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Phase Specific Changes in Rate of Force Development and Muscle Morphology Throughout a Block Periodized Training Cycle in Weightlifters

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by

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ABSTRACT

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The purpose of this study was to investigate the kinetic and morphological adaptations that occur during distinct phases of a block periodized training cycle in weightlifters. Monitoring data from nine experienced collegiate weightlifters was examined retrospectively. Isometric mid-thigh pull and ultrasonography results from pre and post three specific training phases within a macrocycle leading up to a competition were compared. Changes in isometric rate of force development and vastus lateralis cross-sectional area reflected the expected adaptations of each training phase.

DEDICATION

This thesis is dedicated to my parents David and Doreen Suarez and my Fiancée Abby Barron. Thank you, Mom and Dad, for your constant support in everything I have ever done. I remember the very first day that I mentioned to you both I am considering moving away and going to school in Tennessee. If it wasn't for your immediate enthusiasm and support of such a big decision I may not have ever been in this position. To my Fiancée, Abby, thank you for always being there for me. Out of all of the amazing things that have happened to me since coming to ETSU meeting you will always be the most important. Thank you for loving me even when I was too busy writing this thesis to give you the attention you deserved. Having you by my side the last few years has made it the best and most rewarding time of my life.

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CHAPTER 1

INTRODUCTION

Statement of Problem

The primary focus of any sport performance program is to maximize an athlete's potential for success in competition. The ability to develop training programs that achieve a peak in performance at crucial time points is vital to sports such as weightlifting that only compete a few times a year. Block periodization is a commonly used framework for sequentially eliciting specific adaptations (e.g., hypertrophy, maximum strength, speed, etc.) throughout training phases, culminating in a "peak," where the athlete has the greatest potential for success on the day of competition (DeWeese, Hornsby, Stone, & Stone, 2015). Weightlifting coaches can benefit from a monitoring program that provides insight into the extent to which these desired adaptations are occurring in their athletes throughout each phase of training.

Block periodization uses sequencing of highly concentrated training workloads that prioritize certain motor and technical abilities (Issurin, 2008). Training in such a manner requires a very sensitive and specific monitoring program to observe if these concentrated workloads are achieving the desired results. Both the isometric mid-thigh pull (IMTP) and ultrasonography (US) have been used previously in an attempt to monitor these changes in weightlifters using block periodization. For example, Hornsby et al. (2017) used the IMTP and vertical jump tests to monitor changes in weightlifters and found IMTP rate of force development (RFD) and static jumps with 20kg to be highly sensitive to changes in training load. Additionally, Bazyler et al., (2017) used US of the vastus lateralis (VL) and found associations between changes in cross-sectional area (CSA) and changes in performance in a national level female weightlifter preparing for multiple competitions. Both RFD and muscle morphology have demonstrated plasticity in response to resistance training programs (Blazevich, Gill, Bronks, & Newton, 2003;

Hornsby et al., 2017; Mangine et al., 2016; Nimphius, McGuigan, & Newton, 2012). Zaras et al. (2016) observed improvements in both RFD and increases in multiple muscle architectural variables after ten weeks of periodized resistance training in throwers. However, no such study has examined these variables throughout different phases of the training process. Therefore, the purpose of this study was to investigate changes in RFD and muscle morphology throughout three distinct phases of a block periodized training program in well-trained weightlifters.

Operational Definitions

1. Block: 3-5 week training period that emphasizes specific physical qualities.
2. Cross-Sectional Area: Total Area of a two-dimensional cross-section of a muscle.
3. Fascicle length: Distance of a muscle fascicle between the superficial and deep aponeuroses.
4. Intensity: Refers to the amount of weight used in an exercise. Relative Intensity is typically expressed as a percentage of a one-repetition max.
5. Isometric Mid-Thigh Pull: A test of muscular strength that is conducted on an immovable bar set inside of an adjustable rack. Subjects set up in a position that resembles the second pull of a clean and perform an isometric pull as fast and hard as they can standing on force plates (Kraska et al., 2009)
6. Macrocyle: Period of training composed of smaller phases that typically lasts throughout a season or the time between major competitions.
7. Muscle Morphology: The underlying structural makeup of muscle tissue (i.e., size and architecture).
8. Muscle Thickness: Distance between the upper and lower aponeuroses of a muscle.

9. Peak Force: Highest instantaneous force value throughout a force-time curve. Measure of maximal force production capability.
10. Pennation Angle: Angle between the muscle fascicle and the muscle tendon.
11. Periodization: “A logical, sequential, phasic method of manipulating training variables to increase the potential for achieving performance goals while minimizing the potential for overtraining and injury through the incorporation of planned recovery (DeWeese, Hornsby, Stone, & Stone, 2015)
12. Power: Product of force and velocity or rate of performing work.
13. Rate of Force Development: Change in force divided by change in time. A measure of “explosive strength.”
14. Strength: Ability to produce force.
15. Volume: Total amount of work performed in training. Usually estimated by calculating volume load (sets x repetitions x load or sets x repetitions x load x displacement) (Hornsby et al., 2018).

CHAPTER 2

COMPREHENSIVE REVIEW OF THE LITERATURE

Training of a Strength-Power Athlete

The process of developing a training plan aimed at maximizing the physical development of an athlete is a serious endeavor that has been compared to the training of soldiers for war (Campbell, 2000; Yessis, 1988). The ability to run fast, throw far, or lift heavy have always been simple but critical abilities for the average man. In modern times these simple qualities are still sought after and contested at the highest levels of sport. Success in strength-power sports largely depends on the physical abilities of the athlete making the development of qualities like strength and speed especially crucial in comparison to higher skill sports. Because of this, the significance of a sound, purposeful, and effective training process is a major priority in the development of serious strength-power athletes.

The Training Process

The primary purpose of training is to maximize an athletes potential of winning. Winning simply requires that the athlete or group of athletes performs better at their specific craft than their competitor. Many times the primary determinant of winning in strength-power sports comes down to the genetics of the athletes (Bouchard, Dionne, Simoneau, & Boulay, 1992; Huygens, Thomis, Peeters, Vlietinck, & Beunen, 2004; Stone, Stone, & Sands, 2007). Genetics, for the most part, is an uncontrollable facet of the training process and therefore the physical, technical, tactical, and psychological preparation of the athlete become the only manageable aspects of winning or losing (Stone et al., 2007). This requires a long term plan based on logical and evidence-based principles to guide the training process to most effectively prepare the athlete for success on the day of competition.

Training Principles

The planning of the training process can in no way be random. Effective training involves the exploitation of training methods that serve a particular purpose. The most evident principle of training, therefore, is the concept of specificity. Specificity deals with the degree of metabolic and mechanical similarity between a training exercise or method and the actual competitive movement (DeWeese et al., 2015). More imperative than the visual similarity is the transfer of training effect, which deals with the degree to which an exercise results in improvements to the desired movement. Verkoshansky (Verkhoshansky & Siff, 2009) in the early 1990s developed a detailed strategy for comparing the specificity of movements termed *Dynamic Correspondence*. Dynamic Correspondence is a set of criteria that can be used to determine the level of specificity of movements by comparing the range of motion and directions of movements, the regions of force production, the magnitudes and velocities of force application, the rate and time of force production, and the type of muscular actions (e.g., concentric or eccentric) (Goodwin & Cleather, 2016; Suarez, Wagle, Cunanan, Sausaman, & Stone, 2019). Careful attention to these aspects maximizes training efficiency by prioritizing exercises and methods that have the highest potential of improving sport performance.

Unfortunately, training is not always as simple as repeatedly performing exercises that are the most sport specific. Initial adaptations to any training strategy come with diminishing returns. This means that the longer a certain strategy is applied, the more likely stagnation will soon occur. Therefore, variation of training type, intensity, volume, and frequency can be applied to prolong the development of the athlete and prevent boredom and injury from overuse (Bompa & Haff, 2009; Stone et al., 1991).

Overload is the third training principle and serves as the primary stimulus for eliciting desired adaptations (Stone, Collins, Plisk, Haff, & Stone, 2000) by forcing the body to achieve levels of performance it has not previously. Overload is applied by the cyclical increase in intensity, volume, or frequency of training aimed at disrupting the athlete's current levels of homeostasis. The gradual increase of these variables forces a response which can be explained by the General Adaptation Syndrome (GAS) originally developed by Hans Selye (1956). Selye proposed GAS as an explanation for his observations on how organisms respond to stress stating that "adaptation occurs if an organism is exposed to an intensity or quality of a stimulus that it is not already adapted too" (Cunanan et al., 2018, p. 4). When exposed to this stimulus the organism initially responds through what he termed an *alarm phase,* which in the case of an athlete results in a reduction of performance from baseline. During the *resistance phase,* the organism then attempts to adapt to the stress potentially causing a rise above previous levels (i.e., adaptation). Finally, if the stimulus is not removed in time, the stressor becomes too much for the organism to handle and results in a decrease back below baseline, termed the *exhaustion phase*. The exhaustion phase serves as a basis for the notion of overreaching or overtraining, where the stimulus of training becomes overwhelming enough to the athlete that improvements halt, and decreases in performance occur (Halson & Jeukendrup, 2004; Meeusen et al., 2013). These phases of response to stress have since been related to the training process in athletes and used as part of the rationale for modern periodization (Cunanan et al., 2018; Haff, 2004a, 2004b; Zatsiorsky & Kraemer, 2006).

Periodization

Periodization focuses on four primary goals: (1) To elevate an athlete's performance at predetermined timepoints, (2) maximize specific physiological and performance adaptations, (3) reduce the potential for overtraining, and (4) provide for long-term athlete development (Bompa & Haff, 2009). When defining periodization DeWeese et al. (2013) stated that "periodization deals with the strategic manipulation of an athlete's preparedness through the employment of sequenced training phases defined by cycles and stages of workload" (p. 14). Preparedness represents the difference between the following two after effects of training: fitness and fatigue (Bannister, 1991; Chiu & Barnes, 2003; Stone et al., 2003). Fitness is the positive, mechanistic response to a stimulus that occurs from recovery and subsequent adaptation. Fatigue represents the acute and chronic adverse effects of training such as reduced force, speed, and power (Beelen & Sargeant, 1991; Häkkinen & Myllylä, 1990; Izquierdo et al., 2009; Smilios, 1998). The stimulus of training results in both increases in fitness and fatigue. Decreases in training volume can cause fatigue to dissipate quicker and to a greater degree than fitness (Bompa & Haff, 2009; Chiu & Barnes, 2003) thus increasing overall preparedness. Periodization serves as a framework for manipulating this fitness-fatigue paradigm within a training program by utilizing the training principles of specificity, variation, and overload. In addition to the use of these principles DeWeese et al. (2013) suggest that periodization models can be enhanced with the inclusion of comprehensive athlete-monitoring programs.

Traditionally when periodization models were first discussed macrocycles referred to an annual training plan (Bompa & Haff, 2009; Matveyev, 1977). However, with modern sports calendars consisting of multiple seasons and competitions within a year macrocycles now more appropriately represent a season or the timeline between major competitions (Jeffreys & Moody, 2016; Siff, 2003). The macrocycle is then traditionally divided into competitive, preparatory, and transition periods designed to optimize performance during competitions (Bompa & Haff, 2009; Matveyev, 1977). This structure is primarily characterized by a shift from a general to more specific training emphasis, concluding with a period of transition between macrocycles. These training periods each consist of more medium duration phases (2-6 weeks) typically referred to as mesocycles or blocks (Issurin, 2008; Stone et al., 2007). Within the mesocycle single weeks of training (microcycles) together create summated microcycles that can be designed to develop targeted fitness qualities by emphasizing and de-emphasizing certain aspects of training (DeWeese et al., 2015).

Block Periodization

Most sports require a certain combination of fitness qualities (i.e., strength, speed, power, endurance) that do not all share the same timelines of development and decay (Counsilman & Counsilman, 1991; Issurin, 2008). These differences in timelines are referred to as *residual training effects* and allow for certain phases of training to be dedicated to more concentrated workloads and serve as the basis for block periodization. Over the years, several sport scientists have suggested that a central tenant of periodization is a sequencing of phasic alterations in the training workload (Matveyev, 1977; Nàdori & Granek, 1989). Typically, block periodization can be characterized by the sequencing of three distinct phases termed *accumulation, transmutation, and realization* (DeWeese et al., 2015; Issurin, 2008; Zatsiorsky & Kraemer, 2006). These phases exploit the strategy of phase potentiation where blocks are ordered in a manner that is directed at developing specific performance qualities designed to augment one another and conclude in a performance peak (Bompa & Haff, 2009; DeWeese et al., 2015).

Accumulation phases of training occur early in the macrocycle and expose the athlete to substantial volumes of training focused at enhancing general qualities such as muscular endurance, body composition, and work capacity (Bompa & Haff, 2009; Jeffreys & Moody, 2016). These qualities are initially developed to advance the performance potential of the athlete and potentiate future phases of training (Bompa & Haff, 2009). These phases are characterized by high volumes of low to moderate intensities of training which have been shown to be effective at developing qualities such as strength-endurance and muscle hypertrophy (Plisk &

Stone, 2003). The development or re-establishment of muscle hypertrophy during accumulation phases is particularly essential to strength-power athletes because (1) lean body mass has been found to be a good predictor of performance in various strength sports (Brechue & Abe, 2002; Siahkouhian & Hedayatneja, 2010; Winwood, Keogh, & Harris, 2012), and (2) the addition of contractile tissue increases the potential for future strength and power adaptations (Minetti, 2002; Stone et al., 2007; Zamparo, Minetti, & Di Prampero, 2002) potentially by enhancing the athletes ability to better withstand heavier loads in subsequent blocks. However, Verkhoshansky (1985) mentions that a concentrated load of strength-endurance over multiple weeks often results in depressed power and speed abilities in trained athletes, primarily due to fatigue. Although, once the athlete returns to normal training an increase in power and speed often above previous values (i.e., supercompensation) can occur (Fry et al., 2003; Siff, 2003; Stone et al., 2007).

The second phase of block periodized training is termed transmutation. Transmutation phases begin to emphasize more sport specific abilities and for strength-power athletes typically consist of the largest focus on the development of maximal strength. The development of maximal strength is emphasized to exploit the enhanced contractile tissue and work capacity developed during the previous accumulation phase. Additionally, strength serves as a vehicle for other important fitness qualities (DeWeese et al., 2015; Stone et al., 2007; Suchomel, Nimphius, & Stone, 2016), and when strength training precedes power training greater improvements in performance have been observed (Behm et al., 2017; Harris, Stone, O'Bryant, Proulx, & Johnson, 2000).

The final phase of training before competition is the realization phase. The realization phase is where the focus of training shifts towards the development of highly specific qualities of the sport and diminishing the accumulated fatigue of training so that preparedness is revealed at the most appropriate time. Typically for strength-power athletes, this is accomplished through the use of higher velocity movements and decreased training volume (i.e., taper). If executed correctly a period of tapered training at the end of a realization phase results in decays in fatigue and a simultaneous increase in sport-specific fitness qualities resulting in a peak in preparedness (Le Meur, Hausswirth, & Mujika, 2012; Mujika, 2009) where the athlete is best able to express the cumulative adaptations developed throughout the sequenced training phases.

Lastly, transition phases of active rest are used to allow the athlete to recover physically and mentally from training and competition (Bompa & Haff, 2009; Nàdori & Granek, 1989). For the strength-power athlete Stone, O'Bryant, and Garhammer (1981) suggested a periodized model aimed at developing hypertrophy, maximal strength, strength and power, and then peaking in that specific order is most optimal and has since been supported by the literature (Minetti, 2002; Zamparo et al., 2002).

Attributes of the Sport of Weightlifting

Weightlifting is a strength and power sport in which athletes within a spectrum of bodyweight categories compete to lift the highest combined amount of weight in the snatch and the clean and jerk. In the snatch, the lifter attempts to lift a barbell from the floor to overhead in one swift motion. While in the clean and jerk the lifter must lift the barbell from the floor to the shoulders (clean) first, and then from the shoulders to overhead (jerk). Both lifts end when the lifter controls the barbell overhead with locked arms, aligned feet, and standing completely erect. Each lifter is allowed three attempts per lift, with the heaviest weight lifted in both the snatch and the clean and jerk used for calculating the athlete’s total. The lifter with the highest total within each bodyweight category is declared the winner. The development of strength, rate of force development (RFD), power, and high-intensity exercise endurance should be the primary focus of the training of weightlifters (Stone, Pierce, Sands, & Stone, 2006). Programming for weightlifting involves the use of periodized resistance training whose programming tactics include both the competitive lifts as well as accessory movements such as squats, pulls, presses, and derivatives of the competitive lifts. Success in the sport of weightlifting depends on a combination of technique, explosive strength, and flexibility (Enoka, 1979; Garhammer, 1989), but the main separator between elite and non-elite lifters seems to come down to force production capabilities (Kauhanen et al. 1994).

Kinetic Characteristics of Weightlifting

Every movement of the bar is the result of the forces the lifter applies to it (Baumann, Gross, Quade, Galbierz, & Schwirtz, 1988). The performance ability of a weightlifter is primarily determined by the strength and power of the legs and hips (Garhammer, 1980). This can easily be observed by looking at the typically well-developed lower bodies of well-trained weightlifters compared to other athletes of similar size. When attempting to find kinetic differences between successful and unsuccessful lifts both Garhammer (1980) and Stone, O'Bryant, Williams, Johnson, and Pierce (1998) observed that successful snatch attempts depend largely on the magnitude of force and RFD generated by the lifter. Additionally, Kauhanen, Hakkinen, and Komi (1984) observed strong correlations between relative ground reaction forces during the pull and weightlifting performance when comparing Finnish elite and district level weightlifters. During the competitive lifts weightlifters must generate extremely high peak forces, RFD, and peak powers outputs, (Storey & Smith, 2012) therefore the ability to produce force and to produce force quickly seems to be a significant determinant of elite weightlifting performance.

Importance of Strength to Weightlifting

Although technical training is an essential aspect of weightlifting, Stone et al. (2005) reasons that since maximum strength is a major contributor to weightlifting performance and technique often becomes stable after a few months to years of training, that continuing to prioritize technique training with advanced weightlifters may be less beneficial than prioritizing strength. Kauhanen et al. (1984) found that, other than, the drop under phase of the jerk, there were no other significant kinematic differences between elite and non-elite lifters. This can be explained by the observation that technique tends to be cemented after the first few years of weightlifting training. Which, is supported by research from John Garhammer (1993) who observed minimal changes in bar and lifter kinematics over several years while the weight lifted and power output increased in the range of 10-20%. Stone et al. (2005) states that since peak power production is likely the major contributing factor to elite weightlifting performance, and force production is a major contributor to peak power, then maximum strength should be a primary focus of weightlifting training. Early on in the development of a weightlifter technique training is unquestionably important, but as a lifter advances it is likely of much greater benefit to their performance for training to develop maximal strength to take priority over technique work.

Physiological Characteristics of Weightlifters

Due to the nature of weightlifting, many elite weightlifters share many similar characteristics of height, weight, body composition, and relative limb lengths. Male weightlifters in the light to middle-weight weight classes (i.e., 56kg-85kg) tend to have body fat percentages in the 5-10% range and share similar compositional characteristics as wrestlers, sprinters, and jumpers of similar weight. While weightlifters in the heavier weight classes (94kg-105+kg) can have body fat percentages ≥17% and similar body compositions to heavyweight wrestlers, powerlifters, and throwers (Storey & Smith, 2012). Weightlifters often attempt to maximize the amount of muscle they can carry within a weight class, which results in weightlifters tending to be much shorter and have higher relative body masses compared to other athletes. In addition to being shorter than other athletes weightlifters have been shown to have proportionally shorter arm spans and tibia lengths, and longer torsos (Carter et al., 1982; Marchocka & Smuk, 1984). These anthropometric characteristics provide mechanical advantages during the competitive lifts. For example, the mechanical torque required to lift a given load is less due to the shorter lengths of the lever arms, as well as the amount of work required is reduced because of the shorter distance that the barbell must be displaced vertically (Keogh, Hume, Pearson, & Mellow, 2007). Lastly, a shorter, leaner body allows the athlete to maximize muscle cross-sectional area (CSA) within their specific weight class, which has been shown to be advantageous to weightlifting performance (Ford, Detterline, Ho, & Cao, 2000).

