly in their size, force generating capacities, and their resistance to fatigue. As the number of motor units being utilized during a movement, so does the force production \(^{(10)}\). This is the basis of recruitment. There is a close match between the size of a motor unit and the type of muscle it contracts. For example, fast twitch fibers are innervated by motor neurons capable of firing at faster frequencies, which allows greater contraction velocities and more force production. Motor units also vary in the number of muscle fibers they innervate \(^{(10)}\). Smaller motor units innervate a smaller number of muscle fibers and are generally responsible for completion of more precise and finely graded movements. Larger motor units that innervate hundreds to thousands of muscle fibers are responsible for the execution of large muscle movements that do not require as much precision. An example of a small motor unit is the control of an eye muscle while focusing on an object, while a large motor unit would be the quadriceps during knee extension.

Specific neural adaptations due to training may include recruitment, rate coding, the incidence of discharge doublets, and to some extent synchronization \(^{(1,6,7,9,12)}\). Recruitment of muscle simply implies changing the number of muscle fibers used during a movement. Muscle fibers are recruited in a specific order according to their size. Small slow twitch endurance type fibers are recruited first with the bigger, stronger, or fast-twitch, fibers being recruited as force requirements increase. Excluding sustained submaximal activity, as the number of muscle fibers recruited increases force production also increases. A second way to increase force production is to increase the rate at
which each motor unit is activated. This is known as rate coding (3). When the firing rate of a motor neuron increases, so does the potential for force output of the muscle. Doublets occur when two twitches are sent to the same motor neuron within 0.05 seconds of each other. Doublets increase RFD significantly and have been shown to increase in occurrence with explosive training methods (1,3). The activation of the motor units in a more or less coordinated way is also known as synchronization. Synchronization, although shown to have less of an impact than recruitment, rate coding or doublets, can still help increase the efficiency of firing, allowing for maximal force production.

Maximal muscular force is only achieved when a maximal number of fibers are recruited during a contraction. This includes both slow and fast-twitch motor units, when rate coding is optimal to produce a fused tetanus in each motor fiber and all motor units work synchronously over the short period of the maximal voluntary contraction. Therefore, maximal muscular force is determined not only by the quantity of involved muscle fibers, but also by the extent that each fiber is activated (10). Each of these trainable and necessary neural adaptations as well as specific methods of training are discussed in greater detail in a later section of this thesis.

**Antagonist**

The production of force in a rapid manner is imperative for success of most athletic performances (1-7). In order for maximal power to be produced, intramuscular and intermuscular coordination must be at the highest possible levels. Included in the intermuscular coordination is the contraction timing and force produced by the agonist as well as the antagonist. The net torque produced at the joint is ultimately the moment generated by the agonist minus the moment of the antagonist (3,13-21). Thus, in order for the agonist to shorten with maximal net torque, the antagonist must be allowed to stretch within reason to keep joint integrity.
During any voluntary contraction co-activation, or activation of both agonist and antagonist, occurs to some extent. Co-activation is important for joint stability; but, it also determines the net torque about the joint \(^{3,13-21}\). The ability to reduce the level of co-activation during certain phases of the muscle contraction show adaptations within the nervous system and increase desired force output \(^{12,13,14,18,19}\). This increased force will show improvements particularly during the early RFD phase which appears vital for optimal athletic performance.

Improving net torque about a joint can be accomplished in two ways; increase the activation of the agonist muscle(s) or decrease activation of the antagonist muscle(s). Increasing force output of the agonist muscle(s) is the most commonly understood method to increase net torque. However, methods of decreasing co-activation of the antagonists can be just as valuable to improve net torque as increasing activation of the agonists.

Strength training, when programmed correctly, has the ability to reduce the interfering effect of co-contraction between the agonist and antagonist muscles in rapid movements such as those seen in athletic competitions \(^{14,16-19}\). Proper training leads to a more efficient control of what is commonly referred to as the “ABC” pattern seen in musculature during dynamic movements \(^{15,16,17}\). The ABC pattern consists of three contraction phases. The three steps in this pattern include a large burst by the agonist muscles early in the movement phase (A), followed by a short braking burst from the antagonist muscles (B), and then a final push by the agonist muscles to complete the movement (C). As the speed of a contraction increases, so does the amount of braking force applied by the antagonists. With this in mind, the thought of decreasing the co-contraction of antagonist muscles to increase net torque becomes a relevant idea as a shorter, more succinct braking phase would mean that agonist muscle action could contribute a larger portion of the total contraction time.
The efficient coordination of the agonist and the antagonist is one of the valuable early adaptations in resistance training responsible for increases in torque production \(^{16,20}\). Adaptations to co-activation appear related to skill development as highly trained athletes show different magnitudes and/or patterns of co-activation during maximal contractions or other given motor tasks when compared to novice or non-athletes \(^{12,13,14,18,19}\).

Weak antagonist muscles may also limit the velocity at which contractions are completed and strengthening of antagonists often lead to increases in agonist muscle movement as well \(^{16,24}\). Antagonist movements in training directly following agonist movement training led to an increase in power to a greater extent than the group training with just agonist exercises \(^{10}\). This displays the importance of training both agonist and antagonist muscles, even if a sport action is considered to be dominant in just one of those muscle groups.

**Transfer of Training**

Another factor in force production in athletics is the transfer of training from the weight room to the competitive event. A strength and performance coach’s goal must be to improve performance in the specific athletic event, not just make an athlete stronger. Increased transfer of training consists of several key factors that include increasing RFD and optimizing muscular activation patterns specific to sport.

In regards to skill learning, the expression of voluntary strength is linked to a skilled act. The primary agonist muscles used must be fully activated along with proper activation of synergistic and antagonistic muscles \(^{14,18,19}\). When subjects are introduced to a new and relatively complicated strength task, excessive co-contraction of antagonist muscles may limit their ability to fully activate the agonists, leading to a decrease in net torque produced \(^{19}\). Practice and training in a specific
movement pattern may reduce the amount of this co-contraction, allowing for optimal torque production about the joint(s).

Improvement in athletic performance is determined by an increase in the coordination of all muscles involved in a movement and not solely on the increase of strength of the individual muscle. It is unlikely that training improvements in one movement will correlate to other movements, even within the same muscle. An example of this can be seen in the quadriceps muscles. Although quadriceps contraction is common for many movements in athletics such as jumping, cycling, and/or sprinting, the sequence of muscle activation for each of these movements differ so that a set of neural connections established as a result of quadriceps training is unlikely to help with multiple movement patterns. For this reason, it is vital to train athletes in patterns similar to the movements seen in competition. This is important for both force production and improvement in activation patterns of muscles seen in their respective event.

Another method that improves transfer of training of an exercise is attempting to mimic the velocity of movements seen in competition. This is difficult as very few movements if any completed in a weight room can match the speed seen in competitive events \(^7\). An example of attempting to improve transfer of training is comparing a heavy set bench press at 80% of an athlete’s 1 repetition max (1RM) compared to a medicine ball chest pass. The medicine ball exercise is much closer to the speed and rate of force development required during an athletic movement, thus it will have a higher transfer of training than the 80% 1RM bench press.

One cannot maximize RFD solely by focusing on a higher transfer of training and ignore maximal strength exercises. Increasing maximal force output also positively correlates with RFD \(^4\). Training for each parameter, maximal force output and sport specific transfer or training depends on the time of year. Training exercises typically begin with a focus on maximal force output and as the
competition event or season approaches, methods of training are shifted to focus on transfer of training to maximize RFD.

The requirement for increasing transfer of training from the weight room to the competitive event must be realized in order to optimize performance. For this reason, it is necessary to train using specific exercises that utilize the similar muscle activation patterns and attempt to mimic the high velocities in sport.

**Why/How Co-activation Occurs**

Co-activation occurs to ensure joint stabilization and varies depending on both the joint angle and the forces acting on the joint. The increased joint stabilization also improves movement accuracy. Higher activity of the antagonist muscles is seen at end ranges of joint motion compared to the middle. This further depicts the importance of antagonist muscle co-activation in joint safety. The deactivation of the antagonist muscles during contraction allows for faster contraction of the muscle, leading to higher net torque.

During voluntary muscle contraction, the central command descending from the primary motor cortex contributes to the simultaneous activation of the agonist and antagonist muscles. The CNS will compromise maximal force production to ensure stabilization and joint integrity, particularly in situations of uncertainty in the motor task, the type of muscle contraction, when high loads are used, and at varying degrees of a joint angle. There is also a sharp increase in antagonist co-activation as velocity of the movement increases. This further suggests co-activation provides the counter-torque necessary to slow down rapid movements and is useful for joint stability. Despite the knowledge of these fundamental roles of the antagonist in co-activation, little is known about the brain mechanisms underlying their control.
The origin of muscle co-activation is both supra-spinal and spinal and tends to decrease with resistance training, which allows, under certain circumstances, an increase in the desired torque developed. However, antagonist muscle co-activation also depends on the characteristics of movement. Although research shows these mechanisms are affected by both training and detraining, the origin and contribution of supra-spinal mechanisms to the antagonist muscle co-activation process have yet to be specified (27,28).

**Why Reducing Co-activation is a Goal for Athletes**

Athletic success is often determined by which competitor can produce the most force in the limited time allowed during an athletic movement. Due to the fact that athletic movements do not allow enough time to create maximal force outputs within the muscle, RFD becomes the most important factor in performance (2). It is important to realize that, not only do agonist muscles produce movement, but also antagonist muscles which, during co-activation, might actually hinder torque production about the joint (12).

Net torque generated about a joint depends on the force developed by the activation of the agonist muscles, minus the force developed by the antagonist muscles. Co-activation of the antagonist may impair the athlete’s ability to fully activate the agonist.

The gains in force output seen at the end of training periods have been attributed to many factors including motor unit recruitment, rate coding, and muscle hypertrophy (2,3,12). Training and strength gains, along with the achievement of a motor skill have been accompanied by a reduction in co-activation of antagonist muscles as well (14,16,17,18). Elite athletes in general, exhibit a reduction in co-activation compared to sedentary subjects, which supports the notion that training has the ability to reduce co-activation. The achievement of a motor skill is another method used to reduce co-activation as elite tennis players showed a significant reduction in co-activation at all angular
velocities during elbow extension over recreational tennis competitors\textsuperscript{(13,18,19)}. Progressive inhibition of muscular activity unnecessary for the achievement of a task has also been shown, further enforcing the achievement of a motor skill associated with reduced co-activation.

Proper training of both agonist and antagonist muscles further enhances the reduction in co-activation. It is possible that strength training causes adaptations within the nervous system that allow the agonists to be optimally activated in specific movements, leading to a better coordination of all muscles associated with movement patterns. Improving the activation and coordination of the agonists leads to either an increase in the amount of force produced in the intended direction of movement or a more efficient movement that conserves energy. The antagonists, when strengthened, will not only improve the joint stability, but are also able to stop the movement in a faster time by applying a better braking force\textsuperscript{(15,16,17,19)}. This increased braking force leaves a greater amount of time within the movement for acceleration, creating higher velocity movements by the agonist muscles. By strengthening the antagonists, the ABC firing pattern can occur at a later time, leading to increased time to produce force in the concentric manner of the completed action.

**Ways Co-activation Could be Affected**

**Improving RFD.** Rate of force development is influenced by many factors. These factors include, but are not limited to the proportion of fast to slow twitch fibers, muscle cross-sectional area, viscoelastic properties of the muscle-tendon, and the efferent neural drive to the muscle fibers\textsuperscript{(1,2)}. Rate of force development has been used to evaluate the capacity of muscles to generate force vital for athletic performance. But, as velocity of a movement increases, the muscle’s ability to produce force is diminished. Because of the inverse relationship between force and velocity, sports training have typically focused on strength.
Whether attention is placed on maximal strength or explosive strength during different, phases, it will certainly have decidedly different influences on RFD \(^{4,9}\). Training with short, high RFD contractions, placing a substantial emphasis on neural drive and explosiveness rather than maximal force, may work to improve the early phase of RFD \(^{1,2,4,5,6}\). Explosive muscle strength can be defined as the rate of rise in contractile force at the onset of contraction. This improvement seen with explosive training in the early phase might very well be the most important aspect to maximize in athletics where maximal contractile force is almost never reached \(^{41}\).

Low resistance, 30-40\% of 1 RM, with high velocity dynamic training potentially causes an earlier recruitment of large motor units, increased rate coding, increased discharge of doublets, improvements in synchronization to some extent and also changes in sarcoplasmic reticulum Ca\(^{2+}\) kinetics \(^{1,2,3,31}\). All of these factors play a vital role in RFD.

**Nervous system.** Three common methods to alter motor unit recruitment, rate coding, and synchronization are aimed at improving sports skills. Each motor unit consists of a motor neuron coming from the spinal cord and the muscle fibers it innervates. When a motor neuron is activated, or recruited, impulses are distributed to all fibers within that motor unit. This is known as the all-or-none principle. By recruiting more motor units, an increase in muscular force can be accomplished. Greater force can also be created through changes in motor unit firing rates. This is known as rate coding. Synchronization allows muscles to be activated or inhibited at appropriate times in order to maximize force production through an entire movement \(^{3}\).

**Recruitment.** During any voluntary contraction, the orderly pattern of muscle recruitment is controlled by the size of the motor neurons. The size principle dictates that smaller motor units are recruited first as they have neurons with the lowest firing threshold \(^{3}\). As the force required by a task increases, so does the number of activated motor neurons, leading to the larger, more powerful,
motor units being recruited. Motor units with the largest motor neurons also have the fastest twitch potentials. They also have the highest threshold and are therefore recruited last.

As the number of recruited fibers increases, so does the force produced by the muscle. In athletics, the ultimate goal is often to produce as much force as possible in a limited amount of time. Thus, improving the body’s ability to create high forces by improved recruitment is an important aspect that cannot be overlooked.

Training the recruitment of large, explosive motor units is necessary in order to improve the force production of muscle\(^3\). This adaptation can be reached by using large, or explosive forces, in order to recruit these fast twitch type II hypertrophy based fibers.

The size principle is applicable and relatively fixed for a muscle involved in a specific motion, even if the movement velocity or RFD is altered. The threshold of motor unit recruitment is typically lower during ballistic movements due to the rapid elevation of force needed to complete the task\(^3\). These two elements are important details to consider in the world of athletics where almost every movement is completed with high velocity and a high rate of force development.

Although currently no techniques exist to definitively establish whether or not training elicits a true increase in motor unit recruitment, experts have argued that specific training affects motor units within a specific muscle movements, leading to a decreased threshold of the large, fast twitch motor units, while no change is seen in other movements. This demonstrates, again, that adaptations due to training are linked to movement patterns and skill development. As the body becomes proficient in a trained movement, the ability to increase force due to recruitment of fibers is improved in that specific movement pattern. This skill learning further demonstrates the importance of utilization of proper exercises and training methods to improve transfer of training.
**Rate coding.** The recruitment of the motor units is just one way the nervous system can adapt to create higher force by a muscle. Force is both a function of the number of motor units activated and the amount of force produced by each activated fiber. The nervous system has the ability to increase the frequency of the signal to a motor unit which leads to an increased rate of firing within that same motor unit (3). This is known as rate coding. When multiple signals, or twitches, occur in a muscle fiber, the tension it produces is increased and overall muscle force is potentially greater.

In general, recruitment is more important than rate coding for early recruited motor units and low loads, while rate coding becomes important as force production nears maximal voluntary contraction (3). Rate coding however, is the primary source when rapid intramuscular tension is required to overcome a load. In small muscles, the majority of motor units are recruited at a level of force less than 50% of the maximal force capability of the muscle (10). Once those motor units are recruited, rate coding plays the major role in the further development of force (3). In larger muscles, such as the deltoids and biceps, recruitment of motor units appears to be the primary mechanism for increasing force development up to 80% maximal force output. In the force ranges of 80 and 100% of maximal force output, an increase rate coding is almost exclusively responsible for increasing force output.

The ability to increase rate coding of a motor unit is important in the production of doublets, which are two twitches sent to a motor unit within 0.05 seconds of each other. Doublets result in a significant increase in RFD as tension produced by a doublet is much greater and develops much more rapidly than if the two twitches were produced on their own. Doublets have the highest occurrence when a high RFD is needed or the speed of contraction is high (3).
Although researchers have yet to demonstrate motor unit excitability in a definitive way, it has been argued training increases rate coding \(^3\). An increase in firing rate of trained muscles is a possible mechanism of improvement in neuromuscular performance as an increase in force production is seen. Improvements in rate coding enhance the magnitude of force generated, which is done by increasing the amount of the force produced by the recruited fibers. As more force is produced, the ability to improve RFD is also enhanced, which leads to a rapid increase in force development.

Training effects on rate coding have been demonstrated by sprinters that show the highest motor unit firing frequency in rapid dorsiflexion, leading to the idea that rate coding, like recruitment is a learned skill specific to training \(^3,1\). With the knowledge that athletic success relies heavily on RFD, it should be a goal of strength and performance coaches to increase the number of doublets produced via specific high intensity training. This can potentially be accomplished by using ballistic type exercises prompting adaptations to motor unit firing frequencies.

**Synchronization.** Another way the nervous system can increase force production is the synchronization of motor units. Synchronization refers to the activation of each motor unit in a more or less synchronous manner, with more synchronization leading to increased force outputs \(^3\). In most contractions, motor units function asynchronously to produce a smooth, accurate movement. Although recruitment and rate coding are the two major factors in RFD, there is some evidence that in elite power and strength athletes, motor units are activated synchronously during maximal voluntary efforts \(^3\).

Motor unit synchronization occurs when two or more units are activated concurrently more frequently than expected for independent random processes, which leads to an augmentation of force and increases RFD \(^3\). The adaptation of the nervous system leading to increased
synchronization assists with co-activation of muscles within a movement, leading to increased intermuscular coordination, and ultimately increased RFD\textsuperscript{(3,12)}.

Intermuscular coordination describes the appropriate activation, in both magnitude and timing, of the agonist, synergist, and antagonist muscles during a movement. In order for a movement to be optimally efficient, the agonist activation must be supplemented by increased synergist activity and decreased co-activation of the antagonist muscles. Only when these steps occur, with precise timing and level of activation of the appropriate muscles, will the flow of power through the kinetic chain be optimal\textsuperscript{(3)}.

The ability to transfer power through the body in a coordinated fashion, like every other adaptation, is a learned skill through training. The utilization of exercises that have high transfer of training to the competitive event will optimize synchronization, leading to the realization of success in athletics\textsuperscript{(7)}.

**Motor learning.** Motor learning is based on the principle of skill development. Skill development, at the most basic level, is the ability of the body to adapt to a stimulus and adjust its response in order to achieve optimal results for that specific task. The accomplishment of any task, especially athletic ones that require high forces and velocities, require proper coordination. This coordination of movement can be improved through the proper training stimulus.

Despite the fact that many muscle systems are characterized by intrinsic strategies, these patterns of activation do not always result in the most effective activation sequence\textsuperscript{(3,14,20,30)}. This is especially important in high velocity actions because they have the potential to lead to inefficient activation sequencing\textsuperscript{(3,30)}. Proper training however can improve this process. After four weeks of resistance training, the level of input to the spinal motor neurons associated with a particular degree of muscle activation or joint torque is lower than before training\textsuperscript{(30)}. This shows that a smaller input
is required to achieve the same muscle activation post-training. It seems reasonable to conclude that training programs engage muscles in patterns of activation that are not promoted by intrinsic strategies of control and may actually promote flexibility in subsequent recruitment patterns.

Motor learning may also play a role in the reduction of antagonist muscle co-activation \cite{14}. In novel or complex tasks, co-activation by antagonist muscles is often excessive, but has been shown to decrease with practice \cite{12,14,18,19}. Lower antagonist co-activation is associated with a high skill level or familiarity with a movement, meaning with enough practice it is a learnable skill \cite{12,14,18,30}. Data also suggests that higher scores in strength tests resulting from training programs largely reflect acquisition of skill \cite{10,14,30}. The development of a specific skill, once again, leads back to the importance of training programs having a high transfer of training. Thus, allowing the learned skills, ranging from nervous system adaptations to increased force output, to be transferred from the weight room to competition \cite{3,30}.

**Myelination.** Myelination of axons is increased with the development of skill \cite{30}. Skill development leading to an increase in myelination is the result of countless hours of practice, which forces the brain to fire the electrical impulses through specific neural circuits to the motor units of the muscles \cite{30}. The increased number of signals continuously sent through a specific group of neural circuits leads to an increase in myelin, which wraps the axon of nerves and acts to speed up conduction velocity \cite{30}.

Myelin is a white, fatty substance that coats axons throughout the brain and human body. Axons act as wires, carrying electrical signals along billions of chains of nerve fibers, relaying messages from the CNS to the peripheral nervous system and then back again \cite{30}. As the amount of myelin increases, the proficiency of the skill correlating with that specific neural circuit is increased as well.
Every task, thought and action that the human body and brain perform is a learned skill or reflex circuit \(^\text{[30]}\). The basic ideas regarding neural transmission can be broken into three points. The first is that every movement, thought, or feeling is a precisely timed electrical signal traveling through a chain of neurons, otherwise known as a circuit of nerve fibers allocated together to perform a task. Second, myelin is the insulation that wraps many of those nerve fibers and increases the signal strength, speed, and accuracy. Finally, myelination is important for skill development. The more a particular neuronal circuit is fired, the more myelin insulates that circuit. These stronger, faster signals lead to more fluidity throughout an athlete’s thoughts and movements \(^\text{[30]}\).

Studies have shown that a physiological adaptation of the brain to learning a new skill is the addition of myelin around the neural circuits responsible for that specific skill \(^\text{[30]}\). A second study showed that myelination could be inhibited by blocking of specific neural circuits. These two studies show stimulation of neural circuits, such as those observed in thoughts and movements, is a requirement to increase myelination \(^\text{[30]}\).

The increased neural conduction velocity can become significant when RFD is important, as seen in competition. This, again, shows the importance of using exercises and high velocity movements that have a high transfer of training to an athletic event. This high transfer is vital as only the neural circuits trained, will show increased myelination. Increased myelination is important to athletes as it has the ability to lead to increased RFD of the agonist or may lead to less co-activation of antagonist muscles \(^\text{[30]}\).

Increasing myelination due to a specific movement calls for better methods to determine how athletes should train and practice. The next step is to find ways to maximize the amount of neural input each athlete processes while competing in their specific event. If this feat is achieved, coaches would have the ability to speed up the development and learning process, which would
ensure athletes reach their full potential (30). There are many theories considered valid that may be responsible for the increase in myelination as this research is still in its infancy and is highly theoretical (30).

Muscle contraction. Skeletal muscle consists of numerous fibers, or muscle cells. Each fiber is made up of many parallel myofibrils, which consist of longitudinally repeated units called sarcomeres. Sarcomeres in turn include thin and thick filaments. Thin filaments consist primarily of actin, while thick filaments are made up of myosin. The actin and myosin filaments partially overlap each other, this becomes important to allow activation to occur. The myosin, or thick, filaments have a small projection called cross-bridges. Cross bridges, once activated attach to the actin filaments and produce tension within the sarcomere.

The force produced by a muscle is the result of activity within the muscle subunits, which include the sarcomeres, myofibrils, and muscle fibers. The amount of tension produced by a sarcomere depends largely on the total number of myosin heads available for cross-bridge links to actin filaments.

The sliding filament theory of muscle contraction describes how the cross-bridge projections attach and detach from actin filaments causing muscles to generate tension. It is also important to understand all steps occurring within the muscle during contraction as each of these steps requires a fixed amount of time. As the velocity of contraction increases, a decrease in the number of cross-bridge attachments is seen. This plays a factor is RFD, which is of paramount importance in athletics.

Although never been shown experimentally, there is speculation that improvements in both speed of occurrence and coordination in the sequence of muscle contraction steps is possible. During a muscle contraction, many fibers undergo the same contraction steps. With the possibility that those steps can be improved, the entire process is primed to create more power and/or produce
power more efficiently. The adaptation of each individual step may be extremely small, but any increase in any step may, ultimately, lead to a bigger influence on contraction speed. It is important not to overlook the possible improvement within each of these steps when determining possible reasons for increased RFD \(^{(3)}\).

These common steps occur in every muscle contraction within the body.

1. Muscle contraction is initiated by a signal from the alpha motor neuron.
2. Action potential releases acetylcholine.
3. Acetylcholine binds to motor end plate, releasing sodium, which enters the cell and depolarizes the muscle fiber.
4. This depolarization reaches the T-tubules, which release stored calcium from the sarcoplasmic reticulum into intracellular space.
5. Calcium binds with troponin-C on the actin filament, moving tropomyosin and exposing actin’s binding sites.
6. Myosin heads attach to the binding site now exposed on actin filaments.
7. Myosin heads tilt, locking the actin filament in place and generating tension in the active muscle fibers.
8. Myosin heads detach from actin when ATP binds to globular head.
9. ATP is split by ATPase into ADP and an inorganic phosphate, releasing energy.
10. Energy release re-cocks the globular head of the myosin filament, priming it for another attachment to actin.

**Muscle spindles.** Muscle spindles act as neuromuscular regulators within the body, as the stretch or force on a muscle changes, muscle spindles relay information to the brain via an afferent pathway. If muscles are stretched by an external force, these intrafusal fibers are also subjected to
being stretched. Stretching causes an increase in muscle spindle discharge, leading to efferent signals back to the extrafusal fibers of the muscle attempting to return it to its initial length in spite of the load initially applied to the muscle. The muscle spindle is ultimately concerned with controlling changes in muscle length rather than force it might generate.

Forced lengthening of a muscle during the eccentric phase of the stretch-shortening cycle causes a mechanical deformation of the muscle spindles, which activates a reflex mechanism\(^3\). When movements are done quickly, the stretch reflex increases extrafusal muscle stimulation, often resulting in increased contraction force during the concentric phase and ultimately contributes to enhanced maximal power\(^3\). In athletics, the ability to involve muscle spindle activity may have a positive effect on RFD.

**Golgi tendon organs (GTO).** Golgi tendon organs (GTO) act as neuromuscular inhibitors. These receptors are sensitive to forces developed in the muscle. If muscle tension increases sharply, the GTO reflex causes an inhibition of muscle action. This leads to a decrease in muscle tension in order to prevent the muscle and/or tendon from incurring damage.

Golgi tendon organs are found within most large tendons and provide negative feedback to the CNS when muscle tension reaches beyond a dangerous threshold. When this threshold is reached, efferent signals to the muscle are inhibited reducing activation of the muscles experiencing these high tensions.

The ability to decrease the activation of GTO’s may lead to an increase in the ability to produce greater force, which might be necessary for optimal sports performance. The majority of GTO’s are pre-set to inhibit a muscle up to 40% below what that structure can actually handle. When GTO’s inhibit a muscle group from reaching its potential force output, a decrease in performance is seen, particularly in the aspect of explosive power development.
Examples of this “pre-set inhibition” in GTO’s are seen in some emergency situations, such as a child being trapped under a car and a grandma lifting the car off of the child. In these extreme cases, muscle damage is often seen, suggesting that the muscular inhibitors were deactivated, or at least overridden during that situation. Such a level of force output should not be achieved in athletic competition; however, if it is possible to reset the limits of the GTO’s it could leads to the belief that skill development or specific training methods, may safely alter the inhibition of the GTO’s. This inhibition would ultimately lead to an increase in force production as the muscle inhibitors would allow a higher threshold to be reached before shutting down the muscle.

**Renshaw cells.** Renshaw cells are yet another way the body can control the neural output to skeletal muscles. As desired recruitment of muscle fibers and rate coding increases, the signal works through a feedback loop containing Renshaw cells. Renshaw cells play an important role in the skill learning process in regards to the activation of appropriate neurons. In the beginning stages of learning a skill, the body often functions inefficiently in the recruitment of muscle fibers, leading to a surplus of the actual needed fibers being activated. Renshaw cells work to inhibit the firing of unwanted motor units. Through proper skill learning Renshaw cells allow the appropriate motor units to be used which leads to optimal force production with minimal energy utilized. In regards to athletics, just as with the GTO’s, an increase in the threshold of the Renshaw cells due to training has the ability to improve force development, especially when it is needed rapidly, as seen in the world of elite athletics. Renshaw cells associated with specific neural pathways have been shown to be dramatically reduced as a skill or movement becomes learned by the body. Reducing the activation of Renshaw cells in these specific pathways can lead to greater force production and displays the importance of skill learning, particularly in high-velocity movements.
**Sarcoplasmic reticulum.** Sarcoplasmic reticulum is a network located inside the cell surrounding muscle myofibrils and functions among other things to release and take up free calcium ions during contraction and relaxation, respectively \(^{31,32,33}\). During repeated muscle contractions, the functioning of the sarcoplasmic reticulum is significantly reduced \(^{31,32,33}\). This reduction in function occurs in both athletes and non-trained persons, and appears to be slightly better in athletes with a chronic training status. A reduction in the ability of the sarcoplasmic reticulum to release and/or take up calcium is directly related to a reduction in muscle force produced.

The functioning of sarcoplasmic reticulum during fatigue seems to be related to muscle fiber type \(^{31,32,33}\). Type I fibers do not see as rapid of a decline in function when compared to type II fibers \(^{31,32,33}\). Type II muscle fibers have an estimated double the calcium release for contraction and up to two to three times higher uptake rate than type I fibers. The higher requirements of type II fibers in regards to calcium release and uptake helps explain their greater susceptibility to fatigue \(^{31,32,33}\).

In the realm of athletics, an increase in RFD could, theoretically, be caused by an enhancement of the sarcoplasmic reticulum calcium release and reuptake \(^{31,32,33}\). Studies to date have yet to conclusively answer whether or not this is trainable. One study did show a significant increase in the peak rate of calcium release after a training period involving high-intensity intermittent training \(^{32}\). This adaptation makes sense in the fact that type II fibers are being trained, which require higher rates and amounts of calcium in order to improve force output. Other studies show there is no change in the release of calcium from the sarcoplasmic reticulum \(^{31,33}\). To date, no study has shown calcium uptake is increased post-training. This lack of adaptation leads to the notion that improved calcium uptake by the sarcoplasmic reticulum is likely not the cause of fatigue if a reduced co-activation is seen within the trained muscle \(^{31,33}\).
A theory for the increased calcium release seen by Matsunaga et al. could be due to multiple factors including, but not limited to, increased sarcoplasmic reticulum in the existing fibers and/or structural changes to the proteins responsible for opening and closing the calcium ion gates (32).

**Cross sectional area.** Success in athletics is often determined by force production, which is determined by both the number of muscle fibers activated during a movement and the level of activation of each fiber. As muscle cross sectional area increases, so does the force producing capability of the muscle (2). The hypertrophy of the powerful, type II muscles is thought to be a primary cause of this adaptation. It is improvements in hypertrophy and force production that cause coaches to focus on maximal strength, or increased muscle mass. If other factors that are needed to create force rapidly are overlooked, a coach will not be preparing his/her athletes optimally for competition.

**Conclusion**

In the realm of athletics, an ability to produce high forces is an important quality. However, based on the limited amount of time allotted to perform movements seen in competition, the rate at which force is produced truly becomes the predictor of performance. Rate of force development is determined based on the force production and coordination of the musculature completing the desired movement, with many sub-categories forming these two factors within the nervous and muscular systems. Specific training has the ability to improve RFD qualities when appropriate methods are implemented.
Chapter II: Proposal

Introduction

The adaptations to training have been demonstrated throughout this thesis and are clearly wide in their spectrum. Training should be viewed as preparation for the rigors of competition in athletics and must be programmed carefully to ensure optimal adaptations occur, as this is the only way to ensure maximal performances are achieved. The methods used, along with their reasoning, within this study are described below.

Training leads to increases in force production and rate of force production. It is likely that this is due to an increase in voluntary activation of the agonist muscles, but changes in the co-activation of the antagonist may take place as well. If a decrease in the antagonist co-activation does occur due to training methods, the net torque of a joint will be increased, leading to more net force being produced with the same level of activation from the agonist muscles[^12].

Heavy resistance training, above 80% of 1 rep max, increases the recruitment of larger, type II muscle fibers, improves rate coding, and increases, to some extent, the synchronization of muscles for maximal force output. These adaptations occur due to the body overcoming the high forces being placed on it through different exercise choices. This above 80% block is completed first in the training cycle due to its low transfer of training to competition and long residual effects, although exercises with high transfer of training should be used. Exercises should use the same muscle groups and require the same activation pattern as the movements seen in competitive movements. In this phase maximal force production is the focus, which has a positive effect on rate of force development, but is not the optimal method to improve the early phase which is required for high-velocity athletic movements. As there are more specific training methods.
Improvements in maximal strength can be maintained up to 30 days after training of this parameter has ceased. This 30 day period allows for other qualities, such as power, and maximal speed to be improved while strength remains at the same high, trained levels. Block periodization and residual effects allow the peaking of all parameters simultaneously, leading to maximal athletic performance.

The above 80% block used in this thesis is broken into two separate blocks, one utilizing eccentric training and the other using isometric training. The two distinct blocks of eccentric and isometric are used because every dynamic movement consists of three parts, the eccentric, isometric, and concentric muscle actions. By training the three phases of dynamic muscle contraction separately, each phase is maximized individually to increase the power output of the movement.

Eccentric or isometric movements, depending on the block, are trained on Monday’s, Tuesday’s, and Friday’s during this block, while Wednesday and Thursday remain high-intensity concentric training days. Training using the antagonist facilitated specialized and oscillatory methods are also used on Wednesday’s and Thursday’s. These methods are described in detail in the following sections. Timed sets are also used with times chose just above, at, and just below times seen in competition. Timing of sets ensures the body is trained in one specific manner each day, and keeps the body from being “pulled” in multiple directions.
**Table 1**

*Weekly Plan for Each Training Group*

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Figure 1 comparing an advanced and an elite athlete is an example of how training of each phase leads to improved performance more than conventional, concentric methods. The advanced athlete’s goal is ultimately to steepen the “V” shape, leading to greater force output in a shorter amount of time.
Figure 1. Greater power development of an elite versus advanced athlete.

The eccentric training phase of movement is vital for deceleration of the body. High loads are required to maximize the improvement within the eccentric phase of movement as this phase is stronger than isometric or concentric movements. These strength differences are clearly demonstrated by the force velocity curve (Figure 2).

Figure 2. Force velocity curve showing where maximal force can be achieved.
Slow eccentric movements cause the myosin-actin binding sites to absorb the majority of the force as the muscle fights lengthening, leading to microscopic damage. These high stressors allow the body to adapt and strengthen tendons as well as the muscle, leading to an overall improved and more rapid eccentric movement. Improving the eccentric phase leads to an increased storage of “free-energy” within your athlete’s tendons during this phase. The isometric and concentric phases, combined with this training, will allow that “free-energy” to be applied to sport-specific movements. Increasing the amount of “free-energy” transferred through the three muscle contraction phases leads to a dramatic rise in rate of force development.

Eccentric muscle actions are not only stronger than the isometric and concentric phases, but they also function differently on a physiological level. The brain, specifically the cortex, uses a different strategy for motor recruitment during muscle lengthening than muscle shortening. During eccentric movements, the motor pool is less activated, leading to fewer muscle fibers being activated. The fact that fewer motor units are activated means there are fewer myosin head attachment sites during this eccentric movement phase. These fewer myosin-actin attachment sites lead to increased stress on those filament attachment sites that are being used.

Slow eccentric movements lead to the myosin head being forcefully ripped from the actin, causing muscle damage. This stress induced damage to the muscle fiber causes the body to adapt and rebuild the damaged fiber even stronger. Once the fiber has been rebuilt, the body has now adapted and equipped itself to handle the stress of high load, slow eccentric movements to a greater extent. The muscle damage from eccentric movements will cause soreness in the muscles, but once the soreness subsides, a strengthened and rebuilt muscle fiber remains. The muscle fiber has now been optimally trained in the eccentric phase of dynamic muscle movement and is prepared to move onto the next block of training.
Eccentric training, when implemented properly, causes adaptations to more than just the muscle fibers. The stretch reflex is also improved due to high load, slow eccentric training. The specifics of the stretch reflex are covered in greater detail in an earlier section. When eccentric training at high loads is used, a reduction in the activation of the Golgi tendon organs has been seen.

During eccentric movements, or muscle lengthening, a stretch is applied to the muscle, which leads to an activation of the muscle spindles. Due to the high loads of training, the Golgi tendon organs interpret the force acting on the muscles and leads to a simultaneous inhibitory reflex. If an athlete reaches competition and is not used to absorbing high levels of eccentric force, their force output through the concentric muscle action will be weakened. The goal of high load eccentric training is to improve the coordination of the afferent and efferent neural pathways between the muscle spindle, CNS, and the muscle, all while desensitizing the Golgi tendon organs. These adaptations allow an athlete to absorb higher levels of force without triggering an inhibitory response from the Golgi tendon organs.

Isometric training is needed as it is responsible for transferring energy stored by the body from the eccentric to the concentric phase. If isometric strength is weak an athlete will lose power and the ability to produce force as rapidly as possible.

In the “V” shape created by the three phases of dynamic contraction, as seen in the Figure 1, the eccentric and concentric phases of movement are clearly seen. Isometric training, however, is commonly missed by coaches and athletes. This comes as no surprise as the isometric phase can be easily overlooked as it is not clearly portrayed within the “V” shape created by every dynamic muscle action. The isometric phase occurs as the brief amount of time the muscle is required to shift from the eccentric to the concentric action. Amortization is another term used for the isometric phase of muscle action. A good coach will realize that the use of high load, slow eccentric training will cause
the “V” to become steeper, which will lead to greater storage of energy in the tendons. This improved ability to absorb force through the eccentric phase will lead to greater stress being placed on the isometric phase of dynamic muscle action.

As the isometric phase improves due to training, the amount of free-energy transferred through the dynamic muscle contraction increases. Although the isometric phase is weaker than the eccentric phase, it is still greater than the abilities of concentric muscle actions. For this reason, high loads are used throughout the isometric phase of training to maximize the ability of this brief, yet vital portion of dynamic muscle contraction.

If the isometric training phase is skipped an athlete will do a less than optimal job of transferring the energy stored from the eccentric phase into power; especially if the eccentric phase has been maximized as explained in the previous article. When the isometric phase is overlooked, the steep “V”, which is the goal for all athletes, may end up looking more like a “U”. Clearly the second shape shown is less than optimal as it takes a longer amount of time to reach the concentric phase, which means less free-energy is transferred through dynamic muscle contraction.

There are still fewer myosin heads activated during the isometric than the concentric phase of the contraction. Fewer activated myosin heads, along with the use of high loads, leads to greater stress on the fibers being used. Greater stress on the fiber leads to continuous remodeling of the myosin heads until they have the ability to withstand the stressor being placed on them. These new and improved myosin head attachments work as anchors to reduce the free-energy lost during rapid dynamic muscle contraction.

Isometric training, with high-loads, also increases rate coding and has the potential to improve the steps of muscle contraction. Isometric training leads to the improvement of the body to stop the movement of high loads instantaneously, which causes the muscle to build tension rapidly.
The rapid increase in muscle tension due to high forces requires rate coding to be increased dramatically. The immediate response of the ten steps of muscle contraction potentially has the ability to be increased due to the rapid starting and stopping of contraction.

After the training of these two phases used in dynamic muscle actions, the complete movement is trained at once. This is completed through the reactive phase of training. Load remains above 80% to continue to improve strength gains from training, but now all three muscle actions are executed. This training is completed to combine all actions that were previously trained on an individual basis and functions to further enhance transfer of training.

Maximal power in lifting is achieved at 78% of 1 rep max, thus the power phase of training consists of exercises between 55 and 80% of 1 rep max. The goal of this training block is the use of high loads at high velocities. Many exercises remain the same as the ones used in the previous block, which improves transfer of training. Any exercises that were changed have become more specific exercises to the specific competition event.

The final phase of training is the peaking phase where the focus shifts to low loads and maximal velocities. Training in this block is designed to mimic the high velocity movements seen in competition, even though no movement in the weight room can match the speed of movements during an athletic event. Exercises primarily shift to low load plyometric, oscillatory, and explosive movements in this final phase before competition, as these will hopefully lead to the highest transfer of training.

**Training methods to reduce co-activation.** The antagonist facilitated specialized method and oscillatory training have both been created to improve the neuromuscular aspects of performance during contraction. Neither of these methods effects on training or co-activation have been studied
at this time. The idea is that with these methods, transfer of training and rate of force development will be maximized.

**Antagonist facilitated specialized method (AFSM).** The antagonist facilitated specialized method (AFSM) is specifically designed to assist in the relaxation of the antagonist muscles at high velocities of movement. An attempt to reduce co-activation of the agonist muscles by having athletes focus on both the pushing and pulling motion during an exercise. During this training the athlete attempts to maximize the velocity of the weight being used in both directions of movement. Rapid accelerations seen in both directions of this method require rapid transitions between eccentric and concentric work within the same muscle. In order for rapid accelerations to occur, there must be a simultaneous, immediate, relaxation of the agonist muscle group while the antagonist muscles are being recruited. The ability of a muscle to relax faster causes less co-contraction to occur, which ultimately leads to improved rate of force development.

Improvements in muscular relaxation of the antagonist or reducing co-activation are most dramatically evident with the highest level of trained athletes. Leo Matveyev of the Soviet Union suggested that superior athletes have the ability to reduce their co-activation much faster than less trained athletes. At the time, the Soviets had a 5 level classification of athletes. Level 1 referred to a novice, while a level 5 athlete would be comparable to a Michael Jordan per se of their respective sport. Although the mechanism of how relaxation was measured is not reported, he proposed level 5 master athletes have nearly a 200% faster relaxation of antagonist muscles than level 1 novice athletes. Level 5 master athletes showed a 50% faster relaxation than level 4 athletes within the same classification system. The best athletes appear to not only contract their muscles at high velocities, but relax their muscles at faster rates, leading to less antagonist co-activation.
The loads for AFSM range from 25 to 55% of 1 rep max to increase transferability of the movement pattern. As described earlier, the explosive movements used in this method will continue to improve the early phase of rate of force development, whether or not any true adaptations occur in co-activation of the antagonist muscles.

**Oscillatory (OC) training.** In the oscillatory training (OC) method the same mentality of pushing and pulling is used as described in the AFSM, however a smaller range of motion of only 3 to 4 inches is used. Each repetition continues to teach the muscles being used to change from a concentric accelerator to an eccentric decelerator. This training method has the potential to increase the amount of exertion given in the same amount of time, particularly when the exercises are completed at a disadvantageous position. The increased number of small repetitions in the same amount of time can also improve the motor learning of the skill, in this case the rapid activation and deactivation of the agonist and antagonist muscles, respectively.

**Purpose**

The purpose of this research is to determine if the use of the AFSM and OC training methods reduce co-activation and improve RFD to a greater extent than traditional methods. Through the measurement of these qualities and their changes, training can be considered successful as these improvements play a role in improving athletic performance.

**Hypothesis**

The following null hypotheses will be tested:

1) There will be a reduction in antagonist co-activation after the antagonist facilitated specialization and oscillatory training methods are utilized.

2) There will be improvements seen in rate of force development after the antagonist facilitated specialization and oscillatory training methods are trained.
Limitations

1) Due to the use of dynamic movements, the use of EMG to determine on/off of muscles may prove to be difficult.

2) Subjects may gain rate of force development adaptations from lifting with the intent of maximal acceleration.

Methods

Experimental Approach to the Problem

Training was completed by elite athletes to determine if the AFSM and OC training methods used in my below 55 peaking model led to a reduction in co-activation during maximal velocity contractions.

Participants

Training for this experiment was performed on 32 students from a Midwestern university. All participants were males and competed on the University baseball team. Each athlete was deemed healthy and capable of completing the requirements of this study. Participants were split into two groups for the training protocol, as described above. The control group consisted of 12 athletes, while 20 athletes were placed into the peaking group. All subjects had spent the previous 8 weeks completing the same strength training program.

Instruments

This experiment used both EMG and force plate data. EMG was used to determine the timing of muscle contraction and ultimately the change in co-activation. The force plate was used to determine changes in rate of force development throughout the training blocks.

Electromyography (EMG) measurement. EMG is a technique used to record and evaluate the electrical activity produced by the motor neurons leading to skeletal muscle contraction. EMG
uses a machine called an electromyograph to display the electrical impulses within the muscle in an understandable format. As discussed in the general overview section at the beginning of this paper, every movement is started with an action potential, or an electrical signal from the body. EMG uses these signals to determine when muscle fibers are activated.

There are two main steps prior to the readings of EMG that must be done carefully to ensure optimal results are given by the electromyography. These steps include skin cleaning and sensor placement. To ensure the electrodes receive the signals traveling through the muscle during contraction, the skin must be prepared by scraping off any excess layers of skin and then cleaned using an alcohol pad. The goal of these steps is to improve test results by allowing for better adhesion and conductivity of the electrode, and the reduction of resistance provided by the skin.

The placement of the electrode is another significant step in the proper utilization of EMG. The specific muscle tested and the size of that muscle are both factors in determining the electrode placement. The subcutaneous fat of an individual also has the ability to dampen the signal received by the electrode. The ideal location of the electrode is on the belly of the muscle, or between the muscle and the tendon insertion point.

EMG testing still has limitations in that many factors can affect the results. Increased subcutaneous fat decreases the reliability of EMG testing as does increased age and muscle cross-talk. Younger subjects’ skin tends to be more compliant, leading to better results during EMG testing. Muscle cross-talk occurs when the EMG signal from one muscle interferes with the tested muscle, which is a cause of decreased reliability of EMG testing. The inability to test for deep muscle activation is another limiting factor of EMG testing.

**Force plate measurement.** All vertical jump testing was completed using a force plate to determine the rate of force development from each subject for every trial used within this testing.
protocol. Rate of force development will be determined based on the positive slope of force change per time. Impulse will be determined for every jump completed and will allow for consistent selection of the jump with the highest impulse within each testing period. Once this selection has been made, the jump chosen will be used to complete the EMG, which is described below, and force testing to determine co-activation of the antagonist muscles used in the jump and the rate of force development, respectively.

**Procedures**

The participants in this study performed training 5 days per week for the eccentric, isometric, dynamic, and 3 days per week throughout the power, peaking and download blocks. Each participant completed a warm-up period similar to the warm-up used prior to training sessions, 4 maximal effort vertical jumps. I chose this exercise as athletes completed it at a high-velocity, much like the actions athletes complete in athletic competition. It is in this movement that the reduction in muscle co-activation may potentially lead to the greatest improvements in rate of force production, which as we have previously covered, is vital for optimal athletic performance.

Surface electrodes for the EMG data collection were placed on the vastus lateralis and its antagonist, the biceps femoris for the vertical jump portion of this test.

As stated above, rate of force development was calculated during each test to display the effects of this training program on potential athletic success.

**Data Analysis**

A paired samples t-test will be used to determine any significant differences ($p < 0.05$) that have occurred throughout training. Specifically, the changes of each subject’s rate of force development after each training block will be compared.
Chapter III: Manuscript

Introduction

The success in athletics, in non-team sports, ultimately comes down to which athlete can produce the most force in the time allowed during their individual competition event, while also being efficient with their movements \(^{(1-7)}\). The goal of a strength and performance coach at any level should be to get athletes to make the greatest performance gains in the shortest amount of time. This is the idea of efficiently applying optimal periodization schemes for athletes.

Rate of force development (RFD) and co-activation. Two phases of rate of force development are often referred to as the early and late phases. The early phase is linked with neural adaptations while the late phase of rate of force development is dependent on training of the muscles involved \(^{(4,8)}\). The neural input, or early phase, of rate of force development can be improved by increased recruitment of motor units, rate coding, synchronization, co-activation, as well as skill learning, while the late phase, or muscular adaptations, can see improvements in force production through increased cross-sectional area \(^{(6-18)}\). Individual athletes generate maximal forces based on two things. The first determining factor is the maximal force capabilities of the individual muscles, with the second being the coordination of muscle activity by the CNS. The ability of the individual muscles to produce force is determined by specific training methods, while the force produced by the coordination of muscle activity is a learned activation pathway of the muscles for optimal safety of the organism while maintaining maximal force outputs \(^{(12,19,20)}\).

The ability to produce force rapidly has been coined the ‘rate of force development’ or ‘RFD’ when abbreviated and is actively sought after by every strength and performance coach. The reasoning for placing importance on improving rate of force development is due to the limited time available for athletes to deliver force in their competition movements \(^{(5)}\). The time available for force
development in athletics movements is much smaller than the amount of time needed in order for the body to produce maximal force, which takes about 0.3-0.4 seconds depending on the muscle action phase (5). Sprinting is an example of this, the ground contact time in maximal velocity sprinting is typically between 0.08 and 0.12 seconds, which is much less than the 0.3 to 0.4 seconds needed to produce maximal force (2). Pre-activation does play a role in increasing force production, however maximal force still is not reached with this method (14).

Pre-activation is especially important when the stretch-shortening cycle is utilized. The stretch-shortening cycle is used in nearly every dynamic muscle action. Pre-activation increases the ability of the viscoelastic tendons to stretch, as the muscles are already contracted, which improves rate of force development further. In order to increase the force produced during sprinting, the ability to produce force rapidly becomes more important than maximal force production. Sprinting is just one example of a movement of sports however, the majority of maximal velocity movements in sport have a time of less than 0.25 seconds to produce force (5). It is for this reason every coach is training with the intent to increase rate of force development.

Co-activation occurs to ensure joint stabilization and varies depending on both the joint angle and the forces acting on the joint (9,11,13,14,17,22,23,24). The increased joint stabilization improves movement accuracy as well (25). As discussed earlier, athletic success is determined by who can produce the most force in the limited time allowed during an athletic movement. The ability to produce force within that time allowed is called the rate of force development. Due to the fact that athletic movements do not allow enough time to create maximal force outputs within the muscle, rate of force development becomes the most important factor in performance. It is important to realize the importance of not only the agonist muscles that produce the movement, but also the antagonist muscles which, during co-activation, hinder the torque output of the joint (3,10,17,26,27,28,30).
The focus of training programs, whether placed on maximal strength or explosive strength have different influences on the different phases found rate of force development. Training with short, high rate of force development contractions, which place a substantial emphasis on producing explosive, rather than maximal force may work has been shown to improve rate of force development to a greater extent, which is most effected by neural drive. 

Training methods to optimize co-activation and increase rate of force development. The antagonist facilitated specialized method (AFSM) and oscillatory (OC) training have both been created to improve the neuromuscular aspects of performance during contraction. Neither these methods effects on training or co-activation have been studied at this time. The idea is that with these methods, transfer of training and rate of force development will be maximized.

AFSM. The AFSM is specifically designed to assist in the relaxation of the antagonist muscles at high velocities of movement. An attempt to reduce co-activation of the agonist muscles by having athletes focus on both the pushing and pulling motion during an exercise. During this training the athlete attempts to maximize the velocity of the weight being used in both directions of movement. Rapid accelerations seen in both directions of this method require rapid transitions between eccentric and concentric work within the same muscle. In order for rapid accelerations to occur, there must be a simultaneous, immediate, relaxation of the agonist muscle group while the antagonist muscles are being recruited. The ability of a muscle to relax faster causes less co-contraction to occur, which ultimately leads to improved rate of force development.

Improvements in muscular relaxation of the antagonist or reducing co-activation are most dramatically evident with the highest level of trained athletes. Leo Matveyev of the Soviet Union suggested that superior athletes have the ability to reduce their co-activation much faster than less trained athletes. At the time, the Soviets had a 5 level classification of athletes. Level 1 referred to a
novice, while a level 5 athlete would be comparable to a Michael Jordan per se of their respective sport. Although the mechanism of how relaxation was measured is not reported, he proposed level 5 master athletes have nearly a 200% faster relaxation of antagonist muscles than level 1 novice athletes. Level 5 master athletes showed a 50% faster relaxation than level 4 athletes within the same classification system. The best athletes appear to not only contract their muscles at high velocities, but relax their muscles at faster rates, leading to less antagonist co-activation.

The loads for AFSM range from 25 to 55% of 1 rep max to increase transferability of the movement pattern. As described earlier, the explosive movements used in this method will continue to improve the early phase of rate of force development, whether or not any true adaptations occur in co-activation of the antagonist muscles.

**OC training.** In the oscillatory training method the same mentality of pushing and pulling is used as described in the antagonist facilitated specialized method above, however a smaller range of motion of only 3 to 4 inches is used. Each repetition continues to teach the muscles being used to change from a concentric accelerator to an eccentric decelerator. This training method has the potential to increase the amount of exertion given in the same amount of time, particularly when the exercises are completed at a disadvantageous position. The increased number of small repetitions in the same amount of time can also improve the motor learning of the skill, in this case the rapid activation and deactivation of the agonist and antagonist muscles, respectively.

The hypothesis of this paper is that the AFSM and OC training methods will reduce antagonist co-activation while improving rate of force development to a greater extent than a training phase more typical to strength and conditioning programs, utilizing loads between 55 and 80 percent of 1RM.
Methods

Experimental Approach to the Problem

Training was completed by elite athletes to determine if the AFSM and OC training methods used in my below 55 peaking model led to a reduction in co-activation during maximal velocity contractions.

Participants

Training for this experiment was performed on 32 students from St. Cloud State University. All participants were males and competed on the University baseball team. Each athlete was deemed healthy and capable of completing the requirements of this study. Participants were split into two groups for the training protocol, as described above. The control group consisted of 12 athletes, while 20 athletes were placed into the peaking group. All subjects had spent the previous 8 weeks completing the same strength training program.

Equipment

This experiment used both EMG and force plate data. EMG was used to determine the timing of muscle contraction and ultimately the change in co-activation. The force plate was used to determine changes in rate of force development throughout the training blocks.

Procedures

The participants in this study performed training 5 days per week for the eccentric, isometric, dynamic, and 3 days per week throughout the power, peaking and download blocks. Each participant completed a warm-up period similar to the warm-up used prior to training sessions, 4 maximal effort vertical jumps. I chose this exercise as athletes completed it at a high-velocity, much like the actions athletes complete in athletic competition. It is in this movement that the reduction in muscle co-
activation may potentially lead to the greatest improvements in rate of force production, which as we have previously covered, is vital for optimal athletic performance.

Surface electrodes for the EMG data collection were placed on the vastus lateralis and its antagonist, the biceps femoris for the vertical jump portion of this test.

As stated above, rate of force development was calculated during each test to display the effects of this training program on potential athletic success.

**Force plate measurement.** All vertical jump testing was completed using a force plate to determine the rate of force development from each subject for every trial used within this testing protocol. Rate of force development was determined based on the slope of force change per time. Impulse was determined for every jump completed and allowed for consistent selection of the jump with the highest impulse within each testing period. Once this selection was made, the jump chosen was used to complete the EMG, which is described below, and force testing to determine co-activation of the antagonist muscles used in the jump and the rate of force development, respectively.

**Electromyography (EMG) measurement.** EMG is a technique used to record and evaluate the electrical activity produced by the motor neurons leading to skeletal muscle contraction. EMG uses a machine called an electromyograph to display the electrical impulses within the muscle in an understandable format. As discussed in the general overview section at the beginning of this paper, every movement is started with an action potential, or an electrical signal from the body. EMG uses these signals to determine when muscle fibers are activated.

There are two main steps prior to the readings of EMG that must be done carefully to ensure optimal results are given by the electromyography. These steps include skin cleaning and sensor placement. To ensure the electrodes receive the signals traveling through the muscle during
contraction, the skin must be prepared by scraping off any excess layers of skin and then cleaned using an alcohol pad. The goal of these steps is to improve test results by allowing for better adhesion and conductivity of the electrode, and the reduction of resistance provided by the skin.

The placement of the electrode was another significant step in the proper utilization of EMG. The specific muscle being tested and the size of that muscle are both factors in determining the placement of the electrode. The subcutaneous fat of an individual also has the ability to dampen the signal received by the electrode. The ideal location of the electrode is on the belly of the muscle, or between the muscle and the tendon insertion point.

The raw EMG signal was collected at 120 Hz and then filtered using a low pass filter of 4. The baseline of the muscle EMG was determined using data points prior to the contraction phase of the vertical jump. Once the baseline of the quadriceps and hamstrings was determined, the filtered EMG reading was divided by that found baseline value. This allowed the comparison between the baseline and registered muscle EMG value. Every filtered value will complete this step so the change from the baseline is determined, which will allow a comparison to be made as to when the muscle will be considered on versus off.

**Results**

The use of EMG to determine co-contraction in antagonist muscles during a dynamic movement, such as the vertical jump in this test, proved too variable after the first two trials. At that time EMG testing was discontinued for the purposes of this paper. The difficulties of collecting EMG are potentially related to human error i.e.: inconsistent placement, even with the used measurement techniques. Or the bi-articular nature of the muscles involved in the vertical jump, which are discussed in the literature review of this paper.
Average rate of force development was statistically different between the peaking (1389±504 lb/sec.) and power (844±448 lb/sec.) groups at the start of the experiment (p = 0.004). The changes in rate of force development after the first phase of training revealed no statistical changes in either group when compared to their initial tested numbers. The peaking group average rate of force development was 1443±476 lb/sec. (p = 0.73) while the power group average rate of force development was 915±464 lb/sec. (p = 0.70). With the final phase of testing neither group showed significant changes in their rate of force development. However, the peaking group did approach statistical significance (p = 0.08) with their average rate of force production increasing to 1769±647 lb/sec. while the power group remained statistically insignificant (p = 0.40) with an average rate of force production of 1071±420 lb/sec.

Table 2 below shows the changes in rate of force development for each subject throughout the testing protocol.

Table 2

Rate of Force Development (RFD) Data for Each Subject

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<th>Jump 3</th>
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Discussion

In this study I considered high-velocity training methods and their effect on rate of force development. An 18 week training protocol was completed in which participants trained identically until the final 3 weeks. During those final 3 weeks of training participants were split into two groups. These two groups consisted of a high-velocity peaking group and a power group. Although this study showed no significant improvements in rate of force development due to training, a trend towards significance can be seen in the final jump within the peaking group ($p=0.08$) while the power group did not approach a significant value ($p = 0.40$). These changes in rate of force development can be viewed in Figure 3 above.

*Figure 3.* The average rate of force development for both groups is represented here (peaking solid, power dashed)
In athletics, rarely is there enough time in a movement to produce maximal force, thus rate of force development plays a key role in athletic success \(^{(1-7)}\). Rate of force development is a product of many factors, including both neural and muscular factors \(^{(4,8-18)}\). However, this experiment was not designed to evaluate these specific changes, but rather the overall change in rate of force development.

The measurement of co-activation was not able to be measured due to large variations in EMG activity during dynamic movements. This occurred even with specific measurement of electrode placement. Previous studies have shown the reduction in muscle co-activation due to strength training along with repeated movements with the same motion, which ultimately lead to an improvement of the net torque produced within a joint. These improvements can also play an important role in improving rate of force production, and thus, athletic performance \(^{(11,21,25,28)}\).

The improvements seen in rate of force development due to this training followed the expectations prior to the experiment, simply to a lesser extent than expected. The power group consisted of mostly younger athletes with lower training ages, even though the same training program was utilized, saw increased results in rate of force development with the higher loads. As many factors play a role in rate of force development, this is in agreement with the fact that they simply did not have the necessary adaptations to produce force rapidly. The athletes in the peaking group did not show as large of an increase in rate of force development during the higher load training, representing the limiting factor in their rate of force development was not the mechanical strength, but rather their neural components of force production. This became even more apparent when these roles were switched after the high-velocity peaking method was implemented. The peaking group showed an almost significant improvement in rate of force development, while the power training group using increased loads did not improve to the same extent. These findings agree
with previous studies and indicate training with low loads at high velocities, focusing on explosive movements, leads to the greatest improvements in rate of force development as this training method is the most specific to the requirements of jumping \(^{2,4,16}\). Loads of 25-55% were used in this peaking model, which seems to agree with a prior study showing a 30% load being the most effective at improving rate of force development \(^{15}\). This experiment continues to show movements that require high rates of force development must be trained in a specific, explosive, manner to improve both the early and late phase of force development \(^{15,18}\).

**Conclusion**

The findings of this study do not support the antagonist facilitated specialized method and oscillatory to improve rate of force development as no significant difference was shown between the peaking and power groups. However, the peaking model used showed a trend towards significant differences in RFD improvements. This trend, although not significant, supports the notion that force production in a rapid manner is a learnable skill that can be trained more specifically through high-velocity, low-load training methods utilizing the antagonistic specialized facilitated specialized method and oscillatory training. Although the hypothesis aimed at co-activation was not able to be answered specifically using dynamic muscle actions, the findings of previous studies show the reduction of co-activation is a learned skill through training and is expected to occur to some extent. This peaking model, although only approaching significant differences, proves necessary for improved transfer of training and improved rate of force development, which are the ultimate goals of any performance coach.
Manuscript References


References


## St Cloud State

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| par w/f        |      |    |    | par w/f        |      |    |    |

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| par w/f        |      |    |    | par w/f        |      |    |    |

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| par w/f         |      |    |    | par w/f         |      |    |    |

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| par w/f         |      |    |    | par w/f         |      |    |    |

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St Cloud State

XLathlete.com

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Sunday

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Matt Van Dyke

Xlathlete.com

Thesis