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Tapering for Strength-Power Individual Event and Team Sport Athletes

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Tapering for Strength-Power Individual Event and Team Sport Athletes

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A dissertation

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Doctor of Philosophy in Sport Physiology and Performance

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by

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ABSTRACT

Tapering for Strength-Power Individual Event and Team Sport Athletes

by

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The overall purpose of this dissertation was to address mechanistic and performance changes following a peaking phase in individual event and team sport strength-power athletes. This purpose was addressed by conducting 4 separate investigations with track and field athletes, volleyball athletes, and a national level weightlifter. The following are the primary findings from these investigations. Division I collegiate throwers increased competition throwing performance, jumping performance, and preserved muscle architecture characteristics following an overreach and taper. There were moderate decreases in division I female collegiate volleyball athlete's vastus lateralis muscle thickness with no statistical changes in jumping performance following a taper with no prior overreach in. There were moderate to very large differences in countermovement jump height supercompensation during the peaking phase in favor of the returners over the new players on a similar team of female volleyball athletes. Changes in serum concentrations of inflammatory, hypertrophic and endocrine markers corresponded with alterations in training volume-load and partially explained changes in jump, dynamic mid-thigh pull, and weightlifting performance following multiple competition phases in a national level weightlifter. Additionally, vastus lateralis cross-sectional area can be maintained following a competition phase in a high level weightlifter provided large changes in body mass are not attempted close to competition. The findings of these investigations support the use of overreach and tapering for strength-power athletes and provide an underlying biochemical, morphological, and biomechanical basis for the observed changes in performance.

DEDICATION

This dissertation is dedicated to my LORD and Savior, Jesus Christ who loved us and gave himself for us to redeem from all wickedness and to purify for himself a people that are His very own, eager to do what is good. At times I felt overwhelmed by work and other obligations and have felt distant from you, but where can I go from your Spirit? Where can I flee from your presence? If I go up to the heavens, you are there; if I make my bed in the depths, you are there. If I rise on the wings of the dawn, if I settle on the far side of the sea, even there your hand will guide me, your right hand will hold me fast. God, your Spirit has guided me, whether I turn to the right or to the left I hear your voice behind me saying this is the way, walk in it. I only pray that you take everything away from me that wants to boast in myself for any accomplishments you have given me. May I never boast except in the cross of my Lord Jesus Christ!

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Lastly, I want to acknowledge the only one who deserves all the credit: Jesus you are my life, breath, and everything I need. I couldn't have made it this far unless your hand were with me. I pray that you continue to guide me throughout the rest of my career and keep me mindful of what really matters: Your Word and the Souls of Man. Lord, you must become and I must become less!

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CHAPTER 1

INTRODUCTION

Tapering in athletics has been previously defined as a "progressive nonlinear reduction of the training load during a variable period of time, in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance" (Mujika & Padilla, 2003). Traditionally, it is the final period in a sequence of mesocycles leading up to a major competition or tournament (Pyne, Mujika, & Reilly, 2009). The taper can be best conceptualized along a training-load continuum with overtraining characterizing one end and detraining the opposite end. Athletes from various sport backgrounds have used tapers for decades to recover and enhance performance prior to important competitions (Banister, Carter, & Zarkadas, 1999; Garhammer, 1979; Mujika et al., 1996; Shepley et al., 1992). Despite numerous studies describing the mechanistic and performance enhancing effects of tapering for endurance athletes (Banister et al., 1999; Luden et al., 2010; Mujika, Padilla, Pyne, & Busso, 2004; Murach et al., 2014; Neary, Martin, & Quinney, 2003; Thomas & Busso, 2005; Trappe, Costill, & Thomas, 2000) a paucity of similar research exists with individual event strength-power athletes (Busso et al., 1992; Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1987; Stone et al., 2003; Zaras et al., 2016). Moreover, there are few studies examining methods used by high level team sport athletes to peak for competition (Claudino et al., 2016; Coutts, Reaburn, Piva, & Murphy, 2007; Freitas, Nakamura, Miloski, Samulski, & Bara-Filho, 2014; Gibson, Boyd, & Murray, 2016; Papacosta, Gleeson, & Nassis, 2013).

Muscle architecture has demonstrated plasticity to heavy strength and plyometric training (Aagaard et al., 2001; Alegre, Jimenez, Gonzalo-Orden, Martin-Acero, & Aguado, 2006; Blazevich, Gill, Bronks, & Newton, 2003; Kawakami, Abe, & Fukunaga, 1993; Kawakami, Abe,

Kuno, & Fukunaga, 1995). Quantifying changes in athlete's muscle architecture following a peaking phase can provide a non-invasive means of explaining corresponding performance changes. Considering the contribution of muscle architectural characteristics to a muscle's force-producing capabilities, changes in muscle architecture should hypothetically be expressed in sport-related movement kinetics. Previous studies have observed changes in single muscle fiber morphology, contractile properties, and enzymatic activity (Luden et al., 2010; Murach et al., 2014; Neary et al., 2003; Trappe et al., 2000) following overreaching and tapering periods (ORT). Furthermore, multiple studies have noted improvements in maximal strength, explosive ability, and repeated sprint ability in individual event and team sport athletes (Claudino et al., 2016; A. Coutts et al., 2007; Zaras et al., 2016). Therefore, it is reasonable to believe that changes in muscle architecture would occur following a peaking phase corresponding with performance changes. However, only one known study has examined changes in muscle architecture following a taper in strength-power athletes (Zaras et al., 2016).

Jumping is a task common to many team sport sports. Vertical jump performance provides an indirect measurement of an athlete's explosive ability and competitive readiness. Squat and countermovement jumps (SJ and CMJ, respectively) have been used previously with various athletes to monitor training responses during a competitive season (Freitas et al., 2014; Gibson et al., 2016). Monitoring jump performance during the competition phase may provide an effective means to determine an athlete's response to training without causing undue fatigue. Additionally, a force-time trace from a SJ or CMJ can provide a more comprehensive analysis of changes in jumping performance following a peaking phase (Mizuguchi, Sands, Wassinger, Lamont, & Stone, 2015; Sole, Mizuguchi, Sato, Moir, & Stone, 2015). Jump performance has also been to shown to discriminant between levels of play (elite, sub-elite, collegiate) in various

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sports such as weightlifting (Carlock et al., 2004), sprinting (Peterson, Alvar, & Rhea, 2006), and volleyball (Pion et al., 2015). Therefore, determining changes in jumping performance following a peaking phase can provide an indirect measure of sport performance changes.

Few studies have addressed the molecular basis for changes in athlete's muscle architecture and sport performance following a peaking phase. The hypothalamic-pituitary-adrenal (HPA) and hypothalamic-pituitary-gonadal (HPG) axis have been implicated in overreaching and overtraining (Smith, 2000). While hormonal changes have been the predominate focus of these studies, inflammatory cytokines, chemokines, and myokines have also been studied. Various biochemical markers have been shown to mediate the inflammatory and hypertrophic responses to training (Busso et al., 1992; Farhangimaleki, Zehsaz, & Tiidus, 2009; Fry et al., 1994; Main et al., 2010; Nieman et al., 2014; Storey, Birch, Fan, & Smith, 2016; Tuan et al., 2008); however, more research is needed examining changes in these markers following a peaking phase. Additionally, to our knowledge, no published research has examined these markers in conjunction with morphological changes in skeletal muscle, sport-related kinetic variables, and sport performance following a peaking phase.

Dissertation Purposes

1. To examine the effects of an ORT on individual-event strength-power athletes preparing for conference championships.

2. To examine changes in team sport athletes throughout a competitive season in preparation for conference championships.

3. To examine differences in the effects of a peaking phase between new and returning team sport athletes in order to identify variables that best explain the variation in performance changes.

4. To examine changes in a national level female weightlifter following three separate competition phases.

<center>Operational Definitions</center>

1. Allometric scaling: the absolute value of a variable divided by the body mass of the subject raised to the two thirds power (Jaric, Mirkov, & Markovic, 2005).

2. Biomarker: substance measured in serum that provides an indication of the presence of some phenomenon such as inflammation, tissue damage or repair, or glucose metabolism (Strimbu & Tavel, 2010).

3. Endocrine: hormones or glands that secrete hormones directly into the blood.

4. Endurance: the ability to maintain or repeat a given force or power output (Stone et al., 2006).

5. Muscle architecture: includes measures of muscle thickness (MT), fascicle pennation angle (PA) and length (FL) often measured via ultrasonography (Abe, Kumagai, & Brechue, 2000).

6. Overreach: an accumulation of training and/or non-training stress resulting in short-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take from several days to several weeks (Kreider, Fry, & O'Toole, 1998); Functional overreaching (FOR) results in an initial decrease in performance that is reversed with a short rest period. During non-functional overreaching (NFOR) the recovery period is delayed and takes longer than desired (Meeusen et al., 2013).

7. Peaking phase: training period an athlete completes prior to a major competition comprised of a taper with or without a prior overreach

8. Performance: outcome of a competition, laboratory assessment or field-based test

9. Rating of perceived exertion (RPE): measure of the athlete's perception of training intensity; in the context of session RPE, it is quantified on a modified 0-10 Borg scale developed and validated by Foster et al. 2001.

10. Rating of perceived exertion training load (RPETL): an athlete's RPE score on a modified Borg scale (0-10) multiplied by the duration of the training session (Foster et al., 2001).

11. Strength: the ability of the neuromuscular system to produce force (Stone, Stone, & Sands, 2007).

12. Strength-Power: used to describe athletes or sports where the anaerobic energy system is the primary provider of adenosine tri-phosphate used during play.

13. Supercompensation- increase in a dependent variable above baseline levels following a taper period (Stone et al., 2007).

14. Taper: a progressive nonlinear reduction of the training load during a variable period of time; used in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance (Mujika & Padilla, 2003).

15. Training Load: the combination of training volume, intensity, and frequency. External training load is used to describe the work the athlete performs, while internal training load is used to describe relative physiological and psychological response to the work they perform (Halson, 2014).

16. Volume-load multiplied by displacement (Vld): resistance training external load lifted for an exercise multiplied by the total number of repetitions performed across all sets and the concentric bar displacement measured manually using a tape measure (Haff, 2010).

17. Volume-load (VL): resistance training external load lifted for an exercise multiplied by the total number of repetitions performed across all sets (Haff, 2010).

CHAPTER 2

REVIEW OF THE LITERATURE

The purpose of the taper is to reduce fatigue accumulated during previous training to
express changes in fitness and thereby maximize performance (Mujika, 2010). Training load
during the taper has been divided into various subcomponents, namely: intensity, volume,
frequency, duration and type of taper (Mujika & Padilla, 2003). A meta-analysis by Bosquet et
al. (2007) demonstrated maintaining training intensity and frequency, and exponentially reducing
training volume over a 2-week tapering period resulted in the largest magnitude of improvements
in endurance performance. Previous investigations on tapering for sport performance have
mostly involved endurance athletes and current tapering recommendations are based on these
studies (Aubry, Hausswirth, Louis, Coutts 2014). Because limited research exists examining the
efficacy of tapering for strength-power athletes, no evidence based tapering standards have been
established, although recommendations have been made similar to those for endurance
performance (Pritchard, Keogh, Barnes, & McGuigan, 2015).

Various mechanisms have been studied to explain the performance enhancing effects of
the taper. These include glycogen supercompensation (Houmard & Johns, 1994; Shepley et al.,
1992), improved anabolic to catabolic hormonal profile (Fry et al., 2000; Fry et al., 1994),
increased muscle shortening velocities resulting from myosin isoform shifting (Type IIa to IIx)
(J. Andersen & Aagaard, 2000; L. Andersen et al., 2005; Terzis, Stratakos, Manta, & Georgiadis,
2008) and possibly increased FL (Alegre et al., 2006; Blazevich et al., 2003), increased myosin
heavy chain IIa fiber size, peak force and absolute power (Luden et al., 2010; Trappe et al.,
2000), altered regulation of growth-related genes (fibroblast growth factor-inducible 14, muscle
ring finger protein-1) in MHC IIa fibers (Luden et al., 2010; Murach et al., 2014), increased

muscle activation (Hakkinen, Kallinen, Komi, & Kauhanen, 1991), and recruitment of high threshold motor units (Cormie, McGuigan, & Newton, 2011).

Considering previous reviews of tapering literature have primarily addressed endurance performance, it would be prudent and benefit sport scientists and coaches to have a comprehensive review of the mechanistic factors and associated performance changes in both endurance and strength-power athletes following a peaking phase in preparation for the remaining dissertation chapters. Thus, the purposes of this review are to: 1) discuss various components of the peaking phase, 2) review mechanisms mediating peaking phase performance outcomes, 3) describe peaking phase performance outcomes in individual event and team sport athletes.

<div align="center">Peaking Phase Components</div>

Training Load

Training load has been previously described as the combination of training volume, intensity, and frequency (Wenger & Bell, 1986). Training load is reduced during a tapering period to mitigate fatigue effects from training allowing for improvements in fitness (i.e. cross-sectional area (CSA), rate coding, mitochondrial density, aerobic enzymes) to be expressed. Training load has been categorized as external and internal (Halson, 2014). Briefly, external training load is used to describe the work the athlete performs, while internal training load is used to describe the relative physiological and psychological response to the work they perform (Halson, 2014). Various methods for quantifying external and internal training load have been proposed (Halson, 2014). Measures of external training load include: speed, distance covered, load lifted, and acceleration; measures of internal training load include: heart rate, lactate response, rating of perceived exertion, and sleep quantity. Generally, external training load is

easier to quantify for individual sports (weightlifting, sprinting, and swimming) than team sports (rugby, volleyball, tennis). However, with the advent of wearable global positioning system (GPS) units, quantifying training load with team sport athletes has become more promising (Aughey, 2011).

Foster et al. (1995) proposed the use of session RPETL, which is the product of the athlete's rating of the training session intensity and the duration of the training session in minutes. Rating of perceived exertion is quantified on a modified Borg scale (0-10) with verbal descriptions of session intensity. Foster and colleauges found strong relationships between session RPE and heart rate and blood lactate response in steady state (1995) and intermittent training conditions (2001). These authors concluded RPETL is a valid and practical means of quantifying training load for aerobic exercise, intermittent training, resistance training and plyometric training. However, objections include: assuming that equal RPETLs in different training modalities result in the same amount of strain and fatigue on an athlete, subjectivity of the measure requires corroboration with physiological data, and scores could be biased based on difficulty of the drill or exercise performed at the end of a session.

Endocrine and non-endocrine serum markers have been used to quantify internal training load. Previous markers include inflammatory cytokines and myokines (i.e. interleukin-6 (IL-6), tumor necrosis factor alpha (TNFα), C-reactive protein (CRP), myostatin, decorin), endocrine hormones (testosterone (T), cortisol (C), epinephrine, and norepinephrine), immune cells (neutrophils, CD4 and CD8 lymphocytes) and amino acids (glutamine, glutamate, branched-chain amino acids). These markers, however, are not often observed on a routine basis with athletes possibly due to time constraints, and expense. Although these markers provide insight

into the mechanistic underpinnings of an athlete's response to training they are often impractical to collect in an applied setting with a large number of athletes.

Questionnaires have been commonly used to provide information of the athlete's subjective response to training. A number of questionnaires have been described in the literature including: profile of mood states (POMS), the recovery-stress questionnaire for athletes (REST-Q-Sport), and the daily analysis of life demands for athletes (DALDA) (Morgan, Brown, Raglin, O'Connor, & Ellickson, 1987; Rushall, 1990). However, limitations include athletes' over- or under-estimating training load, and the frequency, timing, and length of the questionnaire. While questionnaires are relatively easy to implement, physiological data should also be collected to corroborate.

Previous authors have suggested a systems-based approach that involves entering GPS data, heart rate data, RPETL data, and questionnaire data into a data management system that allows for easy access and retrieval of information to more efficiently inform training. Commercially available systems include Training Peaks TSS, Kinetic Athlete, and Smartabase, which are becoming increasingly popular. The utility of the Training Peaks system has been described previously (Halson, 2014). A useful application is monitoring chronic and acute training load to gauge an athlete's response to training, their susceptibility to injury, and predicting future performance. As stated previously, integrating external and internal training load data in a seamless manner is the future for fatigue management in sport (Pyne & Martin, 2011).

Pre-Taper Overreach

Coaches and athletes have used overreaching periods for decades in an attempt to achieve a performance supercompensation during the subsequent taper (Hellard et al., 2013; Stone et al.,

1993; Thomas & Busso, 2005) In a joint position statement from the American College of Sports Medicine and European College of Sport Science, the authors adopted the following definition previously used by Kreider et al. (1998) to define an overreach: "an accumulation of training and/or non-training stress resulting in short-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take from several days to several weeks." Overreaching can be further categorized as functional (FOR) or non-functional (NFOR) (Halson & Jeukendrup, 2004). During a FOR state the athlete experiences a temporary decline in performance; however, given an appropriate recovery period, the athlete may experience a supercompensation effect where performance is enhanced above baseline levels (Meeusen et al., 2013). When this intensified training continues, the athlete could reach a NFOR state resulting in stagnation or decrease in performance without supercompensation following sufficient recovery. During a NFOR state the athlete will likely experience both quantitative (increased training load) and qualitative (psychological, neuroendocrine perturbations) signs and symptoms of overreaching (Meeusen et al., 2013).

It has long been believed by many coaches and researchers that a FOR period prior to a taper will result in a greater supercompensation effect (Hellard et al., 2013; Stone et al., 1993; Thomas & Busso, 2005). Using mathematical modeling simulations, Thomas and Busso (2005) reported greater improvements in endurance performance as a result of 20% increase in training load during 28 day period leading up to taper compared to habitual training during that period. Their findings also demonstrated that a more intense overreach period prior to the taper was more effective at enhancing performance, but required a longer taper. Le Meur et al. (2013) found a 9% decrease in performance in triathletes after a 3-week overreaching phase. After a

recovery week the athletes increased performance over pre-testing levels by 7.9% and exhibited

greater supercompensation effects than a control group that performed "normal" training during

the same period. Coutts et al. (2007) had 7 rugby players ($\dot{V}O_2$max ~ 56.1 ml/kg/min) complete a

6-week progressive OR followed by a 1-week taper that decreased training time by 55% and

intensity by 17%. The overreaching period reduced their capacity to produce force at slower

movement velocities during an isokinetic knee flexion and reduced their performance during a

multi-stage fitness test. Following the taper, only isokinetic measures of set work at 1.05 and

5.25 rad/s and peak hamstring torque at 5.25 rad/s were significantly improved from baseline. In

another study, Coutts et al. (2007) compared 4 weeks of overreaching and a 2-week taper to 4

weeks of "normal" training and a 2-week taper in triathletes. Athlete's 3km time trial

performance decreased after the overreaching phase by 3.7% and rebounded following the taper

by 7%; the "normal" training group increased performance by 3% after 4 weeks. However, no

statistical difference in performance improvements from pre-training to post-taper were observed

between groups. The authors concluded the taper may not have been long enough for the

overreaching group to fully recover. These findings demonstrate mixed results for overreaching

prior to the taper with some studies showing no change or an increase from pre-overreach values

following the taper. Differences between findings are likely related to differences between

athlete's training status, and the length, volume, and intensity of the overreaching phase and

subsequent taper.

In a recent investigation, Aubry et al. (2014) divided 34 well trained male cyclists into a

control and overreaching training group. Cyclists were tested prior to and following the 3-week

overreaching phase. Cyclists who decreased cycling performance on a $\dot{V}O_2$max test were

assigned to the FOR group, while those who maintained or increased were assigned to an acutely

fatigue group. The cyclists were then tested on the same performance measure each week during a 4-week taper. Those assigned to the FOR group returned to pre-overload values, but a supercompensation effect was observed in the acutely fatigued group with significantly greater improvements than the FOR group observed at the end of the second week of the taper. Additionally, there were increased incidences of upper respiratory tract infections in the FOR condition. These findings indicate that responses to an overreaching phase and taper vary amongst a group of similar athletes and the importance of monitoring an athlete's response to an overreach phase.

Previous investigations have found increases in stress-related symptoms following an ovrreaching phase in various groups of athletes (Aubry et al., 2014; Freitas et al., 2014; Fry et al., 1994; Storey et al., 2016). Fry et al. (1994) examined changes in T concentrations in elite junior weightlifters following a fatiguing testing battery (jumps, snatches to failure, snatch pulls) before and after an overreach and before and after 1 year of training. Decreases in T were observed after the testing battery during year 1, but not during year 2 indicating a greater tolerance to high workloads. These findings demonstrate that an athlete's training status (i.e. work capacity) plays a role in how they respond to an overreach. More recently, Storey et al. (2016) reported symptoms of stress from a DALDA questionnaire and negative mood state were worse than normal during a 2-week overreach in international level weightlifters. The increase in stress-related symptoms also corresponded with decreases in maximal snatch and vertical jump height (JH) during the overreach; however, all were restored following a 1-week period of reduced training.

The findings of these investigations demonstrate differences in how athletes respond to ORT phases. Importantly, not all studies have observed performance supercompensation

following an ORT. Many studies report physiological, biochemical, and sport performance measures that return to baseline levels following the taper. However, differences between findings may be related to the intensity, length, and type of ORT implemented. Also, differences in individual responses could be due to the athlete's work capacity, training experience, maximal strength, or genetic characteristics. Future research should further investigate which variables explain response differences between athletes to an ORT.

Taper

The taper has been previously defined as "a progressive nonlinear reduction of the training load during a variable period of time, in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance" (Mujika & Padilla, 2003). The tapering period presents a unique opportunity for athletes to maximize performance for a crucial competitive event (Bosquet et al., 2007; Le Meur, Hausswirth, & Mujika, 2012; Mujika & Padilla, 2003). Mujika et al. (2002) has previously demonstrated that the training an Olympic athlete undertakes during the tapering period can make the difference between winning gold and not making the podium. To further illustrate this point, during the Beijing 2008 Olympics Michael Phelps beat his opponent Milorad Cavic by only a hundredth of a second in the 100m butterfly despite trailing Cavic most of the race. Therefore, the training load prescribed during the taper is of utmost importance for athletes seeking to obtain an edge over their opponents.