Due to the high force demands of their sport, weightlifters have been found to possess a greater abundance and CSA of Type IIa fibers than other athletes (Fry et al., 2003; Serrano et al., 2018). Both the content and size of type IIa fibers have been shown to correlate strongly with weightlifting performance (Fry et al., 2003; Serrano et al., 2018). Because of these muscle fiber qualities, the isometric peak force and contractile RFD of weightlifters have been reported to be ~15–20% and ~13–16% greater, than in other strength and power athletes (Storey & Smith, 2012). During the competitive lifts, weightlifters achieve peak force, peak power, and maximum barbell velocities in less than 260 ms (Garhammer, 1991). However, since the second pull is the primary propulsive phase of the lift extremely high forces must be rapidly generated in even less time during this period. Therefore, maximal contractile RFD is a significant contributor to the performance of a weightlifter. This information suggests that training that maximizes both the amount and size of type II fibers, as well as increases peak force, peak power, and RFD should be a major focus in the preparation of a weightlifter.

Monitoring the Adaptations to Weightlifting Training

A unique aspect of many strength-power sports like weightlifting is the relatively few number of competitions throughout the year. This minimal competition schedule makes it especially important for coaches to have a strong understanding of both the magnitudes and the timelines of adaptation that occur in their athletes resulting from different training stimuli. For example, the benefits of sequenced training as discussed earlier only occur if the desired adaptations of each phase are actually occurring. Therefore, weightlifting coaches can benefit from an athlete monitoring program that provides objective feedback on the alterations and adaptations occurring to their athletes throughout the training cycle. Since weightlifting performance heavily relies on the athlete's ability to generate high magnitudes of force in specific time intervals (Kipp, Redden, Sabick, & Harris, 2012; Stone et al., 1998), the monitoring of certain kinetic adaptations to training are especially beneficial.

Isometric Mid-Thigh Pull

Strength is one of the most commonly monitored performance attributes due to it being an important contributor to sport performance (Suchomel et al., 2016). Strength-power sports especially heavily rely on the ability to produce force and therefore very commonly have used one-repetition maximum (1RM) tests to measure it (Buckner et al., 2017). For a sport like weightlifting that contests the ability to lift a maximum weight, testing of this nature seems intuitive. The problem with such tests is the fatiguing nature of 1RMs inevitably affect the training itself. Isometric tests provide a relatively quick, safe, and minimally fatiguing alternative for monitoring certain strength variables. Using certain technology to monitor training adaptations was used by Dr. Yuri Verkoshansky in the 1970s with what he called a "universal dynamometric stand" (Yuri Verkhoshansky & Verkhoshansky, 2011). Around the same time Dr. Mike Stone and colleagues at Auburn University were experimenting with isometric strength testing on force plates (Comfort, Jones, & McMahon, 2018). Eventually, a test called the isometric mid-thigh pull (IMTP) was devised and first appeared in the literature in a study by Haff et al. (1997) that compared force-time curve characteristics between dynamic and isometric tasks. The IMTP has since become one of the most commonly used athlete monitoring tools for both athletic programs and academic research.

The IMTP is performed standing on force plates in a rack that allows for adjustments of bar height. The ideal pulling position can be slightly dependent on the individual and should resemble the beginning of the second pull in weightlifting. Typically, this position consists of a vertical torso, straightened arms, knee angles between 120-135 degrees, hip angles between 140-150 degrees, and feet flat on the floor (Beckham et al., 2018; Comfort et al., 2019; Kraska et al., 2009). From this position the athletes attempt to maximally produce force vertically on the plates by pulling as fast and hard as possible. By measuring the force trace during these trials variables such as force, RFD, and impulse can be derived. Each of these variables can provide unique insights into an athlete's kinetic abilities (Beckham et al., 2013; Haff, Carlock, Hartman, & Kilgore, 2005), or when used longitudinally, can offer feedback into training adaptations (Hornsby et al., 2017).

Relationships to weightlifting performance. The pulling position of the IMTP is intended to mimic the power position of the clean (Haff et al., 1997) and can be used to measure variables that strongly correlate to weightlifting performance like peak force (PF) and RFD

(Beckham et al., 2013; Hornsby et al., 2017). The power position of the snatch and clean is responsible for generating the highest velocities and power outputs that occur during the lifts (Baumann et al., 1988; Gourgoulis et al., 2002) making it a crucial position for a weightlifter. Additionally, as discussed earlier maximum strength and RFD are extremely vital qualities for successful weightlifting performance. Therefore, the IMTP becomes an especially beneficial monitoring tool for weightlifting by providing the opportunity to safely measure important performance variables in a sport-specific position.

Peak force. The most commonly measured variable from isometric tests is PF. Strong correlations have been observed between PF and tasks such as dynamic mid-thigh pulls (Haff et al., 1997), lower body 1RMs (Mcguigan, Newton, Winchester, & Nelson, 2010; McGuigan & Winchester, 2008), and weightlifting performance (Hornsby et al., 2017). For example, Beckham et al. (2013) observed very strong correlations (r=0.830-0.838) between absolute PF values and absolute values for weightlifting competition performance in twelve novice to advanced weightlifters. In addition to assessing the relationship to weightlifting performance, a few researchers have also used PF to track changes in maximum strength capabilities throughout a training period in weightlifters (Hornsby et al., 2017; Taber, DeWeese, Soto, Stuart, & Stone, 2017). In well-trained strength athletes, PF seems to be relatively stable and only is substantially affected when accumulative fatigue is severe (Hornsby et al., 2017; Norris, Joyce, Siegler, Clock, & Lovell, 2018). The lack of sensitivity to fatigue makes PF primarily a useful variable for monitoring long-term changes in maximum force production ability. Multiple studies have reported very high within and between-session reliability for peak force measures (Brady, Harrison, & Comyns, 2018; Guppy et al., 2018; Haff et al., 2005; Kraska et al., 2009; M. H. Stone et al., 2003).

Rate of force development. The ability to produce force is an undeniably important quality for sport performances, but most sports require force production to be developed within a certain time frame. Therefore, the ability to produce force quickly is perhaps the most important goal of the training process (Taber, Bellon, Abbott, & Bingham, 2016). This notion has been supported in several studies observing relationships between RFD and sports skills such as sprinting, jumping, change of direction ability, throwing, and weightlifting performance (Beckham et al., 2013; Haff et al., 2005; Stone et al., 2003; Wang et al., 2016; Zaras et al., 2016). In addition to being an important quality of athletic performance, RFD has been shown to be a sensitive indirect marker of muscle damage (Crameri et al., 2007; Farup, Rahbek, Bjerre, de Paoli, & Vissing, 2016; Peñailillo, Blazevich, Numazawa, & Nosaka, 2015), neuromuscular fatigue (Rodríguez-Rosell, Pareja-Blanco, Aagaard, & González-Badillo, 2017; Thorlund, Michalsik, Madsen, & Aagaard, 2008), and fiber type (Andersen, Andersen, Zebis, & Aagaard, 2010; Häkkinen, Alen, & Komi, 1984; Viitasalo, Hakkinen, & Komi, 1981; Viitasalo & Komi, 1978). A review by Maffiuletti et al. (2016) states that "RFD seems to be better related to most sport-specific tasks and displays a greater sensitivity to changes in neuromuscular function" (p. 1) making it an effective tool for monitoring the adaptations to the training process.

Calculation of RFD is performed by dividing the change in force by the change in time. The use of specific time bands for the calculation of RFD has demonstrated much higher reliability than quantifying peak RFD values (Haff, Ruben, Lider, Twine, & Cormie, 2015). The various RFD time bands have also been suggested to be governed by different physiological mechanisms dependent on the time frame (Andersen & Aagaard, 2006; Andersen et al., 2010; Waugh, Korff, Fath, & Blazevich, 2013) and therefore may respond differently to various training stimuli (Rodríguez-Rosell et al., 2017). For example, earlier RFD time bands (<100ms) have been suggested to be influenced to a greater degree by neural drive and intrinsic muscle properties (Andersen et al., 2010; Gruber & Gollhofer, 2004; Van Cutsem, Duchateau, & Hainaut, 1998). Conversely, later RFD time bands (≥150ms) are more closely related to maximal muscle strength and size (Folland, Buckthorpe, & Hannah, 2014; Kavvoura et al., 2018; Rodríguez-Rosell et al., 2017). For instance, Kavvoura et al. (2018) observed that taekwondo athletes had greater early RFD when expressed relative to lean body mass than throwers who performed better in late RFD. The throwers had greater lean body mass and vastus lateralis thickness which likely affected the later RFD time bands to a greater degree. Mackey, Thiele, Conchola, and DeFreitas (2018) compared force-time variables as well as bar velocity between explosive and traditional resistance trained males and found the only significant difference was the explosive group displayed greater RFD from 0-50ms. Similar differences in very early phase RFD have also been observed between chronically strength trained individuals and untrained (Del Vecchio et al., 2018). Additionally, there is evidence that the training method used can affect the RFD time bands differently. Oliveira, Rizatto, and Denadai (2013) found that fast velocity resistance training significantly increased RFD from 0-10ms up to 90ms, but had no effect on any time bands after 100ms in active males. Mangine et al. (2016) split resistance trained males into a high-volume group and a high-intensity group and found that the intensity group significantly improved RFD from 0-50ms, but the volume group did not experience any significant changes in any of the RFD measures. Therefore, by monitoring both early and late RFD a more comprehensive representation of adaptations to the training process can be made.

Ultrasonography

Ultrasonography (US) is a valid and reliable method of assessing muscle size and architecture (Hides, Richardson, & Jull, 1995; Palmer, Akehi, Thiele, Smith, & Thompson, 2015; Raadsheer et al., 1994). Although, primarily used in medical research and the health care industry, more recently US has been used to quantify measures of muscle morphology like CSA, muscle thickness (MT), muscle fiber pennation angle (PA), and fascicle length (FL) in athletic populations (Bazyler et al., 2018; Blazevich et al., 2003; Kavvoura et al., 2018). A few studies have used this technology as longitudinal athlete monitoring tools and observed associations between the alterations to the muscle and certain performance variables (Bazyler, Mizuguchi, Harrison, et al., 2017; Bazyler, Mizuguchi, Zourdos, et al., 2017; Nimphius et al., 2012; Zaras et al., 2016). Additionally, recent research has revealed that the position of the subject when measured (i.e., lying vs. standing) can affect the observed relationships between the measurements taken and certain performance variables (Wagle et al., 2017). The use of US technology by sport scientists offers a non-invasive athlete monitoring tool for quantifying and monitoring changes in multiple muscle morphology variables.

Muscle size. The quantifications of muscle size from US is typically conducted by measuring either MT or CSA. Although, correlated (Franchi et al., 2018) both offer certain advantages over the other. MT simply measures the thickness of a muscle at a single point dependent on where the probe is placed. The simplicity of measuring MT with the US makes for a quick collection period and has a much smaller learning curve for the technician than CSA collection. However, since the measurement is only taken at a single site, effective measurements reflecting changes to the whole muscle are difficult. Conversely, CSA collects a panoramic sweep which allows for quantification of the area of an entire "slice" of muscle. By measuring CSA, regional changes to the muscle can be quantified (Franchi, Reeves, & Narici, 2017; Mangine et al., 2018). However, the collection and analysis of CSA images through US requires much more attention, time, and experience from the technician. As a result, most of the research conducted in athletic populations on changes in muscle size using US have only measured MT (Bazyler et al., 2018; Nimphius et al., 2012; Zaras et al., 2016).

Observations on the changes in MT within trained populations have been mixed and likely depends upon the sport and style of training being conducted. Most studies have investigated changes in these variables in the vastus lateralis (VL) because of the ease of measurement as well as the importance of lower body musculature to most sports. Nimphius et al. (2012) observed increases in VL MT after 14 weeks of concurrent periodized resistance training and softball practice with no change mid-cycle in resistance trained softball players. The authors suggested that the MT adaptations lagged behind the actual training stimulus which is supported in the literature by what is called the *long-term lag of training effect* (Stone et al., 2007). Both Bazyler et al. (2017) and Zaras et al. (2016) observed increases in VL MT post training cycle in competitive track and field throwers. In contrast to Nimphius et al. (2012) findings Bazyler et al. (2017) observed increases in MT mid-cycle within a 12 week period, Zaras et al. (2016) however only measured MT post training. There is clear evidence that a 10-14 week resistance training period can result in increases in muscle size at least measured by MT in trained athletes. The timelines of when these increases occur is less clear. Additionally, whether these changes in MT are also reflected in a similar manner by changes in CSA measured by US in trained athletes has not yet been thoroughly examined.

To better understand the timeline of changes in muscle size measured by US Damas et al. (2016) measured changes in both VL CSA and echo-intensity, an indirect marker of edema-induced muscle swelling (Gonzalez-Izal, Cadore, & Izquierdo, 2014), in untrained individuals throughout a ten-week resistance training period. They suggested that the early increases (i.e., 3-4 weeks) in whole muscle CSA from resistance training are largely due to increases in muscle swelling induced by training, which in their study was reflected by a corresponding increase in both echo-intensity and CSA after the first testing period (week 3). By the end of the ten-week training period echo-intensity values decreased, but CSA was still significantly higher than pre-training. Therefore, at least in untrained populations, initial increases in CSA may be primarily attributable to muscle swelling, and meaningful hypertrophy of contractile elements likely occur several weeks later.

Muscle hypertrophy is highly dependent on training volume (Schoenfeld, 2010; Schoenfeld et al., 2019). Therefore, periods of reduced training volume like a taper, pose the risk of decreases in muscle size. Two studies by Bazyler et al. (2018) examined corresponding reductions in muscle size during a tapering period. In the first study, both MT and body mass in a group of volleyball players decreased throughout a taper. The second study observed changes in CSA throughout multiple tapering periods in a national level female weightlifter, and the only reported decrease in CSA occurred when the weightlifter cut more than 6 kilograms of body mass leading up to a competition. Therefore, decreases in muscle size during a tapering period are likely highly dependent on the maintenance of body mass, especially for weight class athletes.

Muscle architecture. In addition to muscle size, muscle fiber PA and FL are commonly monitored architectural variables. Increases in PA are typical of resistance training programs and are often associated with corresponding increases in muscle size (Aagaard et al., 2001; Kawakami, Abe, & Fukunaga, 1993; Kawakami, Abe, Kuno, & Fukunaga, 1995). Conversely, FL is more often associated with speed qualities and is usually increased during periods of training with a large focus on high-velocity tasks (Alegre, Jiménez, Gonzalo-Orden, Martín-Acero, & Aguado, 2006; Blazevich et al., 2003).

Blazevich et al. (2003) investigated the timelines of muscle architecture adaptations in athletes and observed decreases in PA and increased FL in only five weeks from subjects only performing high-velocity training. Nimphius et al. (2012) also noted increases in FL and decreases in PA throughout a training period in resistance trained softball players. Zaras et al. (2016) observed increases in FL throughout a ten-week training period in throwers but found no alterations in PA. Therefore, muscle architecture has displayed plasticity in response to changes in training stimuli, and since it has been associated with certain athletic performances (Abe, Fukashiro, Harada, & Kawamoto, 2001; Zaras et al., 2016), it can be a useful addition to athlete monitoring protocols when available.

Summary

The physical development of a weightlifter should emphasize (1) maximizing strength and RFD abilities, (2) increasing and maintaining muscle CSA, (3) developing the size and content of type II muscle fibers, and (4) effectively sequencing training to achieve a peak in performance at the competition. The longer the training age of an athlete the more unlikely substantial improvements in these abilities are to be observed. Therefore, variables that are especially sensitive to small adaptations to the neuromuscular system like RFD must be further investigated. Additionally, it is unclear the extent to which increases in muscle size can occur in well-trained athletes from a single hypertrophy phase, and limited information on the time course of changes to the muscle from these training periods currently exists. Therefore, the following investigation sought to better understand both the kinetic and morphological adaptations to block periodized training in advanced strength athletes using the IMTP and US as longitudinal athlete monitoring tools.

CHAPTER 3

PHASE SPECIFIC CHANGES IN RATE OF FORCE DEVELOPMENT AND MUSCLE MORPHOLOGY THROUGHOUT A BLOCK PERIODIZED TRAINING CYCLE IN WEIGHTLIFTERS

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Abstract

Purpose: The purpose of this study was to investigate the kinetic and morphological adaptations that occur during distinct phases of a block periodized training cycle in weightlifters. **Subjects:** Athlete monitoring data from nine experienced collegiate weightlifters was used in the study. **Methods:** Isometric mid-thigh pull (IMTP) and ultrasonography (US) results were used to compare the changes in rate of force development (RFD) and muscle morphology that occur during three specific phases of a training cycle leading up to a competition. **Results:** During the high volume strength-endurance phase (SE) small depressions in RFD but statistically significant increases in vastus lateralis cross-sectional area (CSA), and body mass (BM) were observed. The lower volume higher intensity strength-power phase (SP) caused RFD to rebound above pre-training cycle values despite statistically significant reductions in CSA. Increases only in the earlier RFD time bands (<150ms) occurred during the peak/taper phase (PT) while CSA and BM were maintained. Small increases in RFD and CSA occurred throughout the training cycle. **Conclusions:** Changes in IMTP RFD and CSA from US reflect the expected adaptations of block periodized training phases. Changes in early (<100ms) and late (≥150ms) RFD time bands do not occur proportionally throughout different training phases. Small increases in RFD and CSA can be expected in weightlifters throughout a single block periodized training cycle.

Introduction

Competitive success in the sport of weightlifting relies on the kinetic and kinematic abilities of the athlete. However, after a few months to years of training weightlifting technique tends to become highly stable (Aján & Baroga, 1988; Kauhanen et al., 1984), while the weight lifted and power outputs continue to increase (Garhammer, 1993). There is also ample evidence that suggests weightlifting success is heavily dependent on the magnitude and rate of force development (RFD) generated by the lifter (Garhammer, 1980; John Garhammer, 1985; Stone et al., 1998). Therefore, the performance of more advanced weightlifters is likely primarily determined by the capacity to generate high forces, RFD, and peak power outputs (Stone et al., 2005; Storey & Smith, 2012) during the competitive lifts. These characteristics are often specifically targeted through unique training periods that aim to create certain adaptations to the neuromuscular system. Therefore, the ability to assess both the magnitudes and timelines of which these adaptations occur can be beneficial to designing the training of weightlifters.

Weightlifters benefit from only participating in a few major competitions per year allowing for certain training phases to be dedicated to the development of specific adaptations (e.g., hypertrophy, maximum strength, speed, etc.). Block periodization can serve as a framework for sequentially eliciting these adaptations across training phases, culminating in a peak where the athlete has the highest potential of success on the day of competition (DeWeese et al., 2015). This strategy is conducted in phases often referred to in the literature as accumulation, transmutation, and realization (Issurin, 2008; Zatsiorsky & Kraemer, 2006). This sequence of training phases is intended to initially emphasize the development of work capacity and force generating potential in order to potentiate the following phases of more specific training. DeWeese et al. (2015) suggests that the training process for a strength-power athlete not only requires an appropriate stimulus for adaptation but also benefits from an appropriate method of assessing progress (i.e., monitoring).

The isometric mid-thigh pull (IMTP) is a commonly used method to both assess the kinetic ability of an athlete as well as monitor changes in their performance potential throughout a training period (Hornsby et al., 2017). The IMTP is especially valuable for the monitoring of weightlifters since it provides the opportunity to safely measure important performance variables, such as peak force (PF) and RFD in a sport-specific position. Strong correlations ($r = \geq 0.70$) have been observed between these variables and weightlifting performance (Beckham et al., 2013; Haff et al., 2005; Hornsby et al., 2017). However, research suggests that RFD is more closely related to most athletic tasks (Maffiuletti et al., 2016; Taber et al., 2016) and is more sensitive to fatigue (Hornsby et al., 2017; Norris et al.). Haff et al. (2015) reported that calculating RFD using specific time bands results in higher reliability than quantifying peak RFD values. Additionally, these various RFD time bands have been suggested to be governed by different physiological mechanisms and therefore may respond distinctively to various training phases. For example, earlier RFD time bands (<100ms from onset) have been suggested to be influenced to a greater degree by neural factors and intrinsic muscle properties (Andersen & Aagaard, 2006; Andersen et al., 2010; Gruber & Gollhofer, 2004; Methenitis et al., 2017; Van Cutsem et al., 1998). Conversely, later RFD time bands (>100ms from onset) are more closely related to maximal muscle strength and size (Folland et al., 2014; Kavvoura et al., 2018; Rodríguez-Rosell et al., 2017). Since block periodized training consists of distinct phases that emphasize certain physical qualities, the RFD time bands may be affected differently. For instance, a concentrated load of strength-endurance over multiple weeks often results in depressions in measures of power and speed in trained athletes (Verkhoshansky, 1985), but once the athlete returns to regular training increases potentially above previous values (i.e., supercompensation) can occur (Hornsby et al., 2017; Siff, 2003; Stone et al., 2003; Stone et al., 2007). Realization phases apply a substantial decrease in training volume with a corresponding increase or maintenance in training intensity aimed at substantially decreasing neuromuscular fatigue and inducing certain adaptations such as shifts to faster fiber types (Häkkinen, Kallinen, Komi, & Kauhanen, 1991; Luden et al., 2010; Murach et al., 2014). Adaptations commonly associated with these phases therefore may be most apparent in the earlier RFD time bands, but need to be further investigated.

Both PF and RFD are influenced by the size, architecture, and composition of muscle fibers (Aagaard & Thorstensson, 2003; Harridge et al., 1996; Kavvoura et al., 2018; Methenitis et al., 2017; Zaras et al., 2016). Ultrasonography (US) provides a non-invasive method for assessing and monitoring muscle qualities like muscle thickness (MT), cross-sectional area (CSA), pennation angle (PA), and fascicle length (FL) (Hides et al., 1995; Palmer et al., 2015; Raadsheer et al., 1994). Reported changes in these variables throughout training periods are mixed and seem to be dependent on the style of training (Bazyler, Mizuguchi, Harrison, et al., 2017; Blazevich et al., 2003; Nimphius et al., 2012; Zaras et al., 2016). Increases in the size of a muscle from resistance training has been well established. However, the extent to which a single three to four week hypertrophy phase as is often seen in block periodized programs, results in increased muscle size in well-trained athletes is unclear. Also, less well understood are the timelines of which changes to muscle morphology occur throughout different phases of the training cycle. Additionally, muscle hypertrophy is highly dependent on training volume (Schoenfeld, 2010; Schoenfeld, Ogborn, & Krieger, 2017; Stone et al. 1996), and studies investigating changes in muscle size during periods of reduced training volume have observed concomitant reductions in body mass and muscle size (Bazyler et al., 2018; Bazyler, Mizuguchi, Zourdos, et al., 2017). Therefore, weight class athletes who often deliberately lose body mass leading up to a competition may be at a greater risk of muscle loss during realization phases.

Coaches and sport scientists of any strength-power sport can benefit from further clarification into the expected magnitudes and timelines of adaptation to block periodized training. Therefore, this investigation sought to better understand the kinetic and morphological adaptations that occur during distinct phases of a training cycle in advanced strength athletes using the IMTP and US as longitudinal athlete monitoring tools.

Methods

Participants

Athlete monitoring data from a total of nine experienced collegiate weightlifters was used for analysis (Table 3.1). All nine of these athletes had competed at least at the university national level, three at the senior national level, and one had previously competed internationally as a junior and university world team member. All athletes were familiar with the testing procedures, and the data were collected as part of an ongoing athlete monitoring program. The study was approved by the University's Institutional Review Board and the athletes provided consent for their monitoring data to be used.

Table 3.1 - Summary of Subject Characteristics (Mean ± SD)

Sex	Age (yrs)	Height (cm)	BM (kg)	BF (%)	RT age (yrs)	WL age (years)	Snatch (kg)	C & J (kg)	IPF (N)
Males	22 ± 2	170 ± 4	84 ± 7	12 ± 3	5 ± 1	4 ± 0	118 ± 8	148 ± 14	6147 ± 861
Females	21 ± 3	157 ± 4	58 ± 7	17 ± 2	7 ± 3	7 ± 3	69 ± 8	91 ± 10	4431 ± 610

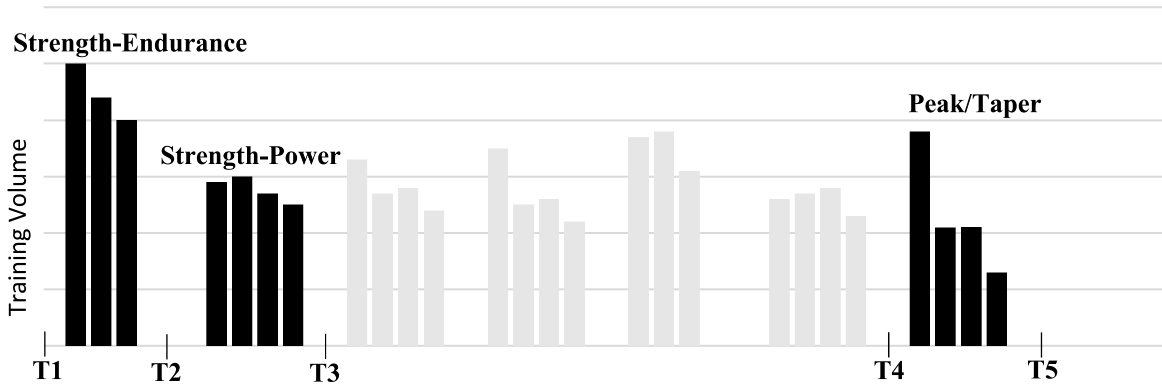
Note: Males (n = 5), Females (n = 4), BM = body mass, BF = body fat, RT = resistance training, WL = weightlifting, C & J = clean and jerk, IPF = isometric peak force.

Experimental Design

This study compared pre- and post-block testing results from three specific training phases throughout a single macrocycle leading up to a competition. The initial training phase (T1-T2) consisted of three to four weeks of high volumes and low to moderate relative intensities, termed a *Strength-Endurance Phase* (SE). The second phase of training (T2-T3) consisted of three to four weeks of moderate volumes at much higher intensities, termed a *Strength-Power Phase* (SP). The final block of training (T4-T5) occurred at the very end of each macrocycle where the athletes underwent a single week of a sharp increase in volume (Overreach), followed by a three-week taper of low volume and moderate intensities, termed a *Peak/Taper Phase* (PT).

Because of variations in the subjects training age and performance levels, the length of the athlete's macrocycles varied (~4-7 Months) depending on the time between their most important competitions. Therefore, for the purposes of this study pre- and post-block testing results from three distinct training phases were selected for each athlete (Figure 3.1). Each training phase closely resembled the relative volumes and intensities of the other athletes and took place as the very first and second blocks of the macrocycle and the very last. Ultrasound testing sessions were conducted at the end of the final training week at least 24-48 hours after the previous training session. Testing conducted with the IMTP occurred on Monday mornings approximately 48 hours after the last training session (Saturday) and before beginning a new block of training, or on Wednesday morning after the peak/taper block (T5) to allow dissipation of fatigue from travel to and back from competition the previous weekend. All testing sessions occurred after a planned week of reduced training volume.

Figure 3.1 - Example Macrocycle and Testing Schedule



Training

Training was organized in a four day per week push-pull layout, and an example training plan is summarized in Tables 3.2 and 3.3. The training program was designed, implemented, and adjusted by nationally certified coaches, and the researchers had no influence on the training itself.

Table 3.2 - Example Training Plan

Phase	Week	Sets x Reps	Daily Intensities (M, W, Th, S)
SE	1	3 x 10	M, M, VL, VL
SE	2	3 x 10	MH, MH, L, L
SE	3	3 x 10	L, L, VL, VL
SP	1	3 x 5 (1 x 5)	M, M, L, VL
SP	2	3 x 5 (1 x 5)	MH, MH, L, VL
SP	3	3 x 3 (1 x 5)	H, H, L, VL
SP	4	3 x 2 (1 x 5)	MH, L, VL, VL
PT	1	5 x 5 (1 x 5)	MH, M, L, VL
PT	2	3 x 3 (1 x 5)	M, MH, VL, VL
PT	3	3 x 3 (1 x 5)	MH, M, VL, VL
PT	4	3 x 2 (1 x 5)	ML, L, VL, Meet

Note: SE = Strength-Endurance, SP = strength-power, PT = Peak/Taper, VL = very light (65-70%), L = light (70-75%), ML = medium light (75-80%), M = medium (80-85%), MH = medium heavy (85-90%), H = heavy (90-95%), VH = very heavy (95-100%). Intensities are based off a set-rep best system (DeWeese, Sams, & Serrano, 2014). Sets and reps in parentheses represent a drop set at approximately 60%.

Table 3.3 - Example Exercise Selection

Strength-Endurance	Strength-Power	Peak/Taper
Monday/Thursday	**Monday/Thursday**	**Monday/Thursday**
AM Back Squat **PM** Push Press Press from split DB Press	**AM** Back Squat **PM** Push Press Jerk Lockout BTN Press DB Press	**AM** Back Squat* **PM** Jerk Dead Stop Parallel Squat** BTN Press DB Press*
Wednesday	**Wednesday**	**Wednesday**
AM Snatch Tech CGSS CG Pull - Floor **PM** Snatch Tech CGSS CG Pull – PP CG SLDL DB Row	**AM** Snatch Tech CGSS CG Pull - Floor **PM** Snatch Tech CGSS CG Pull – Knee CG SLDL CG Bent Over Row	**AM** Snatch Tech CGSS CG Pull - PP **PM** Snatch Tech SGSS SG Pull – Floor CG SLDL* DB Row*
Saturday	**Saturday**	**Saturday**
Snatch Tech SGSS Snatch C & J SG SLDL DB Row	Snatch Tech SGSS Snatch C & J SG SLDL SG Bent Over Row	Snatch Tech SGSS Snatch C & J SG SLDL DB Row

Note: DB = dumbbell, CG = clean grip, CGSS = clean grip shoulder shrug, SLDL = stiff legged deadlift, SG = snatch grip, SGSS = snatch grip shoulder shrug, BTN = behind the neck, C & J = clean and jerk. *Dropped during last week of taper. **Only used during overreach (week 1).

Hydration

Before IMTP and Ultrasound testing sessions the hydration levels of the athletes were estimated using a handheld refractometer (Atago 4410 PAL-10S, Tokyo, Japan) to calculate urine specific gravity (USG) on a scale ranging from 1.000 to 1.060. If the athletes USG registered as ≥ 1.020, they had to continue to rehydrate until they registered below 1.020. This was performed to control for dehydration having any adverse effects on the athletes' performance (Judelson et al., 2007) and the overall testing results.

Warm-up

Isometric mid-thigh pull testing was preceded by a standardized warm-up protocol consisting of 25 jumping jacks followed by a set of five dynamic mid-thigh pulls with a 20kg bar. Athletes then performed three sets of five repetitions, with approximately one-minute rest between sets, of dynamic mid-thigh pulls with 60kg (males) or 40kg (females) (Beckham et al., 2013).

Isometric Mid-Thigh Pull

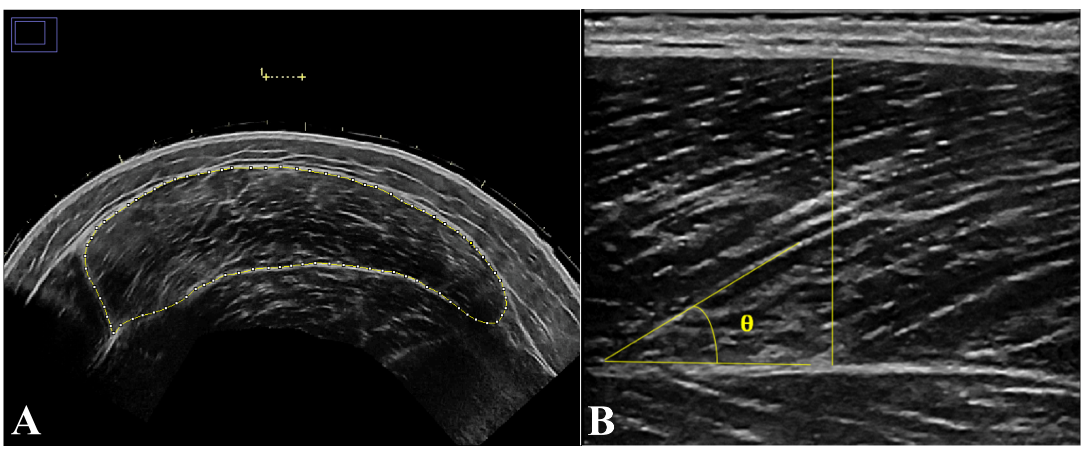
Isometric Mid-Thigh Pull Testing was performed standing on dual force plates (Rice Lake Weighing Systems, Rice Lake, WI; 1000Hz sampling rate) inside of a custom- designed power rack that allows adjustment to the desired bar height (Kraska et al., 2009). Athletes began the testing by assuming a mid-thigh pull position for which they were already familiar performing both in training and for testing. Knee angle was measured to be 125 ± 5 degrees (measured using a handheld goniometer), and the lifter was then instructed to perform a 50% effort warm-up isometric pull. After a brief rest, the athlete performed another warm up pull at 75% and was then secured to the bar with both lifting straps and athletic tape. Athletes were instructed to "pull as fast and hard as possible" beforehand. For the trials, verbal instruction was given to get into position and apply a steady amount of pre-tension to the bar to reduce slack in the body, and to help minimize a countermovement. Once a consistent force trace was observed by the tester a verbal countdown of "3,2,1 pull" was given with loud verbal encouragement given until the tester noticed a plateau or decrease in force. Athletes then received 90-120 seconds of seated rest before reattempting. Additional trials were performed if there was a >250N difference in peak force from the first attempt. The force trace was analyzed by the same investigator using custom designed lab view software (National Instruments, Austin, TX). The mean of the best two attempts for PF as well as RFD time intervals of 0-50ms (RFD50), 0-100ms (RFD100), 0-150ms (RFD150), 0-200ms (RFD200), and 0-250ms (RFD250) was used. Within session intraclass correlation coefficient (ICC) and coefficient of variation (CV) for each variable were: PF (ICC = 0.99, CV = 2%), RFD50 (ICC = 0.86, CV = 15%), RFD100 (ICC = 0.85, CV = 13%), RFD150 (ICC =0.91, CV = 10%), RFD200 (ICC = 0.93, CV = 8%), RFD250 (ICC = 0.94, CV = 7%).

Figure 3.2 – Isometric Mid-Thigh Pull Position

Ultrasonography

A 7.5 MHz ultrasound probe (LOGIQ P6, General Electric Healthcare, Wauwatosa, WI) was used to measure CSA, MT, FL, and PA of the vastus lateralis (VL). Measurements were taken in a standing position as described by Wagle et al. (2017), as this position has been shown to correlate better with both isometric and dynamic performance. The tester identified and marked 50% of the distance between the greater trochanter and the lateral epicondyle of the right leg. Three MT images were then taken five centimeters anteromedial to the mid-femur mark. The best image from the three was selected for analysis, and the mean of three MT and PA measurements was taken from the first, second, and third portions of the image. Three CSA images were attained by using a panoramic image sweep perpendicular to the VL muscle at the mid-femur mark. CSA was then determined by selecting two out of the three images that best displayed the region of interest and using an image processing software (ImageJ 1.52a, National Institutes of Health, Bethesda, MD, USA) to trace the intermuscular area (Figure 3.3A). Lastly, FL was estimated by calculating MT · $\sin(PA)^{-1}$ (Figure 3.3B). The US technician remained the same throughout all five testing sessions, and all images were analyzed by a single researcher on the same computer. Within session intraclass correlation coefficient (ICC) and coefficient of variation (CV) for each variable were: CSA (ICC = 0.99, CV = 1%), MT (ICC = 0.96, CV = 2%), PA (ICC = 0.83, CV = 9%), FL (ICC = 0.73, CV = 9%).

Figure 3.3 - (**A**) Cross-Sectional area measurement. (**B**) Muscle Thickness and Pennation Angle Measurement.



Statistics

All data has been represented as mean ± SD. One-way and two-way repeated measures analysis of variance (ANOVA) were performed to determine the effects of training phase (one-way) and the main and interaction effects of phase and RFD time bands (two-way) on the measured variables. Statistical effects were followed up with post hoc tests. Effect sizes (Cohen's d) and 95% confidence intervals were calculated to better provide population parameter estimates of mean change and to infer practically meaningful changes. These changes were interpreted using the following scale: 0.0-0.2 (trivial); 0.2-0.6 (small); 0.6-1.2 (moderate); 1.2-2.0 (large); 2.0-4.0 (very large; 4.0+ (nearly perfect) (Hopkins, Marshall, Batterham, & Hanin, 2009). The critical alpha of 0.05 was used for all null hypothesis testing unless familywise error was expected. Statistical analyses were performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA), Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA), and RStudio (Version 1.1.383; RStudio, Inc., Boston, MA).

Results

Isometric Mid-Thigh Pull

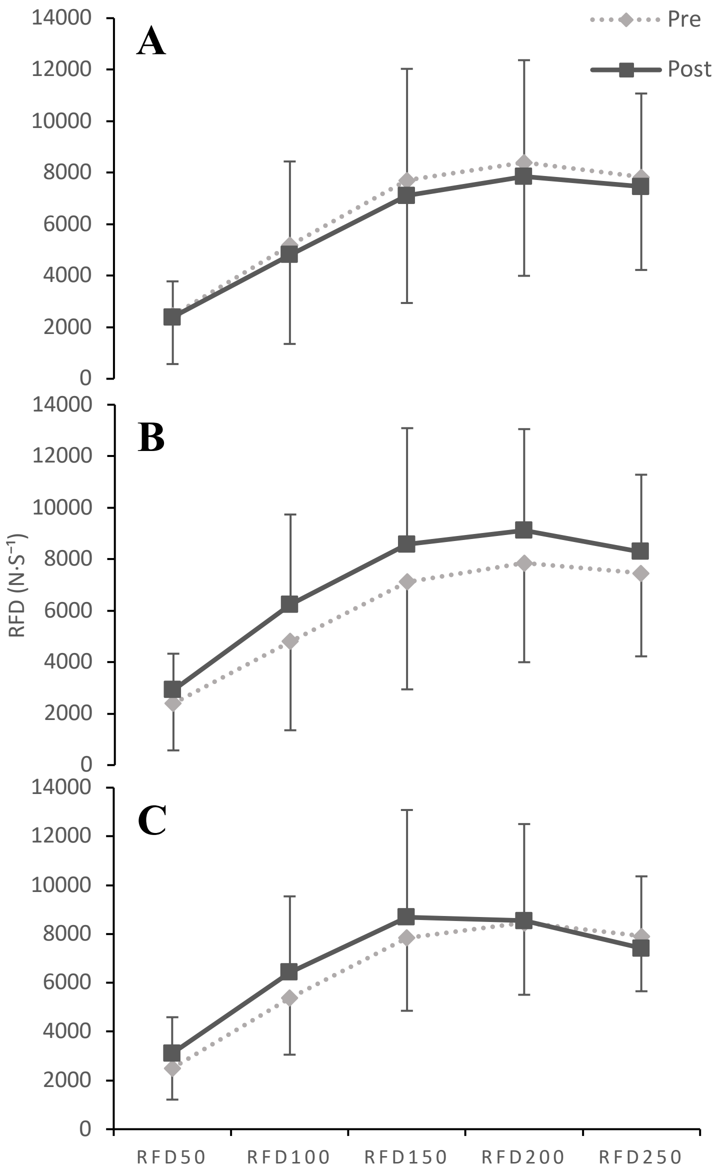
No statistical main or interaction effects ($p \leq 0.05$) occurred for any of the IMTP variables (Table 3.4). During the SE phase (T1-T2) there were trivial to small decreases in RFD50 (d = -0.12, 95% CI [-1.04-0.81), RFD100 (d = -0.43, [-1.37-0.53]), RFD150 (d = -0.35, [-1.28-0.32]), RFD200 (d = -0.27, [-1.20-0.67]), and RFD250 (d = -0.22, [-1.14-0.72]). During the SP phase (T2-T3) there were moderate increases in RDF50 (d = 0.98, [-0.10-2.01), RFD100 (d = 1.05, [-0.05-2.09]), RFD150 (d = 0.68 [-0.33-1.65]), RFD 200 (d = 0.60, [-0.39-1.56]), and a small increase in RFD250 (d = 0.52, [-0.46-1.46]). Lastly, the PT phase (T4-T5) resulted in moderate increases in RFD50 (d = 0.78, [-0.25-1.76]), RFD100 (d = 0.80, [-0.23-1.79]), and RFD150 (d = 0.60, [-0.39-1.56]) only. When comparing RFD after each training phase to pre-training cycle values there was a moderate increase in RFD50 (d = 0.91. [-0.15-1.93]) and RFD100 (d = 1.09, [-0.01-2.15]), and small increases in RFD150 (d = 0.58,[-0.41-1.53]), RFD200 (d = 0.40,[-0.56-1.34]) and RFD250 (d = 0.28,[-0.67-1.20]) from T1-T3. There were also moderate increases in RFD50 (d = 0.87, [-0.18-1.87]) and RFD100 (d = 0.69, [-0.32-1.66]), and a small increase in RFD150 (d = 0.40, [-0.56-1.33] from T1-T5. Changes in PF throughout every timepoint were trivial (d = -0.23-0.03).

Table 3.4 - Dependent variables at each timepoint. Mean ± SD.

Variable	T1	T2	T3	T4	T5
PF (N)	4956 ± 1418	4942 ± 1499	4884 ± 1412	4948 ± 1378	4902 ± 1224
RFD50 ($N \cdot S^{-1}$)	2452 ± 1329	2392 ± 1820	2910 ± 1416	2503 ± 1290	3111 ± 1478
RFD100 ($N \cdot S^{-1}$)	5183 ± 3253	4808 ± 3455	6240 ± 3494	5379 ± 2325	6436 ± 3108
RFD150 ($N \cdot S^{-1}$)	7699 ± 4332	7112 ± 4170	8565 ± 4524	7852 ± 2999	8687 ± 4397
RFD200 ($N \cdot S^{-1}$)	8397 ± 3970	7850 ± 3853	9116 ± 3936	8465 ± 2955	8542 ± 3965
RFD250 ($N \cdot S^{-1}$)	7830 ± 3243	7450 ± 3226	8290 ± 2991	7917 ± 2261	7420 ± 2945
BM (kg)	71.9 ± 14.5	73.6 ± 15.5†	73.2 ± 14.5†‡	72.7 ± 14.3	72.7 ± 14.4
CSA (cm^2)	39.2 ± 10.0	42.3 ± 10.1†	41.0 ± 9.6†‡	40.2 ± 9.9	40.1 ± 10.3
MT (cm)	2.82 ± 0.43	2.98 ± 0.43	2.88 ± 0.42	2.89 ± 0.42	2.88 ± 0.43
PA (°)	21.2 ± 5.45	21.5 ± 3.64	21.01 ± 5.16	19.9 ± 3.93	19.3 ± 4.89
FL (cm)	8.1 ± 1.9	8.2 ± 1.0	8.4 ± 2.1	8.7 ± 1.8	9.0 ± 1.3

Note: PF = Peak Force; CSA = Cross Sectional Area; MT = Muscle Thickness; PA = Pennation Angle; FL = Fascicle Length. †Significantly different from the previous timepoint ($p \leq 0.05$). ‡Significantly different from T1 ($p \leq 0.05$).

Figure 3.4 - Phase Specific Changes in Rate of Force Development.

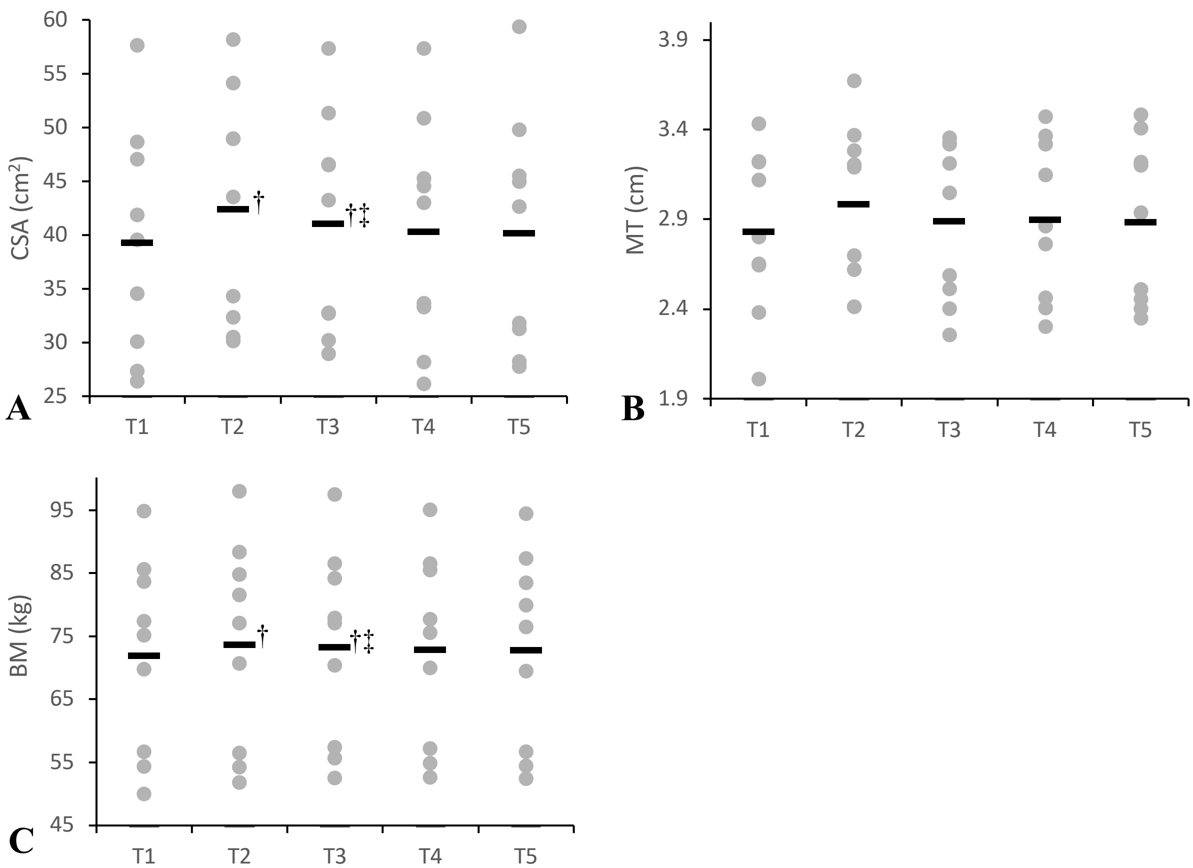


Note: (**A**) Strength-Endurance phase (T1-T2). (**B**) Strength-Power phase (T2-T3). (**C**) Peak/Taper phase (T4-T5). Mean ± SD.

Ultrasonography

The ANOVA revealed a statistically significant effect of time on CSA (p = <0.001) and BM (p = 0.01). During the SE phase (T1-T2) a statistically significant increase in CSA (p = 0.004; d = 1.90, [0.53-3.21]) and BM (p = 0.007; d = 1.6, [0.38-2.90]) occurred. During the SP phase (T2-T3) CSA significantly decreased (p = 0.009; d = -1.61, [-2.82 - -0.34]) while BM remained mostly unchanged (p = 0.08; d = -0.37, [-1.3-0.57]). Both CSA (p = 0.03; d = 1.19, [0.06-2.27]) and BM (p = 0.02; d = 2.10, [0.65-3.50]) at T3 remained significantly higher than T1. No statistically significant change in CSA (p = 0.83; d = -0.10, [-1.02-0.83]) or BM (p =0.96; d = -0.02, [-0.94-0.89]) occurred during the PT phase (T4-T5). Overall from T1-T5 there was a non-statistically significant but moderate increase in CSA (p = 0.19; d = 0.67, [-0.34-1.63] and BM (p = 0.79; d = 0.94, [-0.12 – 1.96]. There was a moderate increase in MT (d = 1.03, [-0.06-2.08]) during the SE phase, followed by a moderate decrease after the SP phase (d = -0.81, [-1.80-0.23]), and a trivial decrease during the PT phase (d = -0.14, [-1.06-0.79]). From T1-T5 the overall increase in MT was small (d = 0.34, [-0.61-1.27]). No statistically significant change in PA or FL was observed however a moderate increase in FL (d = 0.70, [-0.30-1.68]) and a corresponding small decrease in PA (d = -0.58, [-1.53-0.41]) occurred between T1-T5.

Figure 3.5 - Muscle size (CSA and MT) and Body Mass Throughout Each Time Point.



Note: Gray dots represent individual subjects and black line represents the group mean. †Significantly different from the previous timepoint ($p \leq 0.05$). ‡Significantly different from T1 ($p \leq 0.05$).

Discussion

The primary finding of this investigation was that changes in IMTP RFD and CSA from US reflect the expected adaptations to block periodized training phases. The SE phase resulted in slight depressions in force production (Figure 3.4A), likely due to high levels of accumulated fatigue, but also caused significant increases in CSA (Figure 3.5A). During the SP phase, all RFD time bands rebounded above previous values (Figure 3.4B), and CSA decreased, but remained higher than baseline. After the PT phase only the earlier (≤150ms) RFD time bands increased (Figure 3.4C) and CSA was maintained.

In most cases where changes were observed the calculated confidence intervals suggested the responses could range from very large improvements to small decrements in performance. The only clearly substantial changes occurred in CSA from T1-T2, T2-T3, and T1-T3. Meaning it is very likely a three to four week SE phase first results in small to large increases in CSA, followed by a reduction during the following phase, but a maintenance above original values (Figure 3.5A). This is possibly explained by Damas et al. (2016) observations of early increases in CSA being primarily attributed to muscle swelling. Damage to the muscle from high volume training during the SE phase would also explain the trend of decrements in force production that were observed, and that has been reported previously (Hornsby et al., 2017). After the SP phase, the RFD values in all time bands rebounded to above pre-training cycle values (Figure 3.4B). The significant increase in CSA and BM, the likely reduction in muscle damage from the lowered volume, and the reintroduction of higher intensities all likely contributed to this supercompensation effect. Although, not statistically significant the values of CSA, MT, and BM progressively decreased between T2-T5 (Figure 3.5), indicating that the increases in muscle size that occurred early in the training phase gradually decreased across the rest of the training cycle as the athlete's body mass lowered leading up to the competition. No statistically significant change in CSA or MT occurred during the PT phase most likely because this group did not significantly alter their body mass within this short period. Seven out of the nine lifters experienced increases in CSA after the training cycle while only four ended with a greater body mass (Figure 3.5C). Therefore, increases in muscle size are more likely to occur in athletes who have room within their weight class to gain body mass throughout a training cycle, but may still be possible in those that maintain their weight and improve their body composition. There were no clear effects of any individual training phase on muscle architecture however there was a moderate increase in FL and a small decrease in PA from T1-T5 (Table 3.4). Similar changes in

FL throughout a periodized training period have been observed in athletes (Bazyler et al., 2017; Nimphius et al., 2012; Zaras et al., 2016) and may be representative of a shift to higher velocity movements across the training cycle.

As has been observed previously PF remained very stable throughout the entire training cycle and RFD exhibited a much greater plasticity (Hornsby et al., 2017). Changes in RFD did not at any point reach statistical significance but trends for the different training phases were observed in most of the time bands. Previous research has suggested that early RFD time bands are more closely related to neural function and late RFD is more commonly associated with maximal muscle strength (Rodríguez-Rosell et al., 2017). Larger effects throughout each training phase in this study occurred in RFD50, RFD100, and RFD150. The lack of more substantial effects in the later RFD time bands is not too surprising as maximal force abilities, measured by PF, did not change considerably at any point.

A major limitation of this study was the post-PT testing session occurred several days after the theoretical "peak" would have occurred. It is a common observation within our laboratory that fatigue from the competition, travel, and possible emotional let-down after the meet negatively influences these testing sessions. Additionally, due to differences in the length of the athlete's macrocycles, it is difficult to determine the effects of what occurred between the SP and PT phase (T3-T4) had on the final two testing sessions. Therefore, it is challenging to properly compare the results at T5 to the other time points. Increases in the earlier RFD time bands (≤150ms) were still observed between T4-T5 so it is possible that on the day of competition RFD may have been at its highest point in all time bands. But, further research must be conducted to better elucidate the effects of PT phases on early versus late RFD.

Research into the adaptations that occur in well-trained strength athletes who compete in individual sports is often difficult because the timelines of the training programs may differ dependent on the competitions they have qualified for. Therefore, within the literature many insights into training adaptations in individual sport athletes are conducted as case studies. A novel aspect of this study was the grouping of athletes pre and post monitoring results together based off of similar training phases. This allowed for observations to be made on a larger sample size of well-trained subjects making the results more applicable to a wider range of athletes. Coaches and sport scientists may benefit from the use of a similar methodology in order to better evaluate the effectiveness of a training program on a group of athletes whose training cycles may not line up.

The overall increases in muscle size and RFD throughout the entire study were not statistically significant. However, effect sizes and confidence intervals suggest small to moderate effects occurred in most variables. Additionally, all of the subjects in this study were well-trained experienced strength athletes, and the baseline values at T1 were collected after the previous training cycle, and not after a period of detraining. Therefore, it can be expected that the changes that occurred during this macrocycle would occur throughout most training cycles in athletes at this level. In the context of a long-term athlete development plan then, these effects may be quite meaningful as they could be compounded over several collective macrocycles.

Practical Applications

The plasticity of RFD in addition to its greater relevance to most athletic tasks (Maffiuletti et al., 2016; C. Taber et al., 2016) make it a superior monitoring variable than PF. In well-trained strength athletes, PF may be more effectively used for monitoring long term changes in maximal force producing abilities while RFD provides a more comprehensive indication of the current performance potential of the athlete. Since IMTP RFD is such a valuable metric, greater attention should be placed on obtaining trials that not only display consistent PF values but also a similarity in the slope of the force-time curve. Additionally, it is important to measure RFD across multiple time bands because changes in early and late RFD may not occur proportionally. Both RFD and CSA from US seemed to reflect the expected general adaptation trend of each training phase. Therefore, coaches and sport scientists interested in assessing the kinetic and morphological adaptations to periodized training can benefit from these monitoring tools. Based on the results of this study small increases in RFD and muscle size can be expected throughout a single block periodized training cycle in well-trained weightlifters. Therefore, these results appear to support the long term use of block periodization alongside of an effective monitoring program.

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CHAPTER 4

SUMMARY AND FUTURE INVESTIGATIONS

The purpose of this study was to use results from an athlete monitoring program to better understand the magnitudes and timelines of kinetic and morphological adaptations that occur from typical block periodized training phases. The use of retrospective monitoring data resulted in certain limitations but allowed for a longer investigation with a higher level of athletes than is typical within the sport and exercise science literature.

This study offered some important insights into the kinetic and morphological adaptations that occur in experienced strength athletes. Additionally, since the data was collected as part of an ongoing athlete monitoring program, it provides support for the use of these monitoring tools for coaches looking to monitor these same qualities in their athletes. Many of the methods in this investigation can be directly applied and improved through the findings of this study. The most clear outcome of this investigation was the adaptations of a high-volume strength-endurance phase followed by a lower volume high-intensity strength-power phase. It was shown that increases in muscle size during these phases occur in well-trained athletes especially when body mass is elevated. It also examined a supercompensation effect from the two sequenced phases supporting the use of such programming tactics. The findings of the peak/taper phase were limited in this investigation as the monitoring methods used are unable to be transported, and testing sessions had to be conducted several days after the competition. To adequately assess the effects of a peak/taper phase on RFD a more thorough investigation should be conducted with a testing session occurring very close to when the theoretical peak in performance is expected. Ideally, these testing sessions would also occur without being affected by travel or any post-competition fatigue.

The substantial increase and subsequent decrease in CSA fit previous observations of short term increases in muscle size being primarily attributed to muscle swelling (Damas et al., 2016), but this study did not directly assess this. Therefore, further investigations must be conducted in well-trained athletes to determine the extent to which muscle swelling occurs from typical resistance training phases. Furthermore, the exact mechanisms of depressed RFD followed by a rebound above pre-training values can only be speculated from these results. Lastly, the peak/taper phase resulted in increases just in the early RFD time bands meaning specific adaptations such as shifts to faster fiber types or increases in neural drive may have occurred during this training phase. However, this would require more invasive monitoring methods and a more controlled study design to determine the mechanisms of this observation conclusively.

Overall, the results of this study support the use of these monitoring methods for practitioners interesting in assessing kinetic and morphological adaptations. Additionally, the observed changes in these variables support many of the proposed adaptations of block periodization.

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Publications:	**Suarez, D. G.**, Wagle, J. P., Cunanan, A. J., Sausaman, R. W., & Stone, M. H. (2019). Dynamic Correspondence of Resistance Training to Sport: A Brief Review. *Strength & Conditioning Journal*.
Abstracts:	Marsh D.J., Bazyler C., Mizuguchi S., Gahreman D., Cunanan A.J., **Suarez D.G**., Stone M.H. Peaking for a National Weightlifting Competition. South East ACSM Conference, Greeneville, SC, February, 2019 **Suarez D.G**, Ushakova K.P., Mizuguchi S. , Hornsby W.G. and Stone M.H. Changes in Isometric Rate of Force Development During Specific Phases of a Block Periodized Training Cycle in Weightlifters. International Coaching and Sport Science College, Johnson City, TN, December, 2018. Marsh D.J., **Suarez D.G**, Rodriguez-Castellano L., Rochau K., Ishida A., Bazyler D. C., Assessing the Validity and Reliability of a Freehand Tool Method for Analysis of Ultrasound Cross-Sectional Area Images. International Coaching and Sport Science College, Johnson City, TN, December, 2018. Mizuguchi S., Cunanan A.J., **Suarez D.G**., Cedar W.E., Gahreman D., South M.A., Marsh D.J., Hornsby W.G., Stone M.H., Sinclair Total and Countermovement Jump Height of

Weightlifters Competing at 2018 USA Youth National Championships. International Coaching and Sport Science College, Johnson City, TN, December, 2018.

Travis S.K., Goodin J., **Suarez D.G.**, Bazyler, C. Identifying a Surrogate Measure of Weightlifting Performance. Coaching and Sport Science College, Johnson City, TN, December 2017

Honors and Awards: International Coaching and Sport Science College best overall poster, 2018

ETSU Dean's List for Academic Achievement 2014-2017