Tapering involves the manipulation of various factors including training volume, intensity, frequency, and duration (Mujika & Padilla, 2003). Based on a meta-analysis, Bosquet et al. (2007) reported the largest magnitude of change in endurance performance following a 2-week taper during which training volume is exponentially reduced by 41-60%, without any

modification in training intensity or frequency. The magnitude of change in swimming, cycling, rowing, running, and triathlon performance following the taper is ~3% (0.5-6%) (Mujika & Padilla, 2003). Previous investigations on tapering for sport performance have mostly involved endurance athletes and current tapering recommendations are based on these studies (Aubry et al., 2014; Le Meur et al., 2012; Mujika & Padilla, 2003). Because limited research exists examining the efficacy of tapering for strength-power athletes no evidence based tapering standards have been established, although recommendations have been made similar to those for endurance performance (Pritchard et al., 2015).

The training load during a tapering period can be characterized with the intensity, volume, and frequency of training (Le Meur et al., 2012). Decreases in training load should be programmed so that the balance between fatigue reduction and fitness preservation is maximized. While reducing training load is important, detrimental effects on performance can occur if the training load remains low for an extended period (detraining). Arguably the most important variable influencing performance outcomes following the taper is training intensity (Mujika, 2010). In one of the earliest studies examining adaptations following a reduced training period, Hickson et al. (1985) had 12 moderately active subjects run and cycle for 40 min, 6 days/week for 10 weeks. Training intensity was reduced for an additional 15 weeks by 1/3 (n=6) or 2/3 (n=6). The authors reported decreased VO_2 max, left ventricular mass, short-term and long-term exercise endurance in both groups with greater decrements in the group that reduced their intensity by 2/3. In further support of this, Mujika et al. (1995) found that performance improvement in 18 elite level swimmers following a competition period was highly correlated (r=0.69) with their mean training intensity during the season, but not with volume or frequency. Iaia et al. (2009) had endurance runners reduce their weekly running volume from 45 km to 10

km for weeks, while supplementing their training with 8-12, 30 s sprint runs 3-4 times/week. These authors observed maintenance of muscle oxidative capacity, capillarization, and 10 km running performance with improved running economy at submaximal running speeds. Zaras et al. (2014) examined the effects of a 2-week taper using light versus heavy loads in 13 international level track and field throwers. Heavy resistance training (>85% 1-repetition maximum (RM)) resulted in greater improvements in leg press 1RM, rate of force development (RFD), SJ power, and shot throws than light resistance training (30% 1RM). These findings are corroborated by Stone et al. (2003) who demonstrated strong positive relationships among maximal strength (isometric mid-thigh pull peak force), dynamic mid-thigh pull (MTP) peak power (PP), and throwing performance (shot-put and weight throw) in collegiate throwers. In this study, the ORT period (strength-power block) resulted in improved 1RM power snatch, isometric MTP peak force, dynamic MTP peak RFD, and throwing performance. The findings of these investigations support training intensity as the most important variable influencing performance outcomes following the taper in endurance and strength-power athletes.

In regards to training volume, previous investigators have found that this training load parameter can be reduced without losing training induced adaptations, and is in fact crucial for attaining performance benefits from a taper (Bosquet et al., 2007; Le Meur et al., 2012). Previous literature reviews and a meta-analysis examining the endurance performance improvements following a taper have concluded that training volume should be reduced by at least 41% during a taper (Bosquet et al., 2007; Le Meur et al., 2012; Mujika & Padilla, 2003). Shepley et al. (1992) had 9 male middle-distance runners ($\dot{V}O_2$ max: 66-71 ml/kg/min) complete 3 different 7-day tapers (high intensity, low-intensity, complete rest) in a cross-over design. The greatest improvements in muscle glycogen concentrations, treadmill run to exhaustion, total blood

volume, red blood cell volume, and citrate synthase activity were observed in the high intensity

taper condition where run volume was reduced from 60-80 km/week to 7.5 km (composed of

strictly interval training). Importantly, the reduction in training load should be commensurate

with the training load prior to the taper. Using computer simulations, Thomas and Busso (2005)

determined that a 20% increase in training load over a 28-day period prior to a taper requires a

step-taper of ~65% over 3 weeks compared to only 2 weeks when no overreach period is

performed. Gibala et al. (1994) had 8 strength trained males perform 10 days of training

following a 3-week training phase. Resistance training intensity was maintained while volume

was reduced by 72%. The authors reported significant improvements in maximal voluntary

isometric (MVIC) elbow extension torque following the taper. Additionally, MVIC and maximal

low-velocity isokinetic peak torque of the elbow flexors were improved at days 2, 4, 6, and 8 of

the taper. These findings demonstrate that maximal strength of the elbow extensors and flexors

can be improved with as little as 2 days of tapering. Therefore, it has been recommended that

training volume be reduced by 30-70% and intensity maintained or slightly increased during a

tapering period for strength-power athletes (Pritchard et al., 2015).

It has been recommended that training frequency be maintained during a tapering period

for endurance and strength-power athletes (Bosquet et al., 2007; Mujika & Padilla, 2003;

Pritchard et al., 2015). However, Johns et al. (1992) reported increased power output and

swimming performance in competitive swimmers when training frequency was reduced by 50%.

Additionally, Dressendorfer et al. (2002) found improvements in a simulated 20-km cycling time

trial after training frequency was reduced by 50% during a 10-day taper. Graves et al. (1988) had

24 men and 26 women reduce their strength training frequency from 3 to 2 days per week, 2 to 1

day per week or 1 to 0 day per week for 12 weeks. Mean peak MVIC increased by 21% in the

groups that trained twice or one day per week, whereas the group that stopped training decreased MVIC by 68%. These findings demonstrate the importance of maintenance of a minimal training stimulus to prevent losses in strength and that strength can be maintained in recreationally subjects with minimal training. Support for maintaining training frequency with athletes is supported by Mujika et al. (2002) who reported that highly trained middle distance runners achieved significant improvements in an 800-m race with daily training during a 6-day taper, whereas no improvements were observed when the athletes rested every third day of the taper. These findings support previous recommendations that training frequency should be maintained above 80% for higher trained athletes, and that low to moderately trained individuals can sustain performance with fairly low training frequencies (~50%). However, considering the overlap between training frequency and volume, it is difficult to isolate the effects of either on performance outcomes following a taper.

Confounding Factors

While the above literature provides a strong support for the taper, there are many confounding variables that affect decisions coaches make when planning a peaking phase for their athletes. An obvious, but often overlooked factor, is the individual differences between athletes. This is important when considering the training load prescribed by a coach. Wallace et al. (2009) found a clear discrepancy between coaches' perception of athlete's internal training load using session RPETL and athlete's reported RPETL. The athlete's reported greater RPETL than coaches for sessions that were intended to be easy, and lower RPETL for sessions intended to be hard. Therefore, coaches should closely monitor prescribed training load during the taper and individual athlete's perception of the prescribed training load to ensure they are similar. It is also important to quantify what is a meaningful change in performance for individual athletes.

Hopkins (2000) recommends using typical error determined from a reliability study of the performance measure and the smallest worthwhile change (SWC) based on the athlete's previous competition performances. Using this information, the probability (precision) that an athlete's performance is a greater than a reference value can be quantified, as well as the probability that there is a worthwhile change from one performance to the next.

The majority of tapering studies have been conducted with individual sport athletes (Pyne et al., 2009). This is likely because it is easier to quantify training load and performance in these sports compared to team sports, combat sports, and racquet sports (Mujika, 2007; Pyne et al., 2009). Also, clear moderate to large correlations have been observed between physiological factors, training intensity, and volume and competitive performance (Pyne et al., 2009). An additional difficulty with team sport research is differences in demands placed on athletes depending on their position on a team, starters and non-starters, and new players and returners. Previous research has demonstrated that maximal strength, JH, and power output are different between starters and non-starters and between different levels of athletes for various sports (Fleck, Case, Puhl, & Van Handle, 1985; Forthomme, Croisier, Ciccarone, Crielaard, & Cloes, 2005; Fry & Kraemer, 1991; Gabbett, 2009; Gabbett, Kelly, Ralph, & Driscoll, 2009; Pion et al., 2015; Sheppard et al., 2008; Smith, Roberts, & Watson, 1992). Considering these differences, it is likely that responses to an ORT would vary amongst these subgroups. Future research should therefore address differences in how starters/non-starters, new players/returners, elite/sub-elite athletes respond to an ORT.

Further compounding the issue, new lucrative commercial sponsorships are driving increases in the number of competitions in an already busy sporting calendar (Pyne et al., 2009). Now athletes are attempting to peak for several major competitions per year as compared to one

or two. The competition schedule presents one of the biggest challenges to team sport athletes seeking to peak for a series of competitions. It has been suggested that an ideal approach to peaking for team sport athletes would include a period of recovery after regular-season play followed by a return to fitness/rebuilding period and finalized with a pre-tournament taper (I Mujika, 2007). However, the competition schedule does not always work out this conveniently. Teams may finish regular season play and have only a week to recover prior to tournament play. While training through early competitions in a tournament is an option for stronger teams, weaker teams run the risk of peaking too early and ruining their chances of progressing further. An alternative option is overreaching 2-3 weeks prior to the end of regular season play and unloading the week following regular season play prior to the tournament. Future research on tapering for team sport should examine different strategies for preparing for post-season play.

Another difficulty when preparing for an important competition is travel. Crossing multiple time zones causes desynchronization of human circadian rhythms resulting in travel fatigue commonly known as jet lag. Decrements in maximal strength, reaction time, and arousal have been observed following travel (Reilly, Atkinson, & Budgett, 2001). Differences in response to long travel can be due to the number of time zones crossed, direction of travel, and times of departure and arrival. It is recommended that training load be reduced until the athlete accommodates to the new time zone to reduce injury risk (Pyne et al., 2009). Additionally, napping at inappropriate times of the day following long travel could interfere with re-synchronization (Minors & Waterhouse, 1981). Training load prescribed should be adjusted based on individual athlete's "body clock" resynchronization.

<u>Peaking Phase Mechanistic Factors</u>

<u>Muscular</u>

Trappe et al. (2000) were the first to demonstrate changes in single muscle fiber morphology and contractile properties following a tapering phase with athletes. Muscle biopsies from the posterior deltoid were obtained from six highly trained male swimmers prior to and following a 21-day taper. Increases in Type II fiber CSA, peak contractile force, shortening velocity, and PP were observed without any significant change in Type I fibers. These findings were corroborated in a later study with collegiate cross-country runners following a 3-week taper (Luden et al., 2010). These authors found significant increases in gastrocnemius Type IIa fiber diameter, peak force, and absolute power following the tapering period with no changes in Type I fibers. Additionally, a distinct post-taper gene response was observed following an 8 km run. Expression of proteolytic genes (MuRF-1) was reduced following the taper, whereas myogenic (MRF4) and protective cellular processes (HSP 72, and MT-2A) displayed an exaggerated response. Using the same subjects, Murach et al. (2014) found an increased gene expression of fibroblast growth factor-inducible 14 (FN14) following an 8 km time trial in a tapered compared to an overreached state. Fibroblast growth factor-inducible 14 has been shown to correlate strongly with Type II fiber growth in response to exercise (Raue, Slivka, Minchev, & Trappe, 2009; Schmutz et al., 2006). Therefore, changes in FN14 provide a molecular basis for the observed hypertrophy of Type II fibers following the taper.

Andersen and Aagaard (2000) previously demonstrated that strength training induced a myosin isoform shift from type IIx to IIa, whereas a reduced training period can cause an overshoot in the shift back to type IIx in sedentary males. However, it is important to note that this overshoot was observed following a 3-month detraining period and that maximal isometric

knee extension strength returned to baseline levels. Therefore, it is unknown whether athletes would experience similar myosin isoform shifts following a tapering phase. It is more likely that alterations in Type II fiber morphology, enzymatic activity, and contractile properties explain the performance enhancing effects of the taper in athletes (Luden et al., 2010; Murach et al., 2014; Neary et al., 2003; Trappe et al., 2000).

While research on single-fiber gene expression and mechanical characteristics has provided great insight into the mechanisms underlying the performance enhancing effects of the taper (Luden et al., 2010; Murach et al., 2014; Trappe et al., 2000), this process is expensive, invasive, requires highly trained personnel, and coaches who are willing to allow their athletes to participate in the rigors of such testing. Over the past few decades, ultrasonography has been used as a reliable, less invasive method of determining changes in muscle architecture following training (Ikai & Fukunaga, 1970; Kawakami et al., 1995; Wells et al., 2014; Zaras et al., 2016). Increases in MT and PA have been observed following heavy strength training (Aagaard et al., 2001; Kawakami et al., 1995); however studies where subjects trained with high-velocity contractions and lighter loads (<60% 1RM) have reported increases in FL with no changes in PA (Alegre et al., 2006; Blazevich et al., 2003). Moderate to strong relationships have been observed between vastus lateralis MT and 1RM back squat and deadlift (r=0.82, 0.79), SJ and CMJ height (r=0.63-0.8), isometric MTP peak force (r=0.6), isometric leg press peak force (r=0.85), hang power clean (r=0.71), relative 1RM power clean (r=0.51) and shot-put front throw (r=0.66) in various groups of athletes (Brechue & Abe, 2002; McMahon, Turner, & Comfort, 2015; Secomb et al., 2015; Zaras et al., 2016). Recently, Zaras et al. (2016) reported no statistical alterations in muscle architecture following the taper. The lack of observable changes may have been due to

the short duration of the taper (2 weeks). Further research is needed examining the effects of tapering on muscle architecture.

Neural

In one of the earliest investigations examining the effects of overreaching on strength-power athlete's performance, Barker et al. (1990) found greater anterior bar displacement during a snatch after 1-week of increased training volumes (30,000 kg/week to 90,000 kg/week) in elite junior weightlifters. Considering the well-established link between fatigue and motor output, it has been suggested that technique changes are among the earliest observable effects of overreaching and reduced training (Stone et al., 1993). It has already been established that at high levels of performance, milliseconds and centimeters can make the difference between winning and losing. Therefore, recovery and supercompensation of motor output could partially explain the beneficial effects of tapering. Hakkinen et al. (1991) found greater average electromyography (EMG) of vastus lateralis, vastus medialis, and rectus femoris during an isometric knee extension following a 1-week taper in well trained Finish powerlifters, but not for the weaker non-competitive lifters. However, Gibala et al. (1994) found no statistical changes in motor unit activation (interpolated twitch technique), or maximum rate of torque development following a 10-day taper in strength-trained subjects. They surmised that the interpolated twitch technique may have been too insensitive to detect changes, and using integrated EMG may have been more effective. Dupuy et al. (2014) found slower reaction times during a Stroop task in overreached (2 weeks, 100% above normal training) endurance athletes, which returned to baseline following a 1-week taper (50% below normal training). Flanagan et al. (2014) found greater cortical motor output via electroencephalography in a back squat high volume protocol (6x10 at 80% 1RM) from set 1 through set 6 than other protocols (high force: 6x3 at 95% 1RM,

high power: 6x3 at 30% 1RM, control condition- stand with bar on back for 20 s). The increases in motor output were directly related to fatigue evidenced by the greatest fall-off in PP from sets 1 through 6 in the high volume protocol. Although no research has examined the direct effects of an ORT on cortical motor output, it is probable based on Flanagan and colleague's acute findings that periods of sustained increases in training volumes would result in significant perturbations to cortical motor output, while tapering periods would allow for recovery. The above findings demonstrate that neural mechanisms likely contribute significantly to performance changes following ORT periods; however, considering the paucity of research it is difficult to draw any conclusions.

Biochemical

Observational and experimental studies have examined the effects of an ORT on biochemical profile and sport performance (Busso et al., 1992; Coutts et al., 2007; Fry et al., 1994; Hakkinen et al., 1987; Le Meur et al., 2014). Hakkinen and colleagues (1987) found decreases in the T:C ratio following a 2-week overreach in trained weightlifters. The T:C ratio returned to baseline levels following 2 weeks of normal training and a 2-week taper primarily due to reductions in C. Additionally, there was a positive relationship between change in the T/sex hormone binding globulin (SHBG) ratio and change in clean and jerk performance following the normal training and tapering period. Similarly, Fry et al. (2000) found increases in the T:C ratio following a 1-week overreach and 3 weeks of normal training in elite weightlifters. Also, the change in the T:C ratio during the normal training period was positively related to the change in clean and jerk performance. Additionally, Fry et al. (1994) found that one year of weightlifting experience and prior exposure to an overreaching period results in an attenuated post-training lactate response indicating a higher level of fitness.

Fry et al. (2006) had strength trained subjects perform a daily 1RM on a hack squat machine for 2 weeks to induce a state of overtraining. Decreases in 1RM squat over the 2 weeks corresponded with reduced β_2 receptor sensitivity (ratio of nocturnal urinary epinephrine excretion to β_2 receptor density) in an overtrained state compared to a control group. Epinephrine exerts its effects on muscle contractile force by binding to β_2 receptors, which activate protein kinase A causing an increase in extracellular Ca^{2+} entry and intracellular Ca^{2+} release from sarcoplasmic reticulum (Cairns & Borrani, 2015). Therefore, Fry and colleagues concluded that the decreases in β_2 receptor sensitivity likely explained the observed decreases in 1RM squat in the overtrained group. Although it has not been studied directly, it is possible these changes occur to a lesser extent in an overreached state.

Myostatin has been implicated as an important myokine, which limits myocyte differentiation and growth by binding to the activin type II receptor on the myocyte surface and subsequently inhibiting Akt-induced muscle protein synthesis (Kim, Cross, & Bamman, 2005). Myostatin mRNA expression has been shown to decrease following heavy strength training (Hulmi et al., 2007; Kim et al., 2005; Roth et al., 2003), however, not all studies agree (de Souza et al., 2014; Willoughby, 2004). Decorin is a proteoglycan that is part of the myocyte extracellular matrix and has been shown to bind myostatin and possibly trap it in the extracellular matrix (Miura et al., 2006). Kanzleiter and colleagues (2014) found a positive relationship between acute changes in serum decorin levels following a strength training session and subject's 8RM leg press strength. Additionally, these authors found a positive relationship between changes in decorin mRNA expression and changes in leg press strength following a 12-week strength and endurance training program. Therefore, these myokines may provide insight into how the hypertrophic response is regulated following an ORT.

Interleukin-6, and TNF-ὰ are acute phase proteins that promote secretion of acute phase reactants (i.e., C-reactive protein (CRP), fibrinogen, plasminogen) in response to injury, infection, and tissue damage (Biffl, Moore, Moore, & Peterson, 1996; Smith, 2000). Interleukin-6 has been implicated as an anti-inflammatory myokine responsible for initiating satellite cell proliferation and differentiation, and inhibiting TNF-ὰ expression (Vierck et al., 2000). Both IL-6 and TNF-ὰ have been found to increase glucocorticoid production via interaction with hypothalamic receptors resulting in the secretion of corticotropin releasing hormone (Schobitz, Reul, & Holsboer, 1994). There is also evidence that elevated IL-6 and TNF-ὰ reduce hypothalamic secretion of gonadotropin-releasing hormone possibly leading to reduced T secretion (Schobitz et al., 1994; Wu & Wolfe, 2012). Previous evidence demonstrates TNF-ὰ reduces muscle protein synthesis via inhibition of insulin receptor substrate 1 and increases protein degradation (Copps & White, 2012). Both IL-6 and TNF-ὰ have been shown to be elevated following an overreaching phase (Main et al., 2010; Nieman et al., 2014), and subsequently reduced following a 3-week taper (Farhangimaleki et al., 2009) in endurance athletes. Recently, Storey et al. (2016) reported increased plasma protein carbonyls, increased symptoms of stress, and decreased maximal snatch performance during an overreaching period compared to a reduced training period in international-level weightlifters. These findings demonstrate the profound effects an athlete's training volume has on endocrine and non-endocrine molecules and subsequent sport performance.

<div align="center">Peaking Phase Performance Outcomes</div>

Individual Event

Mujika et al. (2002) followed 99 male and female Olympic swimmers from different countries who competed in the Melbourne Grand Prix Series and 21-28 days later in the Sydney

<div align="center">38</div>

Olympics. He found 91 out of 99 athletes improved swimming performance following the 3-week tapering period with an overall performance improvement of 2.18%, which was greater than the average difference between first and fourth place (1.62%). Interestingly, the change in performance was statistically greater in males than females (2.57% vs 1.78%, respectively). These findings provide a strong practical argument for the taper. Zaras et al. (2016) found greater improvements in impulse and RFD at 100ms, 150ms, 200ms, and 250ms during an isometric leg press in the condition that trained with heavy loads (>85% 1RM) compared to the condition that trained with light loads (30% 1RM) during the 2-week taper. However, no differences were observed between conditions in throwing performance (shot, disc, javelin, hammer). Stone et al. (2003) found that a 4-week ORT period (strength-power block) resulted in improved 1RM power snatch, isometric MTP peak force, dynamic MTP peak RFD, and throwing performance in track and field throwers. Hellard et al. (2013) monitored 32 male and female elite swimmers during 6-week periods (3-week overreach, 3-week taper) prior to a major competition with competitions before and after each 3-week period. The training pattern that resulted in the greatest improvement in swimming performance following an overreaching period was a peak in training load the first week followed by a linear slow decay during the following 2 weeks of the overreach. The training pattern associated with greatest improvements in performance following tapering periods was a training load peak during the first week followed by a slow decay. Importantly, they found that a moderate training load during the overreach that was sustained during the taper was more beneficial earlier in the athlete's career, while a large increase in training load during the overreach and a steep decrease during the taper was more beneficial later in their career. In a simulation study, Banister et al. (1999) found that an exponential reduction in training volume was more effective than a step-taper in improving endurance performance.

These findings were confirmed a group of triathletes; the exponential reduction in training load resulted in a significantly greater improvement in a cycle to exhaustion than the step-taper. Additionally, the fast exponential taper was more effective than the slow exponential taper at improving cycling time to exhaustion, but not 5 km time trial performance. The above findings demonstrate the efficacy of a peaking phase for improving maximal strength, endurance, and explosive ability in a wide range of individual event performances.

<u>Team Sport</u>

To assess the effects of tapering on maximal strength, Izqueirdo et al. (2007) had 11 national Basque ball players perform a 4-week taper involving a progressive increase in training intensity and decrease in volume. The taper resulted in statistical improvements in 1RM half squat and bench press. In the only known study examining ORT responses in volleyball athletes, Freitas et al. (2014) found significantly greater creatine kinase, RPETL, training monotony, and training strain in half of a team of male volleyball players who performed an 11-day overreach compared to the other half of the team who continued with normal training. The authors concluded that CMJ performance should not be used to evaluate training adaptations in volleyball athletes because no significant within-group changes were observed in JH during the overreach or the 14-day taper that followed. In contrast, Claudino et al. (2016) showed that monitoring CMJ JH using the minimal detectable difference could be used to regulate a training phase that elicited FOR and tapering in team sport athletes. The authors divided 17 male futsal players into a control and regulated group. The weekly training load in the regulated group was determined using weekly CMJ results; no changes in CMJ height were observed in the control group during the 2-week taper, whereas the regulated group increased CMJ JH during week 2 of the taper. Gibson et al. (2016) recently demonstrated that CMJ JH can be preserved in elite rugby

sevens players during a 3-week period prior to international competitions when training load is managed appropriately. Coutts et al. (2007) found significance decreases in distance covered during a multi-stage fitness test, meaningful decreases in vertical jump, 3RM squat, 3RM bench press, and chin-ups to failure following a 6-week overreaching phase in trained rugby players. Values during each test tended to return to baseline following a 1-week taper; it is likely the taper was not long enough for athletes to fully recover from the overreach. The above findings show disparate results for ORT with team sport athletes with some studies showing an increase, decrease, or no change in sport-related performance measures. Future research should address what factors explain differences in how athletes within a team respond to a peaking phase.

<u>Conclusion</u>

The purpose of this dissertation is to examine changes following a peaking phase in individual event and team sport strength-power athletes. We can conclude the following from the literature review: 1) A peaking phase prior to important competitions has been shown to alter mechanistic variables and performance outcomes in endurance and strength-power athletes, 2) These mechanistic variables include profound changes to an athlete's muscle contractile properties, motor output, and biochemical profile that partially explain the observed changes in performance, 3) There are clear beneficial performance outcomes in individual event athletes following a peaking phase; however, sport-related performance changes in team sport athletes are less clear.

CHAPTER 3

CHANGES IN MUSCLE ARCHITECTURE, EXPLOSIVE ABILITY, AND THROWING

PERFORMANCE IN NCAA DIVISION I TRACK AND FIELD THROWERS

THROUGHOUT A COMPETITIVE SEASON AND FOLLOWING A TAPER

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ABSTRACT

The purpose of this study was to examine the effects of a coach-designed overreach and taper on measures of muscle architecture, jumping, and throwing performance in Division I collegiate throwers preparing for conference championships. Six collegiate track and field throwers (3 hammer, 2 discus, 1 javelin) trained for 12 weeks using a block-periodization model culminating with a one week overreach followed by a 3 week taper (ORT). Session rating of perceived exertion training load (RPETL) and strength training volume-load times bar displacement (VLd) were recorded weekly. Athletes were tested pre- and post-ORT on measures of vastus lateralis architecture, squat and countermovement jump performance with 0kg and 40kg, underhand and overhead throwing performance, and competition throwing performance. There was a statistical reduction in weight training VLd/session (d=1.21, $p<0.05$) and RPETL/session (d=0.9, $p<0.05$) between the in-season and ORT training phases. Five of six athletes improved overhead throw and competition throwing performance following the ORT (d=0.50, $p<0.05$). Vastus lateralis muscle thickness statistically increased following the in-season training phase (d=0.28, $p<0.05$), but did not change following the ORT. Unloaded countermovement jump peak force and relative peak power improved significantly following the ORT (d=0.59, $p<0.05$, d=0.31, $p<0.05$, respectively). These findings demonstrate that an overreaching week followed by a 3-week taper is an effective means of improving explosive ability and throwing performance in collegiate track and field throwers despite the absence of detectable changes in muscle architecture.

KEYWORDS: *muscle thickness, overreaching, strength training, hammer, discus, javelin*

The tapering period presents a unique opportunity for athletes to maximize performance for a crucial competitive event (7, 22, 27). Tapering involves the manipulation of various factors including training volume, intensity, frequency, and duration (27). Based on a meta-analysis, Bosquet et al. (7) reported the largest magnitude of change in endurance performance following a 2-week taper where training volume was exponentially reduced by 41-60%, without any modification in training intensity or frequency. The magnitude of change in swimming, cycling, rowing, running, and triathlon performance following the taper was ~3% (0.5-6%) (27). Previous investigations on tapering for sport performance have mostly involved endurance athletes and current tapering recommendations are based on these studies (4, 22, 27). Because limited research exists examining the efficacy of tapering for strength-power athletes no evidence based tapering standards have been established, although recommendations have been made similar to those for endurance performance (30).

Track and field throwing events require athletes to generate high force outputs over a short time period (<250ms) (42). It has been previously established that neuromuscular fatigue negatively affects rate of force development (RFD) during maximal leg extension tasks (24, 45). Thus, the taper provides an opportunity for throwers to dissipate fatigue and express higher RFDs. This was demonstrated recently by Zaras et al. (43) who reported improved throwing performance following a 2-week taper in collegiate throwers regardless of the resistance training intensity. However, heavy resistance training (>85% 1-RM (repetition maximum)) resulted in greater improvements in leg press 1-RM, RFD, squat jump power, and shot throws than light resistance training (30% 1-RM). These findings are corroborated by Stone et al. (34), who demonstrated strong positive relationships among maximal strength (isometric mid-thigh pull

peak force), dynamic mid-thigh pull peak power, and throwing performance (shot-put and weight throw) in collegiate throwers. In this study, the overreach and taper period (strength-power block) resulted in improved 1-RM power snatch, isometric mid-thigh pull peak force, dynamic mid-thigh pull peak RFD, and throwing performance. In contrast, a 4-week detraining period following 14 weeks of strength training has been shown to decrease 1-RM squat, backward overhead throw and squat underhand throw in novices (37). These studies highlight the importance of tapering for maximizing throwing performance.

Tapering for strength-power athletes not only involves a reduction in training volume, but should also involve a greater emphasis on power development (33). These stimuli result in specific neuromuscular adaptations that may explain the performance improvements following the taper. These adaptations include increased muscle shortening velocities resulting from a myosin isoform shift (Type IIa to IIx) (3, 37), and increased fascicle length (FL) (2, 6), increased myosin heavy chain (MHC) IIa fiber size, peak force and absolute power (23, 39), altered regulation of growth-related genes in MHC IIa fibers (23, 28), and increased muscle activation (15).

Research on single-fiber gene expression and mechanical characteristics has provided great insight into the mechanisms underlying the performance enhancing effects of the taper (23, 28, 39). However, this process is expensive, invasive, requires highly trained personnel, and coaches who are willing to allow their athletes to participate in the rigors of such testing. Over the past few decades, ultrasonography has been used as a reliable, less invasive method of determining changes in muscle architecture following training (19, 20, 41, 44). Increases in muscle thickness (MT) and pennation angle (PA) have been observed following heavy strength training (1, 20); however, studies where subjects trained with high-velocity contractions and

lighter loads (<60% 1-RM) have reported increases in FL with no changes in PA (2, 6).

Moderate to strong relationships have been observed between vastus lateralis MT and 1-RM

back squat and deadlift (r=0.82, 0.79), squat and countermovement jump (SJ and CMJ,

respectively) height (r=0.63-0.8), isometric mid-thigh pull peak force (r=0.6), isometric leg press

peak force (r=0.85), hang power clean (r=0.71), relative 1-RM power clean (r=0.51) and shot-

put front throw (r=0.66) in various groups of athletes (8, 25, 31, 44). Recently, Zaras et al. (44)

reported no statistical alterations in muscle architecture (MT, PA, or FL) following the taper. The

lack of observable changes may have been due to the short duration of the taper (2 weeks).

Further research is needed examining the effects of tapering on muscle architecture.

Furthermore, there is a paucity of research examining the efficacy of training programs

implemented by coaches with their athletes. Previous training studies with athletes have been

concerned with determining the outcome of an intervention with strict internal controls rather

than preserving ecological validity (29, 35). While these investigations are important for

establishing causality, studies with greater ecological validity are also necessary for greater

external validity to athletic populations, educating coaches, and developing relevant research

questions for future inquiry. There is often a disconnect between what track and field coaches

typically implement in their training, and what current research advocates for the development of

strength and power with these athletes (9, 11). Further research is needed to bridge this gap, and

enhance coaches' education. Thus, the purpose of this study was to examine the effects of an

overreach and taper (ORT) on measures of muscle architecture, jumping, and throwing

performance in Division I collegiate throwers preparing for conference championships. Based on

previous training studies (1, 2, 6), we hypothesized that MT and PA would increase following

the pre/in-season training period (strength-endurance and strength emphasis blocks) and FL

would increase following the ORT (strength-power emphasized block). Corresponding with the changes in FL, we also hypothesized CMJ and SJ variables, overhead shot-put throw (OHT), underhand shot-put throw (UHT), and competition throwing performance (TP) would increase following the ORT.

<div align="center">METHODS</div>

Experimental Approach to the Problem

A repeated measures design was used to examine the effect of the ORT on muscle characteristics, jumping and throwing performance measures. The study was conducted over a 12-week period consisting of the pre-season (3 weeks) and outdoor track and field competitive season (9 weeks). Athletes were tested at the beginning of the pre-season to use as a baseline (T_1) for comparing pre-ORT (T_2) and post-ORT (T_3) testing.

Athletes

Seven National Collegiate Athletic Association (NCAA) Division I throwers were recruited for the study; however, one athlete failed to complete the final testing session, therefore only 6 were included in the analyses (4 male: 2 hammer, 2 discus; 2 female: 1 javelin, 1 hammer) (20.6 ± 0.93 years, 182.3 ± 8.3 cm, 103.2 ± 23.1 kg). All 6 athletes were healthy and received no nutritional supplements during the study period. All athletes signed an informed consent in accordance with the guidelines set forth by the university's Institutional Review Board.

Training

The throwers strength trained using a block periodization model comprised of sequenced phases: strength-endurance, strength, and power over a 12-week period (Table 3.1). Maximal strength was increased prior to explosiveness development through a combination of traditional resistance training and weightlifting exercises using relative intensities to calculate loads. The

first 3 weeks were part of the specific preparation phase, and the following 9 weeks were part of the outdoor track and field competitive season. During the specific preparation phase, emphasis was placed on preparing the athletes for the competitive season. During the competitive season, strength training volume was reduced and emphasis was placed on throw training and technique. Strength training was conducted 2-4 days per week. Throwing training was implemented by the coach 2-3 days per week. Prior to the taper, an overreaching week of increased strength training volume was implemented at the coaches' discretion. During the 3-week taper, training volume was reduced exponentially leading up to the conference championship (Figure 3.1a and 3.1b). The ORT implemented in this study was similar to the strength-power block performed by the throwers in Stone et al. (34).
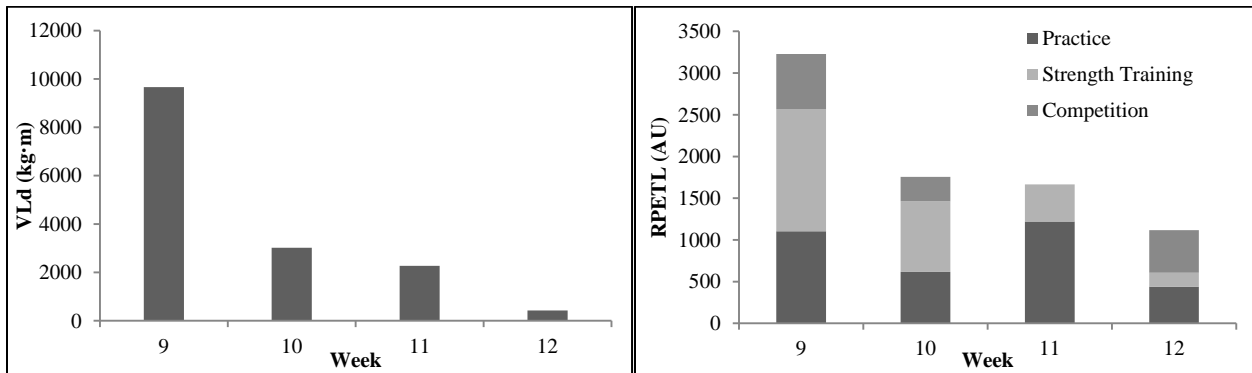
Figure 3.1a and 3.1b: Exponential reduction in strength training VLd and RPETL during ORT. VLd-volume-load multiplied by bar displacement, RPETL- rating of perceived exertion training load, ORT-overreach and taper

Table 3.1 Training program

	Strength Training (1-3 days)	SetxRep	Relative Intensity	Throwing Drills (2-3 days)	Conditioning (1-2 days)
Week 1	BS, PP, IBP, CP, SLDL, BOR, PU	3x10	MH (85-90%)	turns with implement (no throws) 10x5, knee drop drill 5x5, half turn drill 3x5, clock drill 3x5	sprints- 2x10, 15m, 1x20m; jumps- 4-stair and unilateral 2 stair 2x6, hurdle hops 3x5
Week 2	same as week 1	3x10	H (90-95%)	same as week 1	same as week 1
Week 3	same as week 1	3x5	L (70-75%)	turns with implement (no throws) 10x5, knee drop drill 5x5; clock drill 3x5, half turns 2-5reps, 3/4 turns 2-5reps, 5-10 full throws	none
Week 4	1/2 squat w/ext., PJ, FS, CGBP, IBP, MTP, SP, BOR, SLDL, PU	5x5	MH (85-90%)	knee drops 2x5, turn with implement 2x5, partial throws 3-5, 3/4 turns 3-6, 10 full throws	sprints- 2x10, 15m; jumps- 4-stair 4x6, unilateral 2 stair 2x6, single-leg broad jump 3x3
Week 5	same as week 4	3x5	H (90-95%)	knee drops 2x5, turn with implement 2x5, partial throws 3-5, 2-3 half turns, 3-6 reps ¾ turns, 15 full throws	same as week 1
Week 6	same as week 4	3x5	VH (95-100%)	same as week 5	same as week 1
Week 7	1/2 squat w/ext., PJ, FS, CGBP, IBP, MTP, SP, BOR, SLDL, PU	3x5	L (70-75%)	2x5 knee drops, turn with implement 2x5, 2 standing throws, 2 half turns, 3 reps ¾ turns, 3 partial throws, 5 full throws	
Week 8	1/4 squat w/ext., SJ, BS, IBP, PC, SP, SLDL, PU, PP, MTP	3x3	M (80-85%)	2x5 knee drops, 2x5 of turn with implement, 2-3 standing throws, 2-3 half turns, 3-6 reps ¾ turns, 3-5 partial throws, 15 full throws	same as week 1
Week 9	1/4 squat w/ext., 1/2 squat w/ext. SJ, IBP, PC, SP, CP, BOR, PU	5x5	MH (85-90%)	turn with implement 2x5, 2-3 standing throws, 2-3 step-half turns, 3-6 reps ¾ turns, 3-5 partial throws, 15 full throws	Sprints- 2x10m, 15, 20, 1x30m; Jumps- 4-stair 4x6, unilateral 2 stair 2x6, single-leg lateral jumps 2x5, hurdle hops 3x5
Week 10	1/4 squat w/ext., SJ, IBP, PC, SP, BOR, PU	3x3	H (90-95%)	same as week 9	same as week 9
Week 11	1/4 squat w/ext., SJ, IBP, PC, SP, BOR, PU, PP, MTP	3x2	MH (85-90%)	3 partial throws, 1-2 standing throws, 2-3 step-half turns, 5-10 full throws	same as week 9 plus broad to vertical jumps 2x3
Week 12	1/4 squat w/ext., SJ, IBP, EPU	2x2	ML (75-80%)	1-3 partial throws, 1-2 standing throws, 1-2 half turns, 1 3/4 turn, 3-5 full throws; mock competition to preparation for conference championship	none

BS-back squat, PP-push press, IBP-incline bench press, CP-clean pull, SLDL-stiff-leg deadlift, BOR-bent over row, PU-pull-up, PJ-push jerk, FS-front squat, CGBP-clean grip bench press, MTP-mid-thigh pull, SP-snatch pull, PC-power clean, SJ-split jerk, EPU-explosive push-ups

<u>Training Load</u>

Internal training load was estimated using a session rating of perceived exertion (sRPE) collected on a 1-10 subjective scale. Based on previously established methods, sRPE was multiplied by the duration of the session in minutes to form a rating of perceived exertion training load (RPETL) for all competitions practices, and strength training sessions (12). Strength training volume load (VLd) was recorded weekly for 12 weeks for all barbell lifts and was calculated using the following equation (14):

Volume Load (kg*m) = Mass of External Load (kg) x Repetitions x Displacement (m)

Vertical bar displacement was measured with a tape measure from the start position to terminal position of the eccentric phase. Total RPETL and VLd were scaled per session for each athlete to compare training volume completed between testing time points (T_1-T_2 compared to T_2-T_3).

<u>Testing</u>

Testing occurred at the beginning of each training week at least 48 hours following a competition and after a scheduled off day from training. Athletes were instructed to refrain from practicing and strength training 24 hours prior to each testing session. Athletes were given a 24-hour dietary log to complete prior to T_1 and were instructed to replicate the log prior to all subsequent testing sessions. Athletes were tested on measures of vastus lateralis MT, PA, FL, squat jump height (SJH), peak power and peak force allometrically scaled for body mass (SJPP, and SJPF, respectively), and countermovement jump height (CMJH), peak power and peak force allometrically scaled for body mass (CMJPP, CMJPF, respectively). Both jump conditions were performed with 0kg and 40kg. Additionally, OHT, and UHT were performed at all three testing sessions (T_1, T_2 and T_3). Throwing performance was the best throw recorded at scheduled outdoor competitions pre- and post-taper (T_2 and T_3).

Anthropometrics. Body mass was measured using a digital scale (Tanita B.F. 350, Tanita Corp. of America, Inc., Arlington Heights, IL), and percent body fat was estimated from the sum

of 7 skinfold sites using a skinfold caliper (Lange, Beta Technology Inc., Cambridge, MD) (5).

All anthropometrics were measured at the same time of day by the same experienced assistant

for all testing sessions.

Muscle Architecture. Following anthropometric measures, muscle architecture

measurements of MT, PA, and FL were collected using non-invasive ultrasonography by the

same technician. Subjects laid supine with knees fully extended, and sampling location for the

vastus lateralis was determined by the point of intersection between the VL and 50% of the

distance between the greater trochanter and the lateral epicondyle of the femur (21). This

location was marked with permanent ink and the probe oriented longitudinally in the sagittal

plane, parallel to the muscle for each sample. The femur length of each athlete was recorded and

used for subsequent testing sessions to ensure proper placement of the probe. Muscle thickness

and PA were quantified in still images captured longitudinally in the transverse plane using the

measuring features of the ultrasound machine. Muscle thickness was determined as the distance

between subcutaneous adipose tissue-muscle interface and inter-muscular interface, and PA was

determined as the angles between the echoes of the deep aponeurosis of the muscle and the

echoes from interspaces among the fascicles (41). Fascicle length was calculated from MT and

PA using the following equation (21):

$$FL = MT \cdot SIN \, (PA)^{-1}$$

The ultrasound examiner took five images from each sonogram and those which showed the

largest and the smallest muscle thickness were excluded. The means of MT, PA, and FL were

assessed from the three remaining images (2). Repeated measurements yielded a coefficient of

variation of 0.05%, 2.6%, and 1.0% for MT, PA, and FL, respectively.

Squat and Countermovement Jumps. Following a dynamic warm-up, SJs with 0kg and 40kg were measured using dual force plates affixed side by side with a sampling frequency of 1000 Hz (Rice Lake, WI). The tester instructed the athlete to perform a squat to 90° of knee flexion, measured using a handheld goniometer, and hold the position until the force-time trace was stable. Once the force-time trace was stable, the tester shouted "3,2,1...jump" and the athlete performed a maximal effort jump. Countermovement jumps with 0kg, and 40kg were performed following SJs. During the CMJ the athletes were instructed to remain stable in an upright position. Once the force-time trace was stable the tester shouted "3,2,1...jump" and the athlete performed a maximal CMJ from a self-selected depth. All jump trials were recorded and analyzed using a custom program (LabView 8.5.1, 8.6, and 2010, National Instruments Co., Austin, TX). Jump height was estimated from flight time using the formula: $g \cdot \text{flight time}^2 \cdot 8^{-1}$, where "g" is the acceleration due to gravity. The average of two trials within 2cm was used for analysis. Additional trials were performed when the difference in jump height between trials was greater than 2cm. Peak power was determined as the maximal value obtained from the product of the velocity-time and force-time trace and was allometrically scaled for athlete's body mass.

Shot-Put Tests. Following the laboratory tests, athletes were tested on overhead shot put throw (OHT) and underhand shot put throw (UHT) with a 7.26kg implement measured on the same indoor throwing ring. These tests have been used previously to measure changes in throwing performance in field athletes (37, 42). The OHT and UHT have also been shown to correlate strongly with shot-put performance (36), and exhibit moderate to strong relationships with MT measured via ultrasonography (44). A familiarization period was not prescribed as the athletes regularly performed these throwing movements in their daily training warm-up. Athletes were given at least 2 attempts for each throw with full recovery between throws. The average of

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two throws within 30cm was used for analysis. Additional throws were performed when the difference between throws was greater than 30cm.

 Competition Throwing Performance. Throwing performance was measured during two regularly scheduled outdoor competitions pre- and post-ORT (T_2 and T_3) according to NCAA track and field rules. After completing a dynamic warm-up followed by 2-4 standing and partial throws, athletes performed 3-6 maximal effort throws. Considering the athletes specialized in different events, TP was normalized across events using z-scores calculated from the top 500 throws/year in division I over the past 5 years (z-score: -1.28 ± 0.99). The best competition throw was converted to a z-score and used for statistical analysis.

Statistical Analyses

 All data are reported as mean ± standard deviation (SD). Intraclass correlation coefficients (ICCs) for all dependent variables ranged from 0.96 to 0.99. A Shapiro-Wilks normality test was used to determine if the data were normally distributed. One-way repeated measures ANOVA were calculated for all dependent variables to determine if there was a main effect for time. Mauchly's test of sphericity was calculated for the repeated measures analysis to determine if the variance between all possible pairs of levels of the independent variable (time) were equal. Pairwise comparisons between time points were calculated for all dependent variables. Considering the exploratory nature of the study and to reduce the probability of committing a Type II error, no correction was made for multiple comparisons. Alpha level for all analyses was set at p≤0.05. Cohen's *d* with 95% confidence intervals (CI) were calculated from mean differences of all pairwise comparisons and were used to determine the magnitude of performance change. Effect sizes values of 0.0, 0.2, 0.6, 1.2, 2.0, and 4.0 were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively (18). Analyses were

performed using SPSS software version 22 (IBM Co., New York, NY, USA), and Microsoft

Excel 2010 version 14 (Microsoft Corporation, Redmond, WA, USA).

RESULTS

There was a statistical reduction in weight training VLd/session (d=1.21, 95% CI [0.41, 2.0], p=0.01) and RPETL/session (d=0.96 [0.07, 1.9], p=0.04) between in-season (T_1-T_2) and ORT (T_2-T_3) training phases. There were statistical time effects for MT ($F_{(2,10)}$=4.703 p=0.04), CMJPP 0kg ($F_{(2,12)}$=4.187, p=0.04), and CMJPF 0kg ($F_{(2,10)}$=7.051, p=0.01). Fisher's least significant difference revealed statistical improvements with small to moderate effect sizes for MT (T_1-T_2: d=0.28 [0.04, 0.52], p=0.03; T_1-T_3: d=0.41 [0.15, 0.67], p=0.01) (Figure 3.2), CMJPP with 0kg (T_2-T_3: d=0.31 [0.02, 0.6], p=0.04), CMJPF 0kg (T_2-T_3: d=0.59 [0.21, 0.97], p=0.01; T_1-T_3: d=0.43 [0.03, 0.83], p=0.04) (Figure 3.3), and TP (T_2-T_3: d=0.50 [0.03, 0.97], p=0.04) (Table 3.2). The average percentage improvement in TP was 6.3%. It is also worth noting 5 out of 6 athletes improved OHT and TP pre- to post-ORT (Figure 3.4).

Table 3.2 Changes in dependent variables (mean±SD)

	T_1	T_2	T_3
Anthropometrics			
Mass (kg)	103.23±23.14	102.63±24.22	102.49±23.56
Body Fat (%)	21.58±8.37	21.85±8.86	21.52±9.05
Muscle Architecture			
Thickness (cm)	2.66±0.45	2.78±0.5*	2.84±0.5*
Pennation Angle (degrees)	21.74±4.46	22.57±2.28	21.58±4.23
Fascicle Length (cm)	7.42±2.06	7.28±1.3	7.85±1.18
Jumps			
SJH 0kg (m)	0.28±0.07	0.27±0.08	0.27±0.08
SJPP 0kg (W/kg$^{0.67}$)	217.57±52.15	213.36±51.76	220.17±58.53
SJPF 0kg (N/kg$^{0.67}$)	102.09±16.24	101.14±14.9	104.04±16.21
SJH 40kg (m)	0.17±0.05	0.16±0.05	0.17±0.06
SJPP 40kg (W/kg$^{0.67}$)	208.24±53.66	209.48±52.74	211.51±61.47
SJPF 40kg (N/kg$^{0.67}$)	117.9±14.92	117.51±13.04	120.59±13.46[#]
CMJH 0kg (m)	0.32±0.08	0.31±0.09	0.33±0.1
CMJPP 0kg (W/kg$^{0.67}$)	230.08±54.46	223.26±46.63	237.81±60.78[#]
CMJPF 0kg (N/kg$^{0.67}$)	101.91±10.87	99.49±11.99	106.56±14.07*[#]
CMJH 40kg (m)	0.19±0.06	0.19±0.06	0.2±0.07
CMJPP 40kg (W/kg$^{0.67}$)	222.75±57.38	222.34±45.12	227.9±57.63
CMJPF 40kg (N/kg$^{0.67}$)	116.06±10.23	114.89±8.07	119.57±8.67[#]
Throws			
OHT (m)	11.88±2.35	11.83±2.29	12.43±3.35
UHT (m)	11.25±2.14	11.61±2.63	11.48±2.47
TP (z-score)		-1.22±1.07	-0.68±1.1[#]

*significantly different from T1 (p<0.05), #significantly different from T2 (p<0.05), SJH-squat jump height, SJPP-squat jump peak power, SJPF-squat jump peak force; CMJH-countermovement jump height; CMJPP-countermovement jump peak power; CMJPF-countermovement jump peak force; OHT-overhead throw; UHT-underhand throw, TP-competition throwing performance
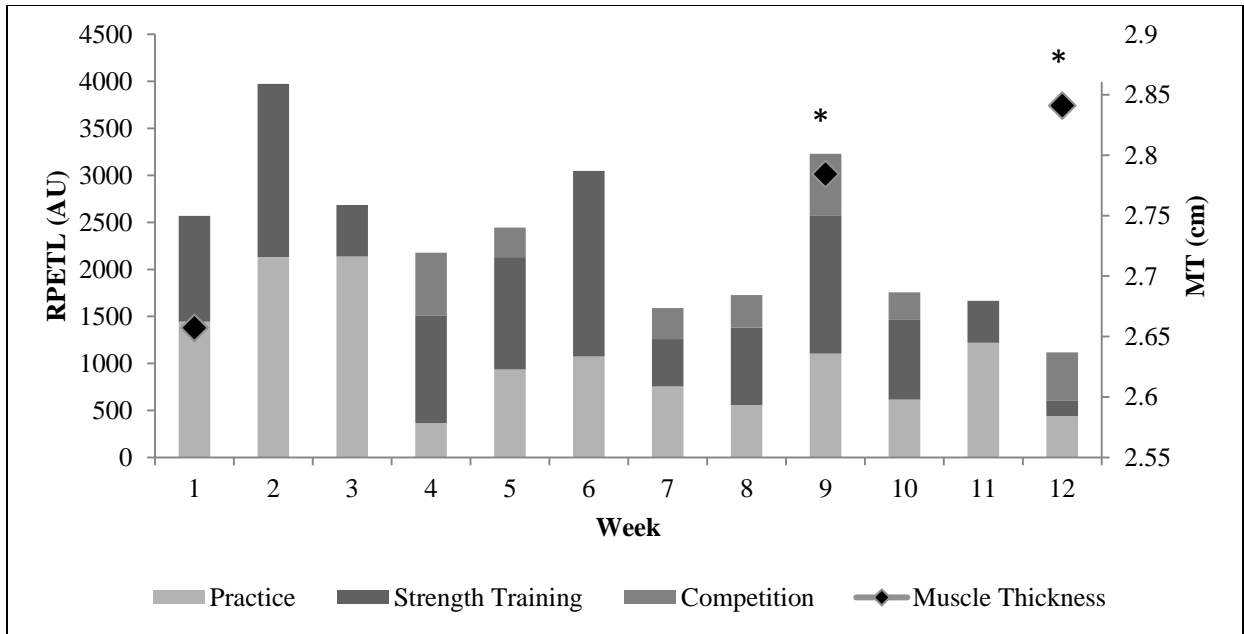
Figure 3.2: Changes in MT overlaying weekly RPETL. *significantly different from T_1 (p<0.05). MT-muscle thickness, RPETL- rating of perceived exertion training load
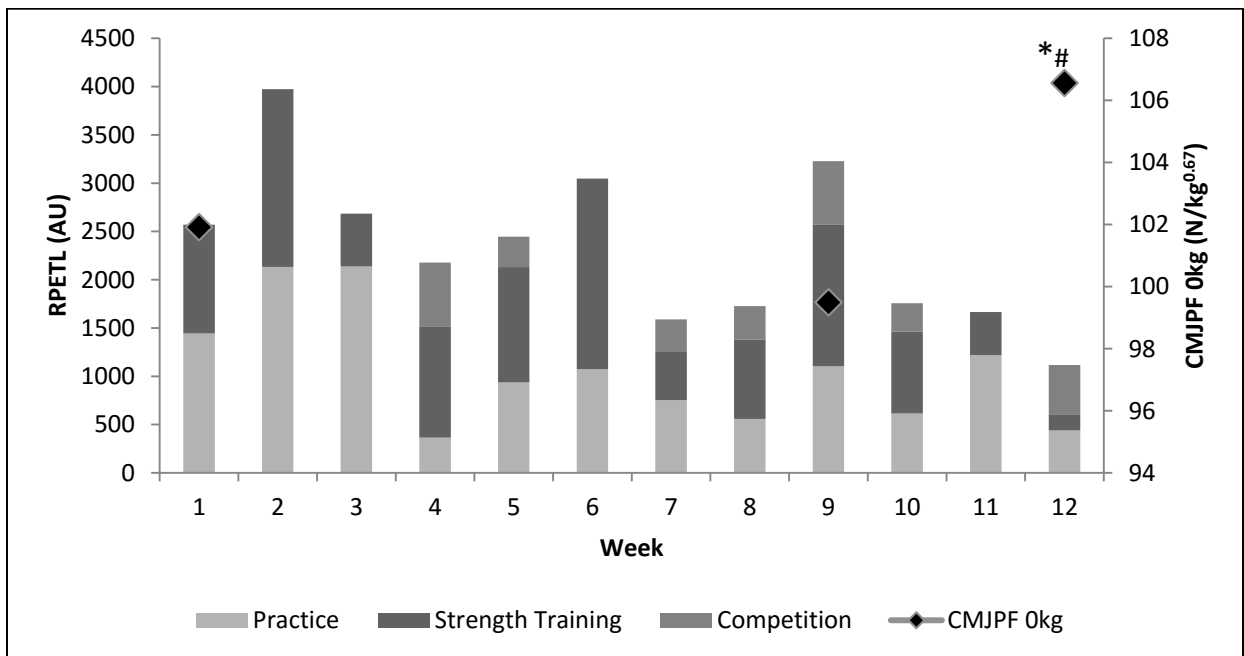
Figure 3.3: Changes in CMJPF 0kg overlaying weekly RPETL. *significantly different from T_1 (p<0.05), #significantly different from T_2 (p<0.05). CMJPF-countermovement jump relative peak force, RPETL-rating of perceived exertion training load
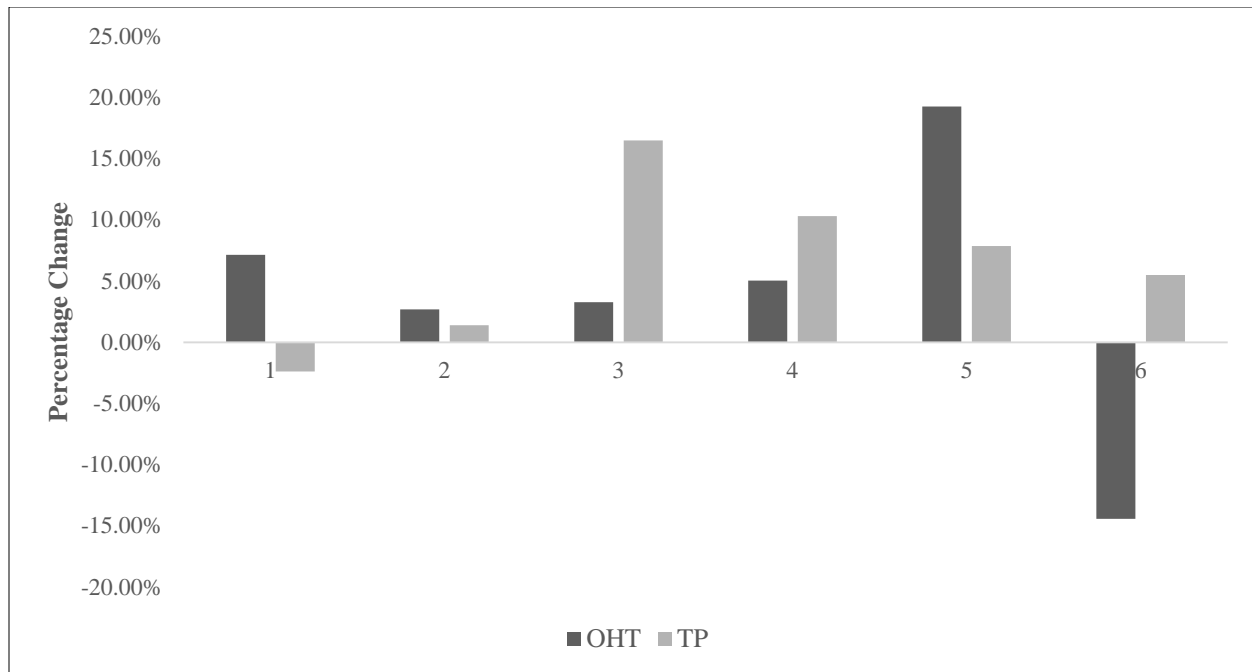
Figure 3.4: Individual changes in OHT and TP following ORT. OHT-overhead throw, TP-competition throwing performance, ORT-overreach and taper

DISCUSSION

The purpose of this study was to examine the effects of a coach-designed overreaching week followed by a 3-week taper on measures of muscle architecture, jumping, and throwing performance in NCAA division I collegiate throwers preparing for conference championships. The primary findings of this investigation are: 1) Increases in vastus lateralis MT and PA following in-season training without any further alterations in muscle architecture after the ORT, and 2) enhanced TP, CMJPF 0kg, and CMJPP 0kg following the ORT. Previous investigations have reported similar improvements in strength and power outcomes following a tapering period (34, 43). A finding unique to this study is the significant increase in vastus lateralis MT corresponding with the greater weight training VL/session during the in-season training period compared to the ORT.

These findings agree with previous research showing that there is lag time between the initiation of a training stimulus and when its effects are realized (16, 40). This concept, known as the long-term lag of the training effect, was originally proposed by Verkhoshansky (40) and forms the basis of block periodization. This is evidenced by the improvements in measures of throwing performance and explosive ability following the ORT even though weight training VLd/session and RPETL/session were statistically reduced and there were no further observable alterations in MT.

Increases in MT measured via ultrasonography have been observed following heavy strength training (1, 20). Additionally, previous investigations have reported strong positive correlations between vastus lateralis MT and the maximal isometric leg extension force (44). Therefore, it appears the increases in MT during the pre/in-season training period may have facilitated the later improvements in TP, CMJPP 0kg, and CMJPF 0kg following the ORT. In agreement with Zaras et al. (44), no statistical alterations in muscle architecture (MT, PA, or FL) were found following the tapering period. Blazevich et al. (6) reported increases in vastus lateralis FL and MT following 5 weeks of sprint/jump training with athletes; however, groups performing concurrent strength training and sprint/jump training increased PA and MT. In the present study, strength and plyometric training volumes were statistically reduced during the ORT, which may have attenuated further alterations in muscle architecture.

Training volume reductions coupled with greater emphasis on developing neuromuscular power have been shown to result in myosin isoform shifts (IIa to IIx) (37), increases in MHC IIa fiber size, peak force and absolute power (23, 39), and greater muscle activation (15). Considering the training performed during the taper in the present study, these adaptations may also be responsible for the observed performance improvements. However, these adaptations

were not quantified in the current investigation. Future research is necessary examining changes in electromyographic activity, spinal and supra-spinal fatigue, muscle fiber gene expression and contractile properties during the taper with strength-power athletes.

It has long been believed by coaches and researchers that a period of intensified training prior to a taper (i.e. an overreach) will result in a greater supercompensation effect (17, 32, 38). Functional overreaching results in an initial decrease in performance that is reversed and is often accompanied by supercompensation following a short rest period. During non-functional overreaching the recovery period is delayed and takes longer than desired with no performance supercompensation (26). While overreaching has been shown to be an effective means of improving endurance parameters and performance during a taper (4, 17, 38), limited evidence exists supporting its efficacy with strength-power athletes (10, 13, 32). It is important to note that CMJPF 0kg is the only variable that exhibited an observable supercompensation over baseline values following the ORT. Also, it is unclear whether the overreaching week prior to the taper was responsible for the performance improvements. Experimental studies with strength-power athletes comparing tapering with and without a prior overreaching phase are necessary.

Mujika and Padilla (27) stated a realistic performance improvement to expect following a taper is ~3% (0.5-6%) based on a review of the tapering literature with swimmers, runners, cyclists, rowers, and triathletes. The findings of the current study agree with Zaras et al. (43) and Stone et al. (34), who reported enhanced throwing performance following the tapering period in collegiate throwers. Zaras and colleagues reported a mean performance improvement of 5.2% following the taper with national level throwers. Stone and colleagues observed a shot put throw improvement of 3.1% and weight throw improvement of 4.3% following an overreach and taper with collegiate throwers. A similar mean improvement of 6.3% was found in the current study

following the taper. Considering the difference between first and fourth place for men's discus at the 2015 NCAA division I national championships was <2.5%, the taper could make the difference between winning a medal or failing to make the podium.

In conclusion, the pre/in-season training appeared to elicit increases in MT, whereas the ORT resulted in improved explosive ability in the absence of further detectable changes in muscle architecture. Additionally, the ORT appeared to augment TP at the conference championships and national ranking, which may have been due to the reduced RPETL and VLd. Collegiate throwers may benefit from an ORT phase where training load is exponentially reduced prior to an important competition.

<div align="center">PRACTICAL APPLICATIONS</div>

The findings of this study show that an overreaching week followed by a 3-week taper is an effective means of improving explosive ability and throwing performance in collegiate track and field throwers. Coaches working with collegiate throwers should develop an annual plan based on the athlete's competition schedule and highlight the most important competition(s) to appropriately plan the taper. During the taper, coaches should significantly reduce training volume while maintaining or increasing relative training intensity (≥85% 1-RM). Greater emphasis should be placed on developing neuromuscular power using variations of the weightlifting movements, potentiation complexes, ballistic and plyometric drills performed with maximal movement intent. Based on this study and previous findings with track and field throwers, coaches and athletes can realistically expect a 3.1-6.3% performance improvement following the taper.

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CHAPTER 4

CHANGES IN MUSCLE ARCHITECTURE AND EXPLOSIVE ABILITY IN NCAA

DIVISON I WOMEN'S VOLLEYBALL ATHLETES THROUGHOUT A COMPETITIVE

SEASON AND FOLLOWING A TAPER.

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ABSTRACT

PURPOSE: The purpose was to examine changes in muscle architecture and explosive ability in NCAA division I collegiate volleyball players throughout a competitive season. METHODS: Ten female volleyball players (20.4 ± 1.1 y, 178.3 ± 4.8 cm, 72.6 ± 5.3 kg) were tested at pre-season (T1), pre-taper (T2), and post-taper (T3) on measures of vastus lateralis muscle thickness (MT), pennation angle (PA) and fascicle length (FL) using ultrasonography, and unloaded and loaded squat jump height (SJH) and peak power allometrically scaled for body mass (SJPPa) on a force platform. Total rating of perceived exertion training load (RPETL) and strength training volume-load multiplied by displacement (VLd) were monitored weekly. RESULTS: There was a reduction in VLd/wk ($p<0.001$, d=3.1) and RPETL/wk ($p<0.001$, d=2.7) between in-season (T1-T2) and tapering (T2-T3) training phases. Athlete's MT ($p<0.001$, d=2.8) and PA increased (p=0.02, d=3.9) following in-season training. However, MT decreased following the taper (p=0.01, d=0.6), but remained elevated above pre-season values ($p<0.001$, d=1.7). There were no statistical changes in FL, SJH or SJPPa. Large to very large, negative relationships (r=-0.51 to -0.81) were observed between relative maximal strength at T1 and changes in SJH and SJPPa with various loads over the season. CONCLUSION: In-season training resulted in favorable changes in muscle architecture, which remained elevated above pre-season values following the taper; however, these changes did not appear to appreciably alter explosive ability throughout the competitive season. Stronger athletes may benefit from an overreaching microcycle prior to the taper to preserve previously accrued muscular adaptations and explosive ability.

Keywords: *jump height, peak power, muscle thickness, strength, training load*

INTRODUCTION

Volleyball is a sport characterized by intermittent bouts of jumping, short sprints, diving, blocking, and hitting. The average work to rest ratio during a volleyball match ranges from 1:1-1:3 with rallies lasting 6-10 s interspersed with 11-15 s rest periods. [1] Depending on the number of sets played, matches can last 2-3 hours. [1,2] Based on these observations, it is clear that volleyball athletes must possess the ability to repeat high power outputs over long periods of time. Previous research has also demonstrated a positive relationship between volleyball-specific fitness characteristics (countermovement jump height and take-off velocity, maximal strength, and motor coordination) and performance indicators (spike velocity, spike jump reach, impact height, and level of achievement). [3-5] Additionally, higher level performers exhibit greater spike velocities, jump heights, impact heights and lower body fat percentages compared to lower level performers. [3,6,7] These findings demonstrate the importance of enhancing these volleyball-specific fitness characteristics.

The tapering period presents an opportunity to enhance these volleyball-specific fitness characteristics by reducing training load and fatigue prior to the most important matches at the end of the competitive season. While numerous studies have demonstrated the beneficial effects of tapering on endurance performance [8-13] and have examined possible underlying mechanisms, [14-21] similar studies with team sport athletes are scarce. [22-25] To our knowledge, only one published study has examined mechanistic and performance changes in volleyball athletes following the taper. [25]

Ultrasonography has commonly been used to assess changes in an athlete's muscle architectural properties following training. Increases in muscle thickness (MT) and pennation angle (PA) have been observed following heavy strength training [26-28]; however, studies where

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subjects trained with high-velocity contractions (e.g. sprint/jump training) and lighter loads (<60% 1-RM) have reported increases in fascicle length (FL) with no changes in PA. [29,30] Previous evidence has also demonstrated contraction mode specific alterations in PA and FL. Specifically, Franchi et al. [31] have demonstrated eccentric loading of the knee extensors increases vastus lateralis FL and heavy concentric loading increases PA. Considering volleyball athletes perform both eccentric and concentric contractions during stretch-shortening cycle actions in practice and strength training sessions, it is possible that increases in PA and FL may occur following training.

Moderate to strong correlations have been observed between vastus lateralis MT, FL and squat (SJ) and countermovement height, isometric mid-thigh pull peak force, 1-RM (repetition maximum) back squat and sprint performance in various athletic groups. [32-35] Considering these findings, leg extensor muscle architecture appears to play an important role in fitness characteristics specific to volleyball performance and may explain alterations in these characteristics following training. Also, to our knowledge, no published research has examined changes in muscle architecture with volleyball athletes throughout the competitive season and following a taper. Therefore, the purpose of this study was to examine changes in muscle architecture and explosive ability in National Collegiate Athletic Association (NCAA) division I collegiate volleyball players throughout a competitive season in preparation for conference championships.

<div align="center">METHODS</div>

Athletes

Fourteen Division I NCAA volleyball players were recruited for the study; however, four athletes failed to complete all testing sessions, and therefore only ten were included in the

analyses (age: 20.4 ± 1.1 y, height: 178.3 ± 4.8 cm, mass: 72.6 ± 5.3 kg). All athletes had at least 1 year of strength training experience and received no nutritional supplements during the study period. The study was performed as part of the athlete's training in preparation for conference championships. All subjects signed an informed consent form in accordance with the guidelines set forth by the University's Institutional Review Board.

Procedures

    Training. The athletes trained using a block periodization model that comprised of sequenced phases: strength, strength-speed, speed-strength, and a taper over a 15-week period (Table 4.1). Maximal strength was increased prior to explosiveness development through a combination of traditional resistance training and weightlifting exercises using relative intensities to calculate loads. The first two weeks were part of the specific preparation phase and the following 13 weeks were part of the NCAA competitive season. During the specific preparation phase, emphasis was placed on preparing the athletes for the competitive season. During the competitive season, strength training volume was reduced and emphasis was placed on maximizing neuromuscular power and managing fatigue. Strength training was conducted 1-2 days per week during the season with most weeks consisting of 3-4 practice sessions and two competitions. Strength training volume loads were calculated using percentage of RM values for sets and repetitions.

Table 4.1: Strength training program

Week	Testing	Block	Frequency (days/week)	Set x rep	Relative Training Intensity	Exercises
Week1	T_1		2	3x5 (1x5)	M (80-85%)	MTP, MTC, BS, MGBP, BOR
Week2		Strength	2	3x5 (1x5)	MH (85-90%)	
Week3			2	3x3 (1x5)	H (90-95%)	

Week						
Week4			2	3x3 (1x5)	ML (75-80%)	
Week5			2	3x5 (1x5)	M (80-85%)	
Week6		Strength-Speed	2	3x3 (1x5)	MH (85-90%)	MTP, MTSP, BS, CGBP, DBBOR
Week7			1	3x3 (1x5)	MH (85-90%)	
Week8			2	3x2 (1x5)	L (70-75%)	
Week9			1	3x3	L (70-75%)	
Week10		Speed-Strength	2	3x3	MH (80-85%)	MTP, BS, CGBP, MBCP
Week11			0	did not lift		
Week12	T_2		1	3x5 (1x5)	MH (85-90%)	
Week13		Taper	1	3x3 (1x5)	M (80-85%)	MTP, BS (week 1 only), 1/4 BS, IBP, MBS, MBCP
Week14			1	3x2 (1x5)	H (90-95%)	
Week15			0	did not lift		
Week16	T_3	Active Rest	0	did not lift		

MTP-mid-thigh pull, MTC-mid-thigh clean, BS-back squat, mid-grip bench press, BOR-bent over row, MTSP-mid-thigh snatch pull, CGBP-clean grip bench press, DBBOR-dumbbell bent over row, MBCP-medicine chest pass, IBP-incline bench press, MBS-medicine ball slam

Training Load. Internal training load was estimated using a session rating of perceived exertion collected on a 1-10 subjective scale. Rating of perceived exertion was multiplied by the duration of the session in minutes to form a rating of perceived exertion training load (RPETL) for all competitions, practices, and strength training sessions. [36] Strength training volume-load (VLd) was recorded weekly for all barbell lifts and was calculated using the following equation [37]: *Volume Load (kg*m) = Mass of External Load (kg) x Repetitions x Displacement (m)* Vertical bar displacement was measured manually from the start position to terminal position of the lift. Total RPETL and VLd were scaled per week for each athlete to compare training volume completed between testing time points (T_1-T_2 compared to T_2-T_3). Total RPETL was reduced by $47 \pm 11\%$ over the 4-week taper leading up to the conference championship (Figure 4.1a and 4.1b).
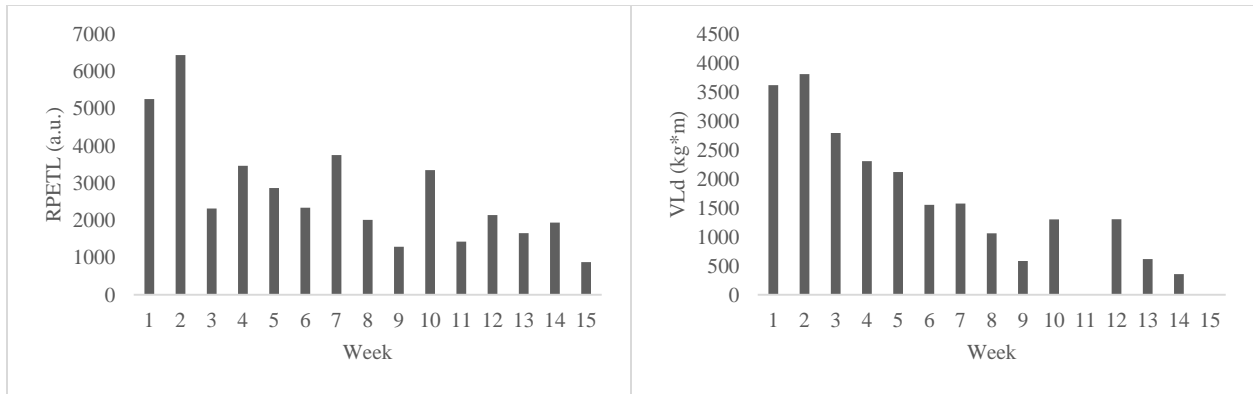
Figure 4.1a and 4.1b: Changes in weekly total RPETL and VLd

Testing

The study was conducted over a 15-week period consisting of the pre-season and competitive season. Body mass, body fat percentage, vastus lateralis MT, PA, FL, squat jump height (SJH), and peak power allometrically scaled for body mass (SJPPa) with 0kg, 11kg, 20kg, 30kg, and 40kg were assessed during the pre-season (T_1), pre-taper (T_2), and post-taper (T_3). Back squat 1-RM was estimated from the Epley equation (1985) using the athlete's 3RM back squat from week three training and was allometrically scaled for body mass (BS 1RMa) to provide a descriptive measure of relative maximal strength. Testing was conducted at the beginning of the week at the same time of day (06:30-08:30 h) for all testing sessions. Athletes were instructed to refrain from practicing and strength training 24 hours prior to each testing session.

Anthropometrics. Body mass was measured using a digital scale (Tanita B.F. 350, Tanita Corp. of America, Inc., Arlington Heights, IL), and body fat percentage was estimated from the sum of 7 skinfold sites using a skinfold caliper (Lange, Beta Technology Inc., Cambridge, MD) [38]. All anthropometrics were measured at the same time of day by the same experienced assistant for all testing sessions.

Muscle Architecture. Following anthropometric measures, vastus lateralis MT, PA, and FL were collected using non-invasive ultrasonography (LOGIQ P6, General Electric Medical Systems, Wauwatosa, WI) by an experienced technician (>500 ultrasounds performed on athletes). The athlete laid on their left side with their hips perpendicular to the examination table in the axial plane with a knee angle set at $120 \pm 5º$ angle as measured by a goniometer. Sampling location for the vastus lateralis was determined as 5cm medial to 50% of the distance between the greater trochanter and the lateral epicondyle of the femur. [39] The location was marked with permanent ink and the probe oriented parallel to the muscle length for each sample. The femur length of each athlete was recorded and used for subsequent testing sessions to ensure proper placement of the probe. Muscle thickness and PA were quantified in still images captured longitudinally in the transverse plane using the manufacturer's measuring features. Muscle thickness was determined as the distance between subcutaneous adipose tissue-muscle interface and inter-muscular interface, and PA was determined as the angle between the echoes of the deep aponeurosis of the muscle and the echoes from interspaces among the fascicles. [39] Fascicle length was calculated from MT and PA using the following equation [40]: $FL = MT \cdot SIN \ (PA)^{-1}$ The ultrasound examiner took five images from each sonogram and those which showed the largest and the smallest MT were excluded. The means of MT, PA, and FL were assessed from the three images left and used for further analysis. [30] Repeated measurements yielded a coefficient of variation (CV) of 0.03%, 3.29%, 2.69% and intraclass correlation coefficients (ICCs) of 0.99, 0.86, 0.95 for MT, PA, and FL, respectively.

Squat Jumps. Following a dynamic warm-up, SJs were performed on dual force plates affixed side by side with a sampling frequency of 1000 Hz (Rice Lake Weighing Systems, Rice Lake, WI). The SJs were performed with a polyvinyl coated pipe (0kg) and loaded barbell (11kg,

20kg, 30kg, and 40kg) placed across the shoulders. The tester instructed the athlete to perform a squat to 90° knee angle, measured using a handheld goniometer, and hold the position until the force-time trace was stable. Once the force-time trace was stable, the tester shouted "3,2,1...jump" and the athlete performed a maximal effort jump. All jump trials were recorded and analyzed using a custom program (LabView 8.5.1, 8.6, and 2010, National Instruments Co., Austin, TX). Jump height was estimated from flight time using the formula: $g \cdot \text{flight time}^2 \cdot 8^{-1}$, where "g" is a constant of 9.81 m·s^{-2} for the acceleration due to gravity. [41] Peak power was determined as the maximal value obtained during the concentric phase of the jump. [42] The average of two best trials within a 2cm difference in jump height was used for analysis. Additional trials were performed when the difference between two trials was greater than 2cm. Intraclass correlation coefficients for all SJ variables ranged from r=0.93 to 0.99.

<u>Statistical Analyses</u>

All data are reported as mean ± standard deviation (SD). A Shapiro-Wilks normality test was used to determine if the data were normally distributed. One-way repeated measures ANOVA were calculated for body mass, body fat percentage, MT, PA, and FL. A 3 x 5 (time by load) repeated measures ANOVA was used to analyze changes in SJH and SJPPa. Mauchly's test of sphericity was calculated for the repeated measures analysis to determine if the variance between all possible pairs of levels of the independent variables were equal. If sphericity was violated Huynh-Feldt results were reported when the epsilon correction factor was >0.75, and Greenhouse-Geisser results were reported when the epsilon correction factor was <0.75 [43]. Statistical time effects were followed by post-hoc comparisons. Alpha level for all analyses was set at p≤0.05 and a Benjamini-Hochberg adjustment was used to correct for multiple comparisons and control the false discovery rate. [44] Cohen's d with 95% confidence intervals

(CI) were calculated for all statistical post-hoc comparisons and were used to determine the magnitude of performance change. Effect sizes values of 0.0, 0.2, 0.6, 1.2, 2.0, and 4.0 were interpreted as trivial, small, moderate, large, very large, and extremely large, respectively. [45] Relationships between estimated back squat 1-RM, mean change in muscle architecture and SJ variables, and training load completed from T_1 to T_3 were evaluated using Pearson product-moment zero order correlation coefficients. Effect size magnitudes for correlations were based on the following scale: trivial, ≤0.10; small, 0.10–0.29; moderate, 0.30–0.49; large, 0.50–0.69; very large, 0.70–0.89; and nearly perfect, ≥0.90. [45] Analyses were performed using SPSS software version 23 (IBM Co., New York, NY, USA), and Microsoft Excel 2013 version 15 (Microsoft Corporation, Redmond, WA, USA).

RESULTS

There were statistical changes in multiple dependent variables across time (Table 4.2). There was a statistical reduction in weight training VLd/session (p<0.001, d=3.12, 95% CI [2.3, 3.0]) and RPETL/session (p<0.001, d=3.12 [0.07, 1.9]) between training phases (T_1-T_2 compared to T_2-T_3). There were statistical time effects for body mass ($F_{(2,18)}$=5.98, p=0.03), body fat percentage ($F_{(2,18)}$=9.33, p=0.01), MT ($F_{(2,18)}$=37.78 p<0.001), and PA ($F_{(2,18)}$=4.57, p=0.03). There were no statistical time effects for FL. There were no statistical time by load interactions or time effects for SJH and SJPPa. Post-hoc comparisons revealed statistical decreases in body mass (T_1-T_3: p=0.03, d=0.32 [0.12, 0.87]; T_2-T_3: p=0.02, d=0.22 [0.07, 0.74]), and body fat percentage (T_1-T_3: p=0.008, d=0.48 [0.29, 0.78]; T_2-T_3: p<0.001, d=0.48 [0.34, 0.68]). MT statistically increased from T_1-T_2 (p<0.001, d=2.8 [1.7, 4.6]) and from T_1-T_3 (p<0.001, d=1.7 [1.3, 2.2]); however there was a statistical decrease from T_2-T_3 (Figure 4.2, p=0.01, d=0.6 [0.42, 0.86]). PA statistically increased from T_1-T_2 (p=0.02, d=3.9 [1.3, 12]).

Table 4.2: Changes in dependent variables over time

	Mean±SD			Cohen's d		
	T_1	T_2	T_3	T_1-T_2	T_1-T_3	T_2-T_3
Anthropometrics						
Mass (kg)	72.57±5.31	71.69±4.93	70.79±4.55*#	0.17	0.34	0.18
Body Fat (%)	22.29±4.3	21.82±3.31	20.24±3.25*#	0.11	0.48	0.48
Muscle Architecture						
Thickness (cm)	2.1±0.3	2.96±0.54*	2.63±0.36*#	2.87	1.77	0.61
Pennation Angle (degrees)	12.59±0.81	15.76±3.38*	15.37±3.86	3.91	3.43	0.12
Fascicle Length (cm)	9.52±1.91	11.31±1.83	10.45±1.56	0.94	0.49	0.47
Jumps						
SJH 0kg (m)	0.28±0.03	0.29±0.02	0.29±0.03	0.33	0.33	0.00
SJPPa 0kg (W·kg$^{-0.67}$)	212.18±21.79	216.82±19.37	210.59±22.08	0.21	0.07	0.32
SJH 11kg (m)	0.24±0.04	0.25±0.02	0.25±0.03	0.25	0.25	0.00
SJPPa 11kg (W·kg$^{-0.67}$)	208.24±25	209.43±16.9	204.74±24.02	0.05	0.14	0.28
SJH 20kg (m)	0.21±0.04	0.2±0.03	0.21±0.03	0.25	0.00	0.33
SJPPa 20kg (W·kg$^{-0.67}$)	206.93±24.26	208.39±17.45	204.64±20.79	0.06	0.09	0.21
SJH 30kg (m)	0.18±0.03	0.18±0.02	0.17±0.03	0.00	0.33	0.50
SJPPa 30kg (W·kg$^{-0.67}$)	203.95±25.35	209.16±22.25	203.73±19.1	0.21	0.01	0.24
SJH 40kg (m)	0.15±0.04	0.14±0.03	0.14±0.02	0.25	0.25	0.00
SJPPa 40kg (W·kg$^{-0.67}$)	197.57±26.28	203.08±22.26	197.74±20.24	0.21	0.01	0.24

*significantly different from T_1 ($p<0.05$), #significantly different from T2 ($p<0.05$). SJH-squat jump height, SJPPa-squat jump peak power allometrically scaled for body mass
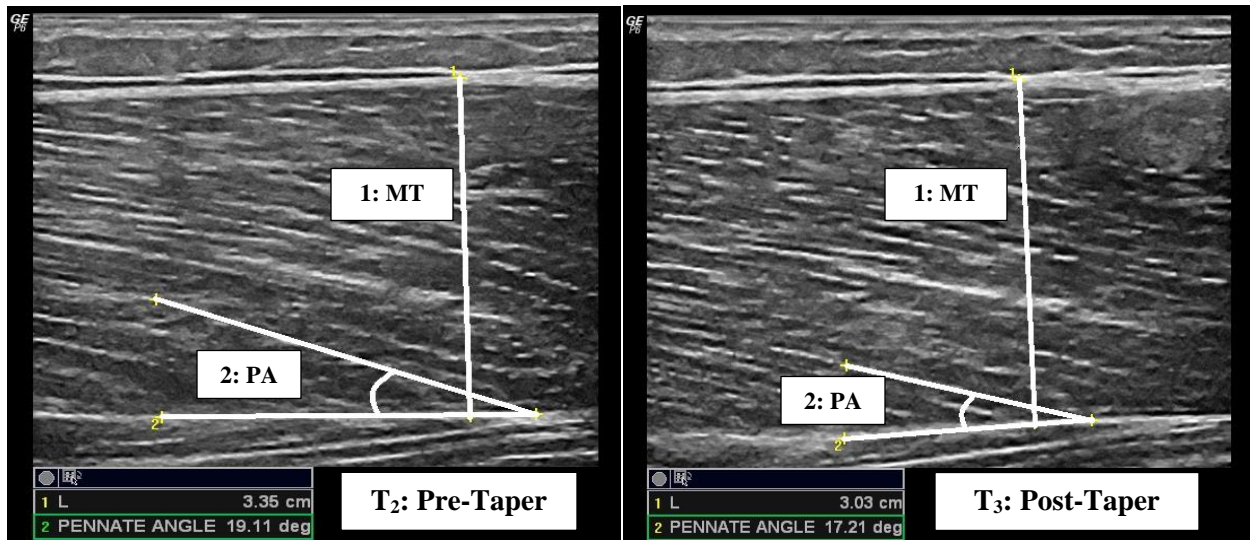
Figure 4.2: Changes in vastus lateralis MT and PA from T_2 to T_3. MT-muscle thickness, PA-pennation angle

There was a nearly perfect, positive relationship between BS 1RMa and VLd completed from T_1 to T_3 (r=0.93, *p*<0.001). There were large to very large, negative relationships between BS 1RMa and mean change in SJPPa from T_1 to T_3 with 0kg (Figure 4.3, r=-0.8, *p*<0.01), 11kg (r=-0.7, *p*=0.02), 20kg (r=-0.81, *p*<0.01), 30kg (r=-0.55, *p*=0.1), 40kg (r=-0.51, *p*=0.13). Similarly, there were large negative relationships between BS 1RMa and mean change in SJH from T_1 to T_3 with 20kg (r=-0.53, *p*=0.12), 30kg (r=-0.64, *p*=0.04), and 40kg (r=-0.53, *p*=0.12). Changes in MT, PA, and FL from T_1 to T_3 were not statistically related to any other variable assessed. Also, there were no statistical relationships between RPETL completed from T_1 to T_3 and any other variable assessed.
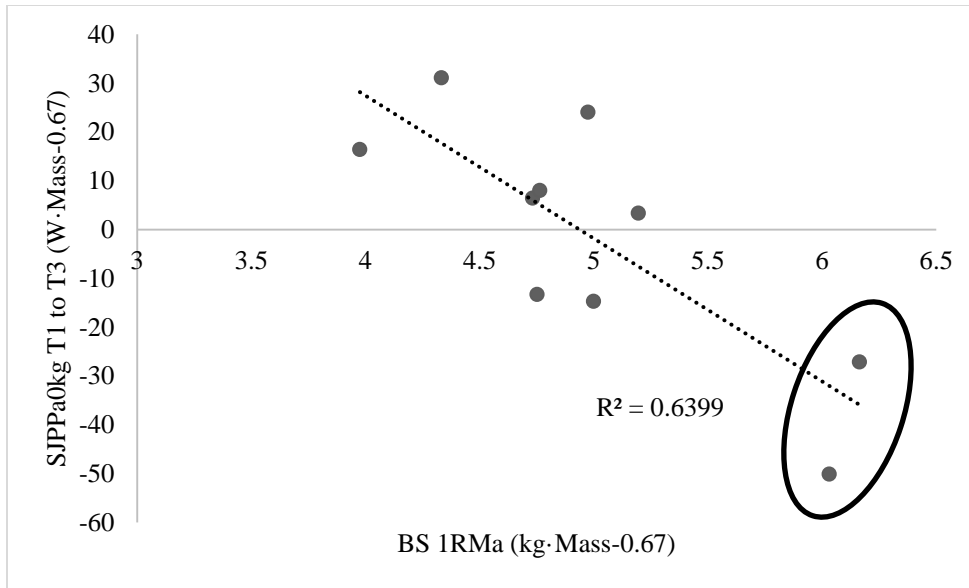
Figure 4.3: Relationship between BS 1RMa and mean change from T_1 to T_3 in SJPPa with 0kg. The two strongest athletes are circled above for applications stated in the discussion.

<div align="center">DISCUSSION</div>

The primary findings in this investigation include positive alterations in collegiate female volleyball athletes vastus lateralis muscle architecture, and preserved explosive ability over the competitive season while performing a periodized training program. Additionally, the tapering period resulted in large decreases in body fat percentage and moderate decreases in vastus lateralis MT with no statistical changes in jumping performance. Although no time effect was observed, effect sizes indicated a small decreasing trend in SJPPa with all loads following the tapering period. Large to very large, negative relationships were observed between maximal strength and changes in SJPPa and SJH with various loads. Additionally, there were no statistical relationships between changes in muscle architecture variables over the course of the season and any other variables assessed. These findings indicate: 1) explosive ability and vastus lateralis muscle architecture can be maintained close to pre-season levels following a taper despite large reductions in practice and strength training volumes, and 2) vastus lateralis architecture is highly

adaptable during in-season play; however, these changes are not strongly related to changes in squat jump performance in a sample of collegiate volleyball athletes.

The observed decreases in body fat percentage are similar to previous research demonstrating positive alterations in female's body composition resulting from sport training. [46-50] Previous investigations have reported increases in vastus lateralis MT and PA in response to heavy strength training. [26-28] However, a limited number of studies have examined changes in muscle architecture in response to concurrent sport and strength training, [29,34,51] and only one of these studies has examined changes following a taper. [51] In this study, Zaras et al. [51] reported no statistical alterations in vastus lateralis MT, PA, and FL following a two week taper in track and field throwers. The moderate decreases in vastus lateralis MT observed in the present study following the taper may have been due to the long duration (4 weeks) and very large, statistical reduction in strength and practice training volume during the taper. However, MT remained elevated above pre-season levels following the taper. In contrast, the greater practice and strength training volumes during in-season training were accompanied by large to very large increases in MT and PA from T_1 to T_2. These in-season changes are in agreement with previous findings by Blazevich et al., [29] who reported increases in vastus lateralis MT and PA in a combined group of male and female athletes following strength training and sprint/jump training. Considering the observed decreases in MT following the taper in the present study, athletes may benefit from a short-term overreaching microcycle (i.e. a period of higher training volume) prior to the taper where strength training volume is acutely increased to preserve muscular adaptations accrued prior to the competitive season.

In one of the few published studies examining longitudinal changes in female athlete's muscle architecture, Nimphius et al. [34] found moderate increases in FL (d=0.80) with no statistical changes in MT and PA over the course of the pre-season/in-season in softball players. These changes in FL primarily occurred from mid to post testing during a period of lower volume, high-velocity training in preparation for a national tournament. No statistical changes in FL were observed in the present study; however, a moderate increase was observed from pre-season to pre-taper (T_1 to T_2: d=0.94). Additionally, these authors observed moderate to large relationships between change in FL and sprint performance, whereas no statistical relationships were observed between changes in muscle architecture and changes in any SJ variable over the course of the season in the present study. The difference in findings may be attributed to differences in the mode of sport training (softball vs. volleyball), conditioning sessions (1-2 sessions/week vs. none), strength training frequency during the peaking phase (2 sessions/week vs. 1 session/week), and testing modality (sprints vs. jumps).

Previous evidence indicates a possible relationship between the force-velocity characteristics of exercises used in training and the corresponding muscle architectural changes. [29,40] Abe et al., [40] found FL was longer in 100m sprinters compared to long-distance runners and concluded these differences may have been related to training adaptations, with longer FLs favoring greater muscle fiber shortening velocities in the sprinters. In support of this, Blazevich et al. [29] found that athletes who trained with a combination of strength training and speed/jump training exercises for five weeks achieved statistical increases in vastus lateralis PA and MT, whereas athletes who ceased performing strength training and performed sprint/jump training alone increased vastus lateralis FL and MT. However, these changes were not observed in the present study during the tapering period. A possible explanation is that the volume and/or

intensity of jump training (practice and competition) during the taper was insufficient to produce increases in FL. It is also possible that differences in adaptations exist within the team between starters and non-starters; however, considering most of the athletes who completed the study were starters (7 of 10), this comparison was not possible. Future research should assess the relationship between playing time and response to the taper in team sport athletes.

Importantly, more recent findings have demonstrated contraction-specific adaptations in FL. [31,52] These studies demonstrated knee extensor eccentric contractions increase vastus lateralis FL and concentric contractions increase vastus lateralis PA. During the tapering phase, athletes primarily performed lower extremity strength training exercises that involved concentric contractions of the vastus lateralis (MTP, ¼ BS), which may partially explain why no changes in FL were observed during this period. Also, the method of determining FL in the present study may have mis-estimated the athlete's true FL because it does not account for changes in fascicle curvature. [53]

Although no statistical changes were observed in SJ performance following the taper in the present study, the small decreasing effect sizes for SJPPa indicate the tapering period (4 weeks) may have been too long. Additionally, it is possible the athletes peaked earlier than the week they were tested. In a meta-analysis summarizing results of tapering studies in endurance events (swimming, cycling, running), Bosquet et al. [11] found that peak performances occurred during the second week of the taper. Considering these findings, future research on tapering for team sport athletes should assess sport-related performance weekly to determine when athletes peak.

It is also possible that the strength training volumes in the present study were insufficient to produce increases in SJH and SJPPa. In further support of this, large to very large negative

relationships were found between BS 1RMa and changes in SJH and SJPPa with multiple loads

from T_1 to T_3. These results are more convincing when considering that 8 out of 10 possible SJ

variables had correlation coefficients ranging from r=-0.51 to -0.81. One possible explanation is

that the training stimulus may have been insufficient for the stronger athletes, which negatively

affected their SJ performance. In support of this, Figure 4.3 shows the two strongest athletes

(relative to body mass) decreased SJPPa at 0kg from T_1 to T_3. Although there was a nearly

perfect linear relationship between athletes relative strength level (BS 1RMa) and strength

training volume completed from T_1 to T_3 (VLd), the SJ correlation results indicate these strength

training volumes may have been sufficient for weaker, but not stronger athletes suggesting a

possible curve linear relationship. The relationship between BS 1RMa and VLd is likely

explained by the large proportion of lower extremity exercises included in the strength training

program. Additionally, the lack of association between RPETL from T_1 to T_3 and change in any

SJ variables indicates athletes perception of the difficulty of training had no relationship with

how they performed on the SJ. Nevertheless, the correlation data should be interpreted with

caution considering the small sample size.

In summary, these findings demonstrate that relatively low volumes of strength training

performed concurrently with sport training are capable of preserving unloaded and loaded SJ

performance during a tapering period in female volleyball athletes. Additionally, concurrent

strength and sport training resulted in increases in vastus lateralis MT, and PA. However,

training volumes did not appear sufficient to maintain vastus lateralis MT during the tapering

period. One solution may be to perform an overreaching microcycle prior to the taper in an

attempt to preserve previously accrued muscular adaptations. These findings also demonstrate

that fluctuations in muscle architecture measures during in-season play are not strongly related to

changes in SJ performance in collegiate volleyball athletes. Negative correlations observed between relative maximal strength and changes in SJ performance may be due to an insufficient strength training stimulus for the stronger athletes. Furthermore, differences may exist between starters and non-starters in response to the taper. Future research on tapering for team sport athletes should address weekly changes in performance measures and determine which factors (e.g. playing time, experience, strength level, opponent strength, etc.) may explain the variation in response.

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CHAPTER 5

DIFFERENCES IN COUNTERMOVEMENT JUMP PERFORMANCE CHANGES

BETWEEN NEW PLAYERS AND RETURNERS FOLLOWING AN OVERREACH AND

TAPER IN NCAA DIVISION I WOMEN'S VOLLEYBALL ATHLETES.

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ABSTRACT

PURPOSE: To examine differences in countermovement jump performance changes between new players and returners in a group of female collegiate volleyball players following a peaking phase, and to determine which variables best explain the variation in performance changes. METHODS: Fourteen female volleyball players were divided into two groups: returners (n=7, 20.66±0.89 y, 68.67±3.69 kg, 176.14±6.82 cm) and new players (n=7, 18.82±0.97 y, 72.86±10.58 kg, 176.43±6.95 cm). Vastus lateralis muscle architecture, relative maximal back squat strength, unloaded countermovement jump height (JH), and relative peak power (PPa) were measured prior to the season to determine between-group differences. Total rating of perceived exertion training load (RPETL), strength training volume-load (VL), JH, PPa, and sets played were recorded weekly during the peaking phase. RESULTS: There were large to very large (cohen's d ± 90% CI: 1.66 ± 1.70, $p=0.002$), and trivial to very large (1.06 ± 1.00, $p=0.08$) differences in changes in JH the first and second week of the taper, and moderate to very large (1.74 ± 0.96, $p=0.007$), and trivial to very large (1.09 ± 0.98, $p=0.07$) differences in JH and PPa supercompensation during the peaking phase in favor of returners over new players, respectively. The number of sets played during the peaking phase (r=0.78 ± 0.21, p=0.003) and athlete's pre-season relative maximal strength (r=0.54 ± 0.35, p=0.05) were the strongest correlates of JH supercompensation during the peaking phase. These findings demonstrate that new players and returners respond differently to an overreach and taper. Training prescription during this phase should differ between athletes based on their relative maximal strength and time spent competing.

Keywords: *jump height, peak power, muscle cross-sectional area, strength, training load*

<u>INTRODUCTION</u>

Tapering in athletics has been previously defined as a "progressive nonlinear reduction of the training load during a variable period of time, in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance." [1] Conceptually it is the final period in a sequence of mesocycles leading up to a major competition or tournament. [2] The purpose of the taper is to reduce fatigue accumulated during previous training to express changes in fitness and thereby maximize performance. [3-5] While numerous studies have demonstrated the beneficial effects of tapering on endurance performance, [1,3,6-9] and have examined possible underlying mechanisms, [10-17] similar studies with team sport athletes are scarce. [18-20] The paucity of research on tapering for team sport athletes has been attributed to difficulties such as long competitive periods, multiple important competitions in close succession, and difficulty in quantifying training load and sport performance. [2,21] It has been suggested that an ideal approach to peaking for team sport athletes would include a period of recovery after regular-season play followed by a return to fitness/rebuilding period and finalized with a pre-tournament taper. [22]

Previous research has focused on the effect of an overreaching period on performance supercompensation during the subsequent taper. [4,10,23,24] The theoretical basis for performing an overreach prior to the taper is derived from the fitness-fatigue paradigm. [25] The overreaching period results in an acute increase in fitness and fatigue; however fatigue masks the expression of the athlete's improved fitness. The tapering period allows for accumulated fatigue to dissipate and fitness to be expressed leading to enhanced performance. Using mathematical modeling, previous investigators have found that greater increases in volume and intensity during the overreaching period lead to larger improvements in performance; however, this requires a larger and longer reduction in training load. [4,6,26] Physiological mechanisms explaining performance

supercompensation during the taper may include glycogen supercompensation, [8,27] improved

anabolic to catabolic hormonal ration profile, [24,28] increased muscle shortening velocities

resulting from myosin isoform shifting (Type IIa to IIx) [29-31] and increased fascicle length (FL),

[32,33] increased myosin heavy chain (MHC) IIa fiber size, peak force and absolute power, [13,14]

altered regulation of growth-related genes (fibroblast growth factor-inducible 14, muscle ring

finger protein-1) in MHC IIa fibers, [14,15] increased muscle activation, [34] and recruitment of high

threshold motor units. [35] Additionally, there appears to be distinct differences in how athletes

respond to an overreach with recent evidence demonstrating that functionally overreached

cyclists exhibit an impaired cardiac response to exhaustive exercise possibly due to reduced

epinephrine excretion, decreased central command and lower chemoreflex activity. [17,36]

Considering differences in sport experience and work capacity between athletes within a team,

it's possible differences exist in corresponding performance changes following an overreach and

taper. Previous research has used countermovement or squat jumps as a monitoring tool to

examine performance changes following a taper in rugby, [19,37] futsal, [20] judo, [38] and volleyball

athletes. [39] Strong, positive relationships have been observed between countermovement jump

(CMJ) height and volleyball performance indicators (spike velocity, spike jump reach, impact

height, and athlete's level of achievement). [40-42] Therefore, weekly CMJ testing during the taper

period can provide an indication of volleyball athlete's neuromuscular status and elucidate

possible differences in preparedness between athletes within a team.

   In a previous investigation, Bazyler et al. [43] found that changes in female collegiate

volleyball athlete's squat jump performance following the taper were inversely related to pre-

season maximal strength scaled for body mass. Additionally, the authors found statistical

decreases in vastus lateralis muscle thickness (MT) following the taper. It was hypothesized that

these findings may have been due to an insufficient strength training stimulus for the stronger athletes and an overreaching microcyle was recommended prior to the taper. Yet, it is unknown whether differences in overreaching and taper responses exist between players within a team. Thus, the purpose of this investigation was to examine differences in countermovement jump (CMJ) performance changes between new players and returners in a group of female collegiate volleyball platers following a peaking phase and to determine which variables best explain the variation in performance changes.

METHODS

Athletes

Fourteen National Collegiate Athletic Association (NCAA) division I volleyball players completed the study and were divided into 2 groups for analysis: returners (n=7, age: 20.66±0.89 y, body mass: 68.67±3.69 kg, height: 176.14±6.82 cm) and new players (n=7, 18.82±0.97 y, 72.86±10.58 kg, 176.43±6.95 cm). All athletes had at least 1 year of prior strength training experience and received no nutritional supplements during the study period. The study was performed as part of the athlete's training in preparation for conference championships. All subjects signed an informed consent form in accordance with the guidelines set forth by the University's Institutional Review Board.

Procedures

Training. The athletes trained using a block periodization model comprised of sequenced phases: strength, strength-speed, strength, and an overreach-taper over a 15-week period (Table 5.1). Maximal strength was increased prior to explosiveness development through a combination of traditional strength training and weightlifting exercises using percentage of repetition maximum (RM) values for sets and repetitions to calculate loads. Strength training was

conducted 1-2 days per week during the season with most weeks consisting of 3-4 practice

sessions and 2-3 competitions. The first 2 weeks were part of the specific preparation phase and

the following 13 weeks were part of the NCAA competitive season. The focus of this study was

the training performed during the peaking phase, which was the final 5 weeks of training (weeks

11-15) prior to conference championships at the end of week 15. Training during the peaking

phase began with an overreaching microcycle prior to reducing training volumes during the

taper. The week of conference championships, a second short overreach was implemented for the

first 2 training days followed by 3 lighter training sessions.

Table 5.1: Strength training program

Week	Testing	Block	Frequency (days/week)	SetxRep	Relative Training Intensity	Exercises	Competitions
Week1	Baseline		2	3x3 (1x5)	MH (85-90%)		
Week2			2	3x3 (1x5)	H (90-95%)		
Week3		Strength	2	3x3 (1x5)	ML (75-80%)	BS, SLDL, BP, BOR	$,$,$
Week4			2	3x3 (1x5)	M (80-85%)		$,$,$
Week5			2	3x3 (1x5)	MH (85-90%)		$,$,$
Week6			2	3x5, 3x3 (1x5)	MH (80-85%)		$,$,$
Week7		Strength-Speed	1	3x3 (1x5)	L (70-75%)	BS, CPK, IBP, PU	$,$$,$
Week8			2	3x3 (1x5)	L (70-75%)		$$,$
Week9		Strength	2	3x5, 3x3 (1x5)	MH (85-90%)	BS, SLDL, BP, PU	$$
Week10			1	3x3 (1x5)	VL (65-70%)		$,$$,$
Week11	Pre-OR$_1$		2	5x5, 3x3 (1x5)	M (80-85%)		$,$
Week12	Post-OR$_1$	Overreach-Taper	2	3x3 (1x5)	L (70-75%)	BS, SLDL, IBP, BOR	$$,$
Week13	T$_1$		2	3x3 (1x5)	L (70-75%)		$,$$
Week14	T$_2$		2	3x5, 3x3 (1x5)	M (80-85%)		$$,$$
Week15	Pre-OR$_2$	Overreach-Taper	2	5x5, 3x5	H (90-95%)	BS, 1/2 BS, SLDL, MTP, BP, PU, 1ADBR	$$$,$$$
Week16	Post-OR$_2$	Active Rest	0	did not lift			

MTP-mid-thigh pull, MTC-mid-thigh clean, CPK-clean pull from knee, BS-back squat, BOR-bent over row, MTSP-mid-thigh snatch pull, CGBP-clean grip bench press, 1ADBR-one arm dumbbell row, MBCP-medicine chest pass, MGBP-mid-grip bench press, IBP-incline bench press, MBS-medicine ball slam, PU-pull-up; H-heavy, MH-moderately heavy, M-moderate, ML-moderately light, L-light, VL-very light; compertitions: $least important, $$moderately important, $$$most important

Training Load. Internal training load was estimated using a session rating of perceived exertion collected on a 1-10 scale. Based on previously established methods, rating of perceived exertion was multiplied by the duration of the session in minutes to form a rating of perceived exertion training load (RPETL) for practice and strength training sessions. [44] Strength training volume-load (VL) was recorded weekly for all barbell lifts and was calculated using the following equation [45]: *Volume Load (kg) = Mass of External Load (kg) x Repetitions* Additionally, sets played in each match during the peaking phase were recorded for each athlete and used for correlational analyses.

Testing

Baseline testing was conducted prior to the pre-season to examine differences between new players and returners. Groups were initially compared at this time point to avoid the potential confounding effects of training. CMJ testing was conducted weekly during the peaking phase to examine changes within and between groups relative to the first week of the overreach-taper (pre-OR$_1$). Athletes were instructed to refrain from practicing and strength training 24 hours prior to each testing session. During the baseline testing session athletes were tested on measures of body mass, body fat percentage (BF%), vastus lateralis MT, PA, FL, cross-sectional area allometrically scaled for body mass (CSAa), CMJ height (JH), and peak power allometrically scaled for body mass (PPa) with 0kg. Additionally, as a descriptive measure of maximal strength, athlete's back squat 1-RM allometrically scaled for body mass (BS1RMa) was estimated from the Epley equation [46] using athlete's heaviest set of 3 repetitions during the back squat from week 2 training.

Anthropometrics. Body mass was measured using a digital scale (Tanita B.F. 350, Tanita Corp. of America, Inc., Arlington Heights, IL), and BF% was estimated from the sum of 7

skinfold sites using a skinfold caliper (Lange, Beta Technology Inc., Cambridge, MD). [47] All anthropometrics were measured at the same time of day by the same experienced assistant for all testing sessions.

Muscle Architecture. A 7.5 MHz ultrasound probe was used to measure vastus lateralis CSAa, MT, PA and FL of the right leg (LOGIQ P6, General Electric Healthcare, Wauwatosa, WI). For vastus lateralis measurements, the athlete laid on their left side with their hips perpendicular to the examination table in the axial plane with a knee angle set at $120 \pm 5°$ angle as measured by a goniometer. This positioning was selected to improve image clarity during cross-sectional scans and it was easier for athletes to relax their knee extensors. Sampling location for the vastus lateralis was determined by the point of intersection between the vastus lateralis and 5cm medial to 50% of the femur length, which was defined as the distance between the greater trochanter and the lateral epicondyle of the femur. [48] The location was marked with a permanent marker and the probe oriented longitudinally in the sagittal plane, parallel to the muscle for each sample. The ultrasonography probe was covered with water-soluble transmission gel to aid acoustic coupling and avoid depression of the skin, which may cause changes in the measured parameters. [49] Vastus lateralis MT and PA were quantified in still images captured longitudinally in the sagittal plane using the measuring features of the ultrasound device (Figure 5.1a). Vastus lateralis MT was determined as the distance between subcutaneous adipose tissue-muscle interface and inter-muscular interface, PA was determined as the angles between the echoes of the deep aponeurosis of the muscle and the echoes from interspaces among the fascicles. [48] Vastus lateralis CSAa was measured by placing the probe perpendicular to the muscle and moving it in the transverse plane to collect a cross-sectional image using the LogiqView function of the ultrasound device (Figure 5.1b). The reliability of this method has

been determined previously. [50] Vastus lateralis CSAa was measured by tracing the inter-muscular interface in the cross sectional images. [51-53] Vastus lateralis FL was calculated from MT and PA using the following equation [48,54,55]: $FL = MT \cdot SIN\ (PA)^{-1}$. The ultrasound examiner took three longitudinal and three cross-sectional images from each sonogram. The means from the three images of MT, PA, FL, and CSAa were assessed from the images and used for further analysis. [56] Repeated measurements yielded coefficients of variation of 0.01%, 1.12%, 0.49%, and 1.32% for MT, PA, FL, and CSAa respectively.
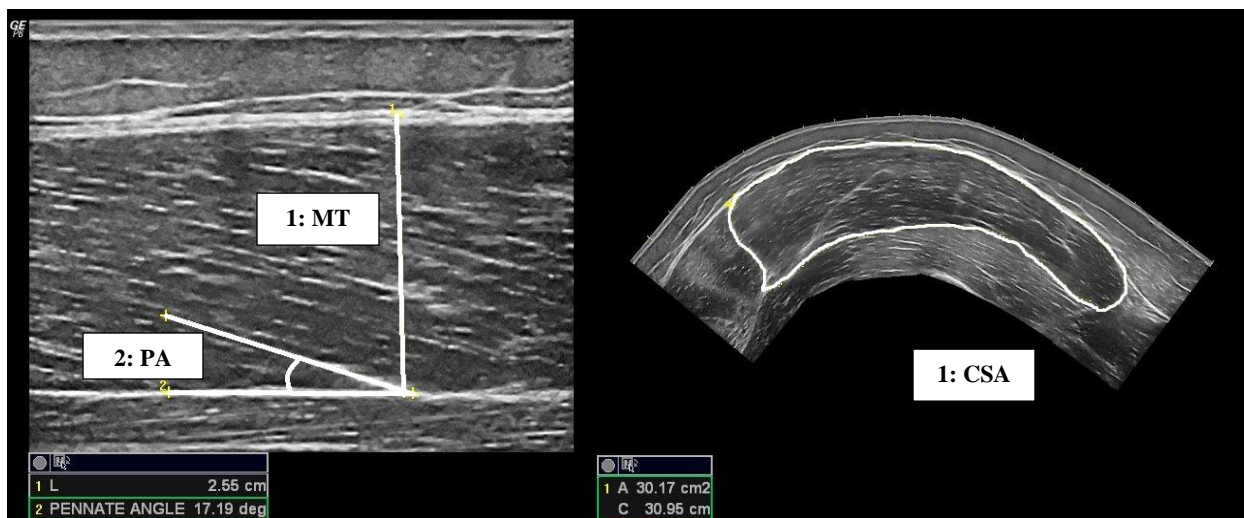
Figure 5.1a and 5.1b: Vastus lateralis longitudinal and cross-sectional measurements

Countermovement Jumps. Following a dynamic warm-up, CMJs were measured using dual force plates affixed side by side with a sampling frequency of 1000 Hz (Rice Lake Weighing Systems, Rice Lake, WI). Countermovement jumps were performed while holding a nearly weightless polyvinyl chloride pipe across their shoulders (0kg) to prevent arm swing and strictly measure performance of the lower extremities. Countermovement jumps with 0kg were performed during baseline testing and were performed weekly during the peaking phase. During the CMJs athletes were instructed to remain stable in an upright position. Once the force-time trace was stable the tester shouted "3,2,1...jump" and the athlete performed a maximal CMJ from

a self-selected depth. All jump trials were recorded and analyzed using a custom program (LabView 8.5.1, 8.6, and 2010, National Instruments Co., Austin, TX). Jump height was estimated from flight time using the formula: $g \cdot \text{flight time}^2 \cdot 8^{-1}$, where "g" is a constant of 9.81 $m \cdot s^{-2}$ for the acceleration due to gravity. [57] Peak power was determined as the maximal value obtained from the product of the velocity-time and force-time trace and was allometrically scaled for athlete's body mass. The average of two best trials within a 2cm difference in jump height was used for analysis. Additional trials were performed when the difference between two trials was greater than 2cm. The week peak JH occurred for each athlete during the peaking phase and the change in JH from pre-OR1 to peak (supercompensation) were determined for further analyses.

Statistical Analyses

Intraclass correlation coefficients (ICC) for all dependent variables ranged from r=0.92 to 0.99. Homogeneity of between-group variance was assessed using a Levene's test. Group descriptive data were compared using an independent samples t-test. Peaking phase CMJ and training load data was analyzed using a 2 x 6 (group by time) repeated measure ANOVA for the mean scores to determine within and between group differences, and a 2 x 5 (group by time) repeated measures ANOVA for the change in mean scores relative to pre-OR$_1$ to determine within and between-group difference in changes. Main effects were followed by post-hoc comparisons using a Benjamini-Hochberg adjustment to correct for multiple comparisons and control the false discovery rate. [58] Magnitude of within-group and difference in between-group changes relative to pre-OR$_1$ were determined using Cohen's d effect sizes with 90% confidence intervals (CI). A Welch-Satterhwaite approximation to the degrees of freedom was used to calculate 90% CI for variables with unequal variances between groups. Effect sizes with CIs

were assessed using the following scale: trivial, 0.0-0.2; small 0.2-0.6; moderate 0.6-1.2; large, 1.2-2.0; very large, 2.0-4.0. [59] Effects were deemed unclear when the 90% CI overlapped positive and negative outcomes (90% CI upper bound >0.2 and lower bound <-0.2). Pearson product-moment zero order correlations with 90% CIs were calculated to determine the relationship between other variables and JH supercompensation during the peaking phase. Correlation coefficients with CIs were based on the following scale: trivial, $\leq$0.10; small, 0.10–0.3; moderate, 0.30–0.5; large, 0.50–0.70; very large, 0.70–0.90; and nearly perfect, $\geq$0.90. [59] Correlations were deemed unclear when the 90% CI overlapped positive and negative relationships (90% CI upper bound >0.1 and lower bound <-0.1). Tests with p-values $\leq$0.05 were considered statistically significant, and tests with p-values $\leq$0.10 were deemed as "approached significance" for all analyses. Analyses were performed using SPSS software version 23 (IMB Co., New York, NY, USA), and Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA).

RESULTS

Baseline

There was a large to very large difference in age with returners being older than new players (mean ± standard deviation (SD): 20.66 ± 0.89 vs 18.82 ± 0.97 years, $p<0.001$, respectively). There were trivial to large differences in favor of the returners over new players for vastus lateralis PA (15.20 ± 2.19 vs 12.92 ± 2.17°, $p=0.08$, respectively), and CSAa (1.80 ± 0.22 vs 1.58 ± 0.20 cm$^2\cdot$kg$^{-0.67}$, $p=0.08$, respectively). Differences between groups at baseline for height, body mass, BF%, and vastus lateralis FL were unclear. There were moderate to very large differences in favor of returners over new players for BS1RMa (5.11 ± 0.86 vs 3.27 ± 1.07 kg$\cdot$kg$^{-0.67}$, $p=0.004$, respectively). There were small to large and trivial to large differences in

favor of returners over new players for JH (0.33 ± 0.02 vs 0.28 ± 0.05 m, $p=0.03$), and PPa

(201.40 ± 13.46 vs 180.37 ± 22.47 W·kg$^{-0.67}$, $p=0.06$), respectively (Figure 5.2).
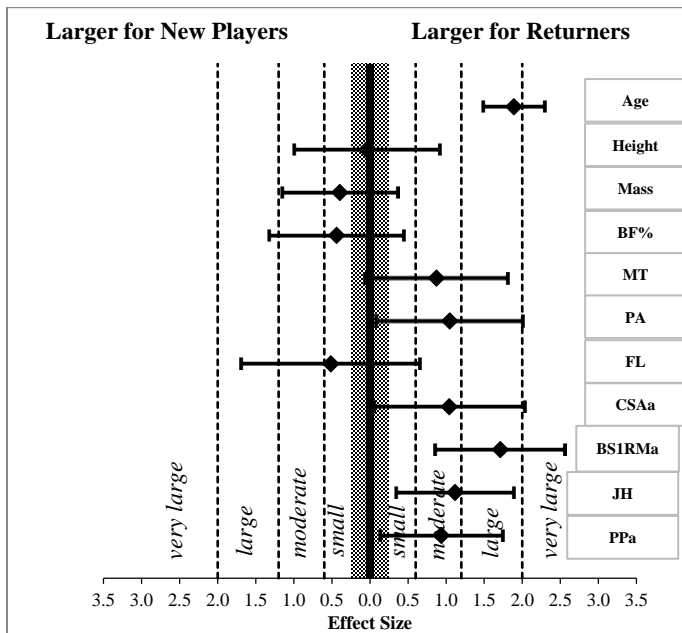
Figure 5.2: Differences between groups at baseline in descriptive and performance characteristics. BF%-body fat percentage, MT-muscle thickness, PA-pennation angle, FL-fascicle length, CSAa-cross-sectional area allometrically scaled for body mass, BS1RMa-estimated back squat 1-repetition maximum allometrically scaled for body mass, JH-jump height, PPa-peak power allometrically scaled for body mass

Rating of Perceived Exertion Training Load and Volume-Load

There were no group by time interactions or group effects for any training load variables.

There were significant time effects for practice RPETL ($p<0.001$), strength training RPETL

($p<0.001$), total RPETL ($p<0.001$), and strength training VL ($p<0.001$) during the peaking phase.

There were significant increases in total RPETL during OR$_1$ ($p<0.001$, $p=0.02$) and significant

decreases in total RPETL during the second week of the taper compared to in-season training for

returners and new players ($p<0.001$, $p<0.001$), respectively (Table 5.2). Additionally, there were

significant differences in sets played during the peaking phase with returners playing more than

new players (36.14 ± 6.52 vs 22.71 ± 12.28 sets, $p=0.03$, respectively).

Table 5.2: Changes in weekly average RPETL and strength training VL during the peaking phase relative to in-season training (mean±SD)

Training Phase	In-season	OR$_1$	Taper			OR$_2$
Duration (Weeks)	**8**	**1**	**1**	**1**	**1**	**1**
New Players						
Strength Training RPETL (A.U.)	275±109	367±130	117±64**	437±162*	409±121*	688±216**
Practice RPETL score (A.U.)	1302±364	1831±575*	1830±1051	438±91**	329±278**	803±722
Total RPETL score (A.U.)	1528±346	2198±555**	1947±1075	750±246**	739±279**	1491±903
Strength Training VL (kg)	5743±524	8313±809**	5350±566	6140±692	6162±973	11893±1110**
Returners						
Strength Training RPETL score (A.U.)	222±45	356±149	196±40	248±121	331±121*	570±296**
Practice RPETL score (A.U.)	1096±164	2041±454**	1441±493	353±70**	748±401*	1032±406
Total RPETL score (A.U.)	1161±210	2296±396**	1525±559	465±148**	1078±468	1602±658
Strength Training VL (kg)	5494±1655	7810±2542*	5185±1102	5636±1163	5511±2053	9533±3242**

within group changes relative to In-season phase: *$p \leq 0.10$, **$p \leq 0.05$. OR$_1$-first overreach, OR$_2$-second overreach, RPETL-rating of perceived exertion training load, VL-volume-load

Table 5.3: Weekly JH and PPa during the peaking phase (mean±SD)

Testing Week	Pre-OR$_1$	Post-OR$_1$	T$_1$	T$_2$	Pre-OR$_2$	Post-OR$_2$
Returners						
JH (m)	0.29±0.02	0.31±0.03*	0.31±0.02**	0.32±0.03**	0.30±0.02*	0.31±0.03**
ΔJH (m)	N/A	0.02±0.02#	0.01±0.01##	0.03±0.02#	0.01±0.01	0.02±0.02
PPa (W·kg$^{-0.67}$)	190.66±11.9	199.62±13.57	197.20±15.72*	202.85±19.28**	196.01±13.08*	206.66±16.98**
ΔPPa (W·kg$^{-0.67}$)	N/A	8.95±14.04	6.54±8.42	12.19±10.77	5.34±7.5	16.00±12.16
New Players						
JH (m)	0.27±0.05	0.27±0.04	0.26±0.05**	0.28±0.05	0.27±0.04	0.27±0.04
ΔJH (m)	N/A	0.00±0.02	-0.01±0.01	0.01±0.03	0.00±0.01	0.00±0.02
PPa (W·kg$^{-0.67}$)	180.58±21.18	185.49±16.74	181.94±16.6	189.9±24.25**	180.97±16.14	187.15±18.17
ΔPPa (W·kg$^{-0.67}$)	N/A	4.91±8.95	1.35±6.54	9.31±12.19	0.39±5.34	6.57±16

Within group change relative to pre-OR$_1$: *$p \leq 0.10$, **$p \leq 0.05$. Difference in between-group changes relative to pre-OR$_1$: #$p \leq 0.10$, ##$p \leq 0.05$. OR$_1$-first overreach, OR$_2$-second overreach, T$_1$-second week of taper, T$_2$-third week of taper, JH-jump height, PPa-peak power allometrically scaled for body mass

<u>Peaking Phase</u>

There were no group by time interactions for JH and PPa or change in mean JH and PPa scores relative to pre-OR_1 during the peaking phase. There were statistical time effects ($p=0.01$, $p=0.01$) and group effects approaching statistical significance ($p=0.06$, $p=0.10$) for JH and PPa, respectively. There were significant time effects ($p=0.04$) and group effects ($p=0.01$) for change in mean JH scores relative to pre-OR_1. The time effect for change in mean PPa scores relative to pre-OR_1 approached significance ($p=0.07$).

Changes in JH for the returners relative to pre-OR_1 were nearly statistically trivial to very large at post-OR_1 ($p=0.07$), statistically small to large ($p=0.03$) at T_1, moderate to very large ($p=0.009$) at T_2, and small to large ($p=0.03$) at post-OR_2. Changes in PPa for the returners relative to pre-OR_1 were statistically small to large ($p=0.02$) at T_2, and moderate to very large ($p=0.01$) at post-OR_2. Changes in JH and PPa for the new players relative to pre-OR_1 were statistically trivial to small ($p=0.03$) at T_1, and trivial to moderate ($p=0.02$) at T_2, respectively (Table 5.3).

Between-group differences in change from pre-OR_1 for JH were nearly statistically trivial to very large at post-OR_1 ($p=0.10$), statistically large to very large ($p=0.002$) at T_1, and nearly statistically trivial to very large ($p=0.08$) at T_2 (Figure 5.3).
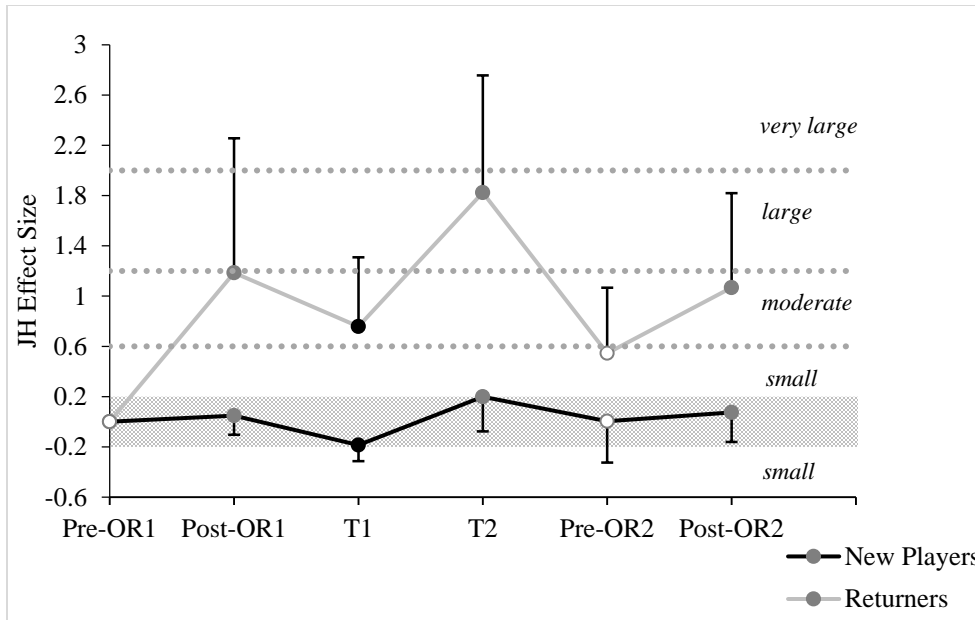
Figure 5.3: Within-group changes and differences in between-group changes in JH relative to pre-OR$_1$. Changes are reported as (d±90%CI). White color marker indicates unclear between-group difference in change from pre-OR$_1$; grey color marker indicates trivial to very large; black indicates large to very large. JH-jump height, OR-overreach. T-taper

Peak and Nadir Performance

  Jump height and PPa supercompensation for the returners were statistically large to very large ($p<0.001$), and large to very large ($p<0.001$), respectively. Jump height and PPa supercompensation for the new players were statistically trivial to small ($p=0.05$), and small to moderate ($p=0.004$), respectively. Between-group differences in JH and PPa supercompensation were statistically moderate to very large ($p=0.007$), and nearly statistically trivial to very large ($p=0.07$), respectively (Figure 5.4a and 5.4b). Irrespective of group, the majority of athletes achieved peak JH at T$_2$ (7 of 14) and nadir JH at pre-OR$_2$ (6 of 14) (Figure 5.5a and 5.5b).
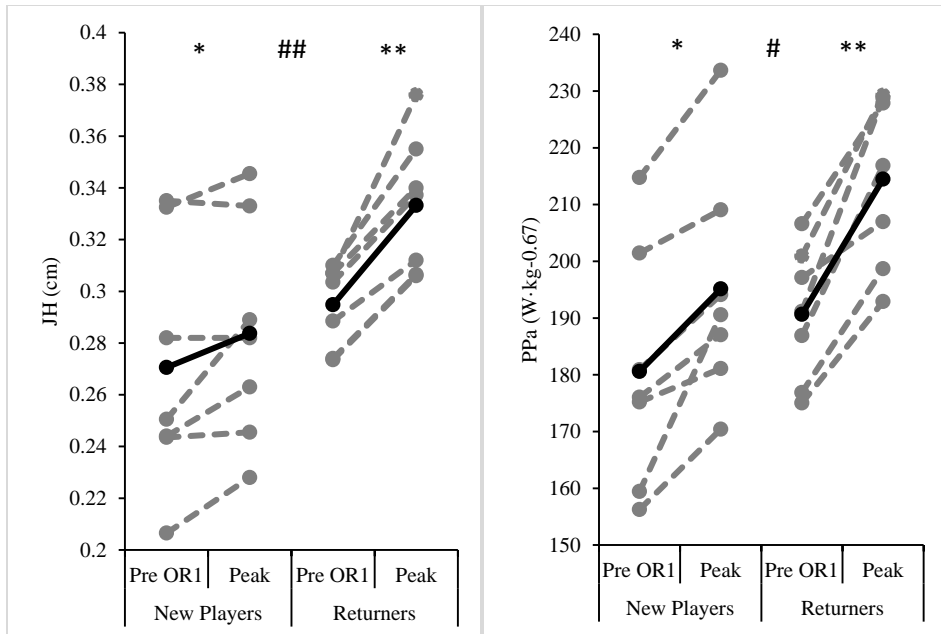
Figure 5.4a and 5.4b: Within-group changes and differences in between-group changes in JH and PPa from pre-OR$_1$ to peak performance during the peaking phase. Within group change relative to pre-OR$_1$: *$p \leq 0.05$, **$p \leq 0.001$. Difference in between-group changes relative to pre-OR$_1$: #$p \leq 0.10$, ##$p \leq 0.05$. Gray dashed lines are individual changes and black lines are group mean changes.
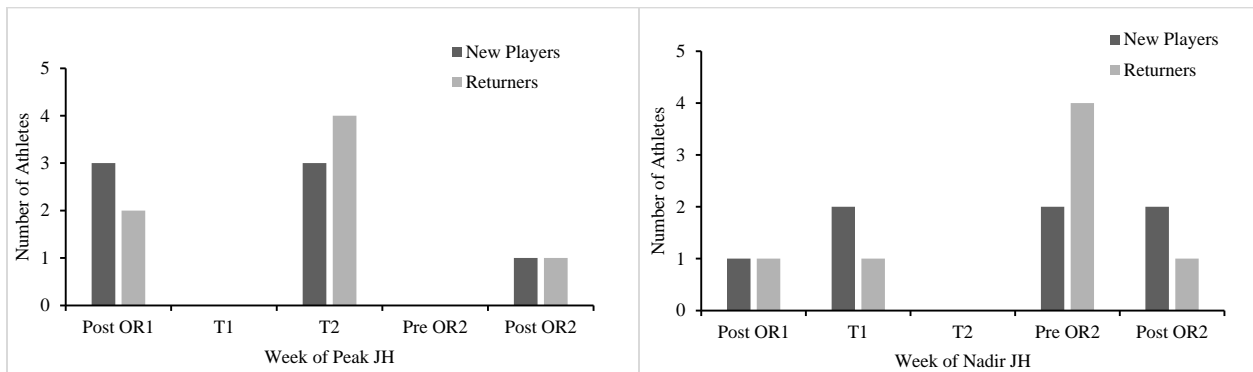
Figure 5.5a and 5.5b: Occurrence of individual JH peak and nadir week during the peaking phase. JH-jump height.

Variables Explaining JH Performance Supercompensation

Jump height supercompensation exhibited a statistically large to nearly perfect, positive relationship with sets played during the peaking phase (r=0.78 ± 0.21, p=0.003), and a statistically small to very large, positive relationship with athlete's BS1RMa (r=0.54 ± 0.35, p=0.05) (Figure 5.6). There was a trivial to very large non-statistical relationship between sets

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played during the peaking phase and BS1RMa (r=0.44 ± 0.39, p=0.12). Additionally, BS1RMa

exhibited a statistically moderate to nearly perfect relationship with PA (r=0.72 ± 0.25, p=0.003)

and MT (r=0.74 ± 0.24, p=0.003), and a statistically large to nearly perfect relationship with

CSAa (r=0.78 ± 0.21, p=0.001).
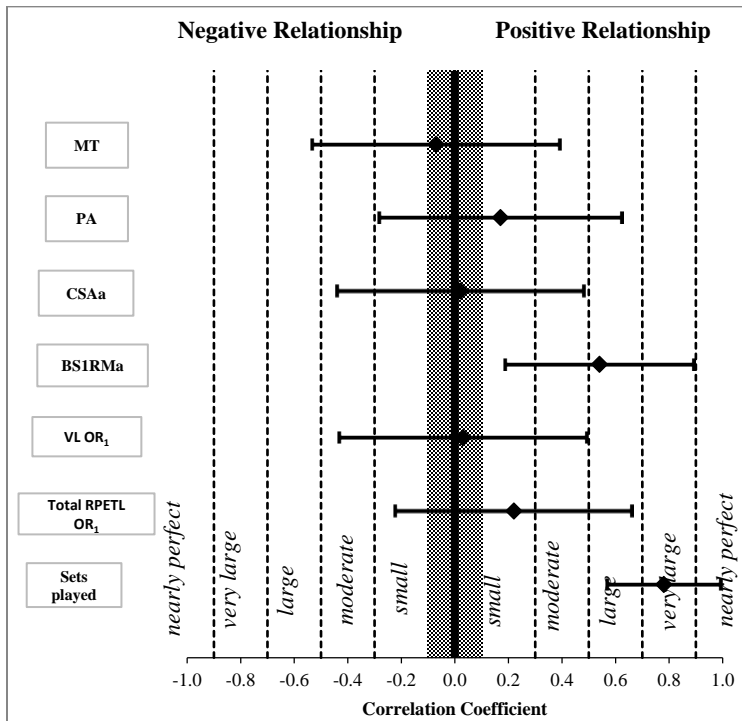
Figure 5.6: Relationships between JH supercompensation and other variables. JH-jump height, MT-muscle thickness, PA-pennation angle, CSAa-cross-sectional area allometrically scaled for body mass, BS1RMa-estimated back squat 1-repetition maximum allometrically scaled for body mass, VL OR_1-volume-load during first overreach, Total RPETL OR_1- total rating of perceived exertion training load during the first overreach

DISCUSSION

The purpose of this investigation was to determine if performance changes during a

peaking phase differed between returners and new players in a group of female collegiate

volleyball players and to determine which variables best explained the variation in performance

changes. The primary findings of this investigation include: a) large to very large differences in

age, trivial to large differences in vastus lateralis muscle architecture, trivial to very large

differences in relative maximal strength and CMJ performance in favor of returners over new players at baseline, b) trivial to very large differences in changes in JH following the initial overreach in favor of returners over new players, c) moderate to very large, and trivial to very large differences in JH and PPa supercompensation during the peaking phase, respectively, d) number of sets played during the peaking phase and athlete's baseline BS1RMa were the strongest correlates of JH supercompensation during the peaking phase.

The baseline testing results demonstrate that the returners were older, had a more advantageous muscle architectural profile, greater relative maximal strength and greater CMJ performance. These findings are in agreement with similar previous research demonstrating maximal strength, jump height, and power output are different between starters and non-starters and between different levels of athletes for various sports. [40-42,60-64]

In the only other known study examining overreaching and tapering responses in volleyball athletes, Freitas et al. [39] found significantly greater creatine kinase, RPETL, training monotony, and training strain in half a team of male volleyball players who performed an 11-day overreach compared to the other half of the team who continued with normal training. The authors concluded that CMJ performance should not be used to evaluate training adaptations in volleyball athletes because no significant within-group changes were observed in JH during the overreach or the 14-day taper that followed. In contrast, we found large to very large, and trivial to small increases in JH during the taper for the returners and new players, respectively. The differences between Freitas and colleagues findings and the present study, may have been due to differences in how JH was measured (contact mat vs. uniaxial force plates) and the caliber of athletes (national vs. collegiate level). Sole et al., [65] recently demonstrated that mechanistic variables (RFD, stretching phase duration, acceleration-propulsion phase shape factor, etc.)

obtained from force-time curve data provide a more comprehensive assessment of jumping performance than JH alone. We conclude, given the appropriate instrumentation, CMJ performance can be used to monitor training adaptations in volleyball athletes and that greater attention should be given to mechanistic variables.

Despite differences in between group changes, the within group changes relative to pre-OR_1 followed a similar trend in returners and new players. In support of this, peak and nadir JH occurred at similar time points in both groups with a fairly even distribution between weeks. Irrespective of group, 7 of 14 athletes achieved peak JH at T_2, and nadir JH occurred at pre-OR_2 for 6 of 14. These findings agree with the meta-analysis results from Bosquet and colleagues, [7] who demonstrated that peak endurance performance occurred after 2 weeks of tapering and diminished after 3 and 4 weeks of tapering. The athlete's competition schedule may also explain the timing of peak and nadir performance. The team played their two worst opponents the week prior to their best jumping performance, and their two best opponents the week prior to their worst jumping performance. Previous research has demonstrated that volleyball matches induce significant increases in blood lactate, and increases in reaction time and decreased knee joint position sense resulting in decreased sensorimotor system acuity. [66,67] It is possible that the rest period between matches and weekly jump testing sessions was insufficient to completely dissipate fatigue effects of play. Additional confounding variables explaining the timing of peak and nadir performance may include psychological readiness, nutritional status, and other external stressors (school, relationships, job, etc.).

Both returners and new players perceived total training load to be more difficult during the initial overreach and lighter during the second week of the taper compared to in-season training. Also, both groups completed greater strength training VLs during the two overreaching

microcycles compared to in-season training. Despite these similarities, the weekly CMJ data demonstrate that the returners consistently achieved greater JH improvements compared to the new players during a similar overreach and taper. These findings beg the question, which variables best explain the variation in JH supercompensation response? There was a large to nearly perfect positive relationship between sets played during the peaking phase and JH supercompensation. A trivial to very large relationship was observed between sets played during the peaking phase and athlete's BS1RMa. Also, previous research has demonstrated that stronger individuals have greater fatigue resistance at a given absolute workload as an adaptation to repetitive high load training. [24,68-70] Therefore, a possible explanation is that athletes who played more also had greater relative maximal strength, which in turn provided them with a greater work tolerance enhancing their ability to respond to the overreach and subsequent taper. In support of this hypothesis, the returners, who had a greater BS1RMa, achieved larger improvements in JH than the new players following the initial overreach. Another important consideration is that returners in this investigation were accustomed to periodized training from previous seasons with the team, whereas new players were introduced to periodized training at the beginning of the pre-season. Previous research has demonstrated that the inflammatory response is greatest when a novel stimulus is applied and is attenuated following successive bouts of similar training. [71-73] This phenomenon has been termed the repeated bout effect. [74,75] Coutts and colleagues [18] have also shown that overreaching prior to a taper results in significant increases in creatine kinase and decreases in the testosterone to cortisol ratio and the glutamine to glutamate ratio in semi-professional rugby league players. Considering the differences in training experience, it is possible that the overreaching period resulted in greater fatigue after effects in the new players compared to the returners.

The proposed hypothesis highlights the importance of lower extremity relative maximal strength to jumping performance supercompensation following an overreach and taper. The correlation results also demonstrate that relative maximal strength was largely related to muscle architectural characteristics, namely, vastus lateralis MT, CSAa, and PA. Previous research has demonstrated large relationships between vastus lateralis MT and relative maximal strength, jumping, sprinting and throwing ability in various groups of athletes. [76-80] Furthermore, longitudinal studies have observed increases in MT and PA following periodized strength training. [33,81-83] Therefore, improving muscle architectural characteristics and relative maximal strength of the lower extremities through periodized strength training may enhance volleyball athlete's ability to respond to an overreach and taper. Future research should develop and test a model to determine the unique contribution of different variables (relative maximum strength, training load, work tolerance, sport experience, etc.) to performance supercompensation during the taper.

In summary these findings demonstrate that differences in muscle architecture, relative maximal strength, and CMJ performance exist between female collegiate volleyball returners and new players. Returners achieved greater CMJ performance supercompensation following the initial overreach and during the subsequent taper compared to new players. The greater CMJ performance supercompensation during the peaking phase in the returners appears to be related to their greater relative maximal strength and number of sets played during this phase. A possible explanation is that athletes who played more sets during the peaking phase had greater relative maximal strength, which may have enhanced their ability to tolerate higher training loads resulting in greater CMJ performance supercompensation during the taper. These results suggest that training prescription during the peaking phase should differ between athletes based on their

relative maximal strength, time spent competing, and training experience. Additionally, emphasis should be placed on developing lower extremity muscle architectural characteristics to enhance strength of the musculature contributing to volleyball performance. Thus, when prescribing training during a peaking phase for returners and new players, sport coaches and strength coaches should consider these factors to ensure athletes are prepared for important competitions.

ACKNOWLEDGMENTS

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CHAPTER 6

BIOCHEMICAL, MORPHOLOGICAL, AND BIOMECHANICAL CHANGES IN A

NATIONAL LEVEL WEIGHTLIFTER PEAKING FOR COMPETITION: A CASE STUDY

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ABSTRACT

The purpose of this study was to examine changes in anthropometrics, muscle cross-sectional area, biomarkers, and performance measures in a national level female weightlifter following three competition phases. Training volume-load, body mass, vastus lateralis cross-sectional area, and unloaded and loaded squat jump performance were assessed weekly during each competition phase. Sum of seven skinfolds, serum biomarkers, and dynamic mid-thigh pulls were assessed pre- and post-competition phase. Weightlifting performance goals were met for the first competition (total: 200 kg) and the second (193 kg), but not the third (196 kg). Her body mass decreased to a greater extent in preparation for COMP3 (-6.0 kg) compared to COMP1 (-2.5 kg) and COMP2 (+2.2 kg). Cross-sectional area very likely decreased following COMP3 (probability: 99%, cohen's d: 2.08). Her T:C ratio likely increased (88%, 2.64), while IL-6 (79%, 2.47) and TNFα (81%, 3.59) likely decreased following COMP3. Myostatin (99%, 1.95) and decorin (99%, 1.96) very likely decreased following COMP2. Unloaded squat jump height likely increased the final week of COMP1 (89%, 0.95) and COMP2 (99%, 1.83), whereas unloaded and loaded squat jump height possibly (69%, 0.99) and likely (82%, 1.52) decreased the final week of COMP3. Changes in endocrine, inflammatory, and hypertrophic markers corresponded with training volume-load; however, body mass, muscle cross-sectional area, squat jump and dynamic mid-thigh pull performance provided a clearer indication of her competition performance. These findings provide a biochemical, morphological, and biomechanical basis for alterations in performance following multiple competition phases in a national level weightlifter.

Keywords: *taper, testosterone, myostatin, jump height, clean and jerk, snatch*

There is a paucity of research monitoring longitudinal changes in physiological, biochemical, and performance measures with high level (e.g. national, international, elite) athletes (Mujika, 2014). This is likely due to the expectation placed on researchers to conduct studies with sample sizes large enough to achieve sufficient statistical power. This expectation, however, is often unrealistic when conducting research with high level athletes. Thus, case studies and single subject designs are viable alternatives to traditional training studies for sport scientists working with high level athletes. Case studies can often provide coaches and sport scientists with a better understanding of how individual athletes respond to a given stimulus. Training results in individual-specific adaptations that depend on an athlete's training age, genetics, and fatigue state (Banister & Calvert, 1980; Bouchard, Dionne, Simoneau, & Boulay, 1992). Case studies can give an indication of the athlete's progress and can be used to aid with training decisions. Previous studies monitoring longitudinal changes in performance using a single-subject design or case study have been conducted with an Olympic-level weightlifter (Gisslen, Ohberg, & Alfredson, 2006), Olympic-level diver (Baker, 2001), world class triathlete (Mujika, 2014), national champion boxer (Halperin, Hughes, & Chapman, 2016), well trained powerlifters (Zourdos et al., 2016), and collegiate volleyball players (Kavanaugh, 2014). These studies ranged from 2 months to 4 years and have monitored training load, anthropometrics, body composition, tendon structural changes, kinetic and kinematic variables, and agility performance. The results of these studies demonstrate positive alterations in these variables along with improvements in competitive performance over the training periods examined.

The tapering period is an important component of the training process that has not been extensively researched in strength-power athletes. Previous research has primarily focused on tapering for endurance performance and thus most literature reviews and meta-analyses on the topic have focused on running, cycling, and swimming (Bosquet, Montpetit, Arvisais, & Mujika, 2007; Le Meur, Hausswirth, & Mujika, 2012; Mujika & Padilla, 2003). Despite weightlifting being one of oldest Olympic sports, tapering research with high-level weightlifters is scarce (Busso et al., 1992; Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1987; Stone et al., 1996). Observational and experimental studies have examined the effects of overreaching and tapering on biochemical profile and weightlifting performance (Busso et al., 1992; Fry et al., 1994; Hakkinen et al., 1987). Hakkinen and colleagues (1987) found decreases in the testosterone:cortisol (T:C) ratio following a 2-week overreach in trained weightlifters. The T:C ratio returned to baseline levels following 2 weeks of normal training and a 2-week taper primarily due to reductions in cortisol. Additionally, there was a positive relationship between change in the T/sex hormone binding globulin (SHBG) ratio and change in clean and jerk performance following the normal training and tapering period. Similarly, Fry et al., (2000) found increases in the T:C ratio following a 1-week overreach and 3 weeks of normal training in elite weightlifters. Also, the change in the T:C ratio during the normal training period was positively related to the change in clean and jerk performance.

Recent advancement in biochemical assay techniques have provided greater insight into molecular responses to training. Results of recent studies demonstrate the profound effects an athlete's training volume has on endocrine and non-endocrine molecules and subsequent sport performance. Interleukin-6 (IL-6) has been implicated as an anti-inflammatory myokine responsible for initiating satellite cell proliferation and differentiation, and inhibiting tumor

necrosis factor alpha (TNF-ὰ) expression (Vierck et al., 2000). Both IL-6 and TNF-ὰ have been

shown to be elevated following an overreaching phase (Main et al., 2010; Nieman et al., 2014),

and subsequently reduced following a 3-week taper (Farhangimaleki, Zehsaz, & Tiidus, 2009) in

endurance athletes. Myostatin is a myokine that limits myocyte differentiation and growth by

binding to the activin type II receptor on the myocyte surface and subsequently inhibiting Akt-

induced muscle protein synthesis (Kim, Cross, & Bamman, 2005). Myostatin mRNA expression

has been shown to decrease following heavy strength training (Hulmi et al., 2007; Kim et al.,

2005; Roth et al., 2003). However, not all studies agree (de Souza et al., 2014; Willoughby,

2004). Decorin is a proteoglycan that is part of the myocyte extracellular matrix and has been

shown to bind myostatin and possibly trap it in the extracellular matrix (Miura et al., 2006).

Kanzleiter and colleagues (2014) found a positive relationship between acute changes in serum

decorin levels following a strength training session and subject's 8-repetition maximum (RM)

leg press strength. Additionally, these authors found a positive relationship between changes in

decorin mRNA expression and changes in leg press strength following a 12-week strength and

endurance training program. Therefore, these myokines may provide insight into how the

hypertrophic response is regulated following an overreach and taper.

     Previous research has demonstrated a strong relationship between weightlifting

performance and vertical jump height (JH) (Haff et al., 2005; Kawamori et al., 2006). Squat and

countermovement jumps have been used previously with various athletes to monitor training

responses during a competitive season (Freitas, Nakamura, Miloski, Samulski, & Bara-Filho,

2014; Gibson, Boyd, & Murray, 2016). Therefore, monitoring jump performance during the

competition phase may provide an effective means to determine a weightlifter's response to

training without causing undue fatigue. The dynamic mid-thigh pull (MTP) has also been used to

assess an athlete's explosive ability at various loads (Haff et al., 2005; Kawamori et al., 2006). Dynamic MTP peak rate of force development and peak force have been shown to be strongly related to vertical jump (r=0.61-0.88) and weightlifting performance (r=0.69-0.74) in elite female weightlifters (Haff et al., 2005). Additionally, changes in athlete's muscle architecture have been observed following a competition phase (Bazyler, Suchomel, et al., 2016); however, other studies have reported no changes (Bazyler, Mizuguchi, et al., 2016a; Zaras et al., 2016). Currently, no studies have examined changes in biochemical markers, muscle architecture, and kinetic and kinematic variables in conjunction with weightlifting performance during multiple competition phases. Therefore, the purpose of this study was to examine changes in anthropometrics, muscle CSA, biomarkers, and performance measures in a national level female weightlifter following three separate competition phases.

METHODS

Athlete Characteristics

The athlete was a U.S. national level female weightlifter competing in the 69kg weight class (age: 21.82 years, body mass: 70.7 kg, height: 161 cm). Her accolades include two first place finishes at University National Championships, two second place finishes at the American Open, and one third place finish at Senior Nationals. She also competed internationally at the Pan-American Junior Championships and Junior World Championships. The athlete had been training competitively for 6 years, and performed 4-7 weightlifting sessions per week using a block-periodization model. The athlete was informed of the risks and benefits of participating in the study and provided written informed consent. The study was approved by the universities' institutional review board.

The study occurred over a ten month period consisting of 3 competitions. Each competition phase was a 4-week mesocycle where VL was reduced based on the importance of the competition (Figure 6.1). The first competition phase (COMP1) led up to a regional championship, the second competition phase (COMP2) led up to a local meet that she trained through (i.e. didn't attempt to peak) prior to the third competition phase (COMP3), which lead up to the national championship. Training prior to regional and national championships consisted primarily of the competition lifts and variations followed by assistance exercises (Table 6.1). External training load was estimated using strength training volume-load (VL) (Haff, 2010).
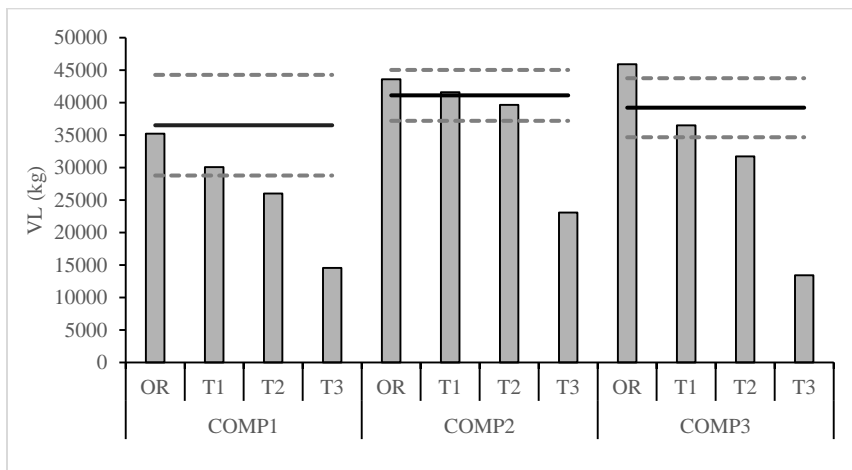
Figure 6.1: Competition phase weekly training volume-load. Black lines represent "normal" average training VL±95% confidence limits (broken lines) per week for the macrocycle corresponding with each competition phase. VL during COMP1 was reduced by 59%. VL during COMP2 was reduced by 47%. VL during COMP3 was reduced by 71%. Changes in average VL relative to normal were -28% for COMP1, -10% for COMP2, and –19% for COMP3. VL-volume-load, COMP-competition phase, OR-overreach, T1-taper week 1, T2-taper week 2, T3-taper week 3

Table 6.1: Final week of training prior to the third competition

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
AM	FS/Jerk : 2x1@75-80%	Rest	Snatch tech: 6x2-3@50-55% SGSS: 3x5@70-75% Snatch: 2x1@65%	Rest	Jerk: 2x1@70% DB OHP: 3x5@65-70%	Snatch: 2x2@40-45% C&J: 2x2@50-55%	Compete

PM	Partial Squat: 3x2@75-80% DB OHP: 3x5@75-80%	Snatch tech: 6x2-3@45-50%
		CGSS: 3x5@70-75%
		MTP: 3x2@70-75%
		SLDL: 3x5@70-75%

FS/Jerk- front squat followed by a split jerk, DB OHP- dumbbell overhead press, tech-technique; SGSS- snatch grip shoulder shrug, CGSS-clean grip shoulder shrug, MTP-mid-thigh pull, SLDL- stiff leg deadlift, C&J- clean and jerk

The athlete completed 18 testing sessions during the three competition phases including 2 baseline testing sessions at the beginning of the 10-month period. The athlete participated in an ongoing athlete monitoring program and was familiar with all tests performed. A full testing battery was conducted pre-and post-competition phase (Figure 6.2), whereas selected tests were performed weekly (i.e. OR, T1, T2, T3) during each competition phase to avoid significant interference with her training. During the full testing battery the athlete completed anthropometrics followed by blood draws and squat jumps the first day of the training week after an off day from training; dynamic MTPs were performed >48 hrs. later after an off day from training. The first day of every training week during each competition phase the athlete completed anthropometrics, ultrasonography measurements, and squat jumps. During the two baseline testing sessions (>72 hrs. apart during a de-load week) the athlete completed the full testing battery.
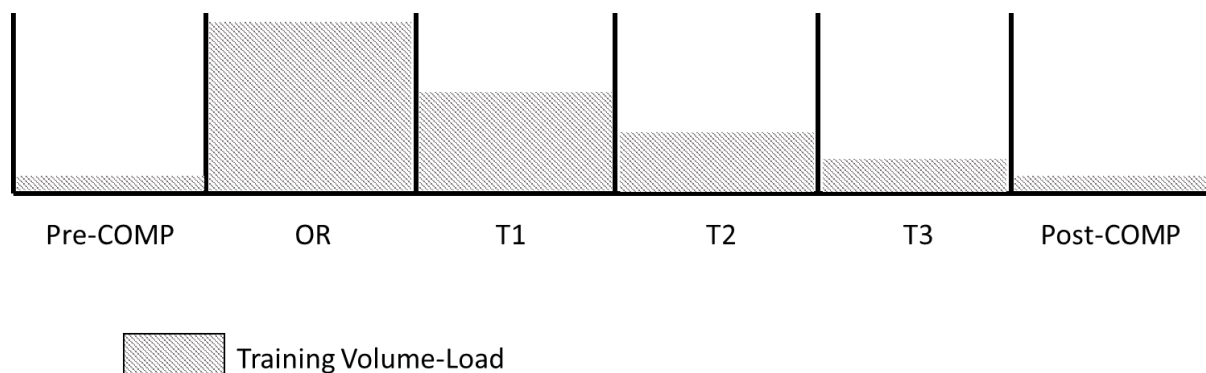

Figure 6.2: Competition phase testing timeline. COMP-competition phase, OR-overreach, T1-taper week 1, T2-taper week 2, T3-taper week 3

Anthropometrics. Standing and seated height were measured to the nearest 0.01 meters using a stadiometer (Cardinal Scale Manufacturing Co., Webb City, MO), body mass was measured using a digital scale (Tanita B.F. 350, Tanita Corp. of America, Inc., Arlington Heights, IL), and the sum of 7 skinfold sites (tricep, subscapular, mid-axillary, supraspinale, chest, abdominal, quadricep) were measured by the same examiner at all testing sessions using Harpenden skinfold calipers (Baty International, Burgess Hill, UK). The following anthropometric measurements were also recorded to determine somatotype using the Heath-Carter method (Carter, 1975): bicep and medial calf skinfolds, bicep girth (flexed 90° and tensed), standing calf girth, abdominal and hip girth, bi-epicondylar femur and humerus breadth.

Biomarkers. All blood draws were conducted between 7am-9am following an overnight fast. Blood was drawn from the antecubital vein into a serum clot tube. The blood was allowed to clot for 20 min. at room temperature. The samples were then centrifuged at 3400 rpm for 15 min. at room temperature. Serum was pipetted into smaller centrifuge tubes and stored in a -80°C freezer. Blood draws were obtained following an off-day from training at the beginning of a de-load week prior to each competition phase and >72 hours following competitions. Two blood draws were obtained at the beginning of the 10-month training period during a de-load week within 72hrs to use as a baseline. Cortisol and SHBG were measured in duplicate using an IMMULITE 1000 automated immunoassay analyzer (Siemens Healthcare, Erlangen, Germany). The coefficient of variation ranged for these assays ranged from 4.9% to 13.7%. Total testosterone, IL-6, TNF-ὰ, myostatin and decorin were measured in duplicate using a solid-phase sandwich enzyme-linked immunosorbent assay (ELISA) according to the manufacturer's procedures (R&D systems, Minneapolis, MN; ThermoFisher Scientific Waltham, MA). Sample concentrations were determined by interpolating their respective absorbance values obtained

from standard concentrations plotted on a 4-parameter logistic curve using a SpectraMax 340 microplate reader and SoftMax Pro analysis software (Molecular Devices, Sunnyvale, CA). The coefficient of variation for these assays ranged from 1.09% to 8.37%. Bioavailable testosterone was calculated from total testosterone, SHBG, and albumin using the Sodergard equation (Sodergard, Backstrom, Shanbhag, & Carstensen, 1982).

Ultrasound. A 7.5 MHz ultrasound probe was used to measure CSA of the vastus lateralis (LOGIQ P6, General Electric Healthcare, Wauwatosa, WI). The athlete laid on their left side with their hips perpendicular to the examination table in the axial plane. Sampling location for the vastus lateralis was 50% of the femur length, which was defined as the distance between the greater trochanter and the lateral epicondyle of the femur (Abe, Kumagai, & Brechue, 2000). The location was marked with a permanent marker and the ultrasonography probe was covered with water-soluble transmission gel to aid acoustic coupling and avoid depression of the skin. Vastus lateralis CSA was measured by placing the probe perpendicular to the muscle and moving it in the transverse plane to collect a cross-sectional image using the LOGIQView function of the ultrasound device (Figure 6.3). The reliability of this method has been determined previously (Howe & Oldham, 1996). Vastus lateralis CSA was measured by tracing the inter-muscular interface in the cross sectional images. The ultrasound examiner took three cross-sectional images from each sonogram and the mean of these images was used for analysis. Intra-session reliability has been previously established for this measurement by the same examiner in our laboratory (intra-class correlation coefficient (ICC): 0.99) (Bazyler, Mizuguchi, et al., 2016b).

Figure 6.3: Vastus lateralis CSA using β-mode ultrasonography. CSA-cross-sectional area

Squat Jumps. Following a standardized dynamic warm-up, squat jumps were performed on dual uniaxial force plates affixed side by side with a sampling frequency of 1000 Hz (Rice Lake Weighing Systems, Rice Lake, WI). The squat jumps were performed with a polyvinyl coated pipe (0kg) and loaded barbell (20kg) placed across the shoulders. The tester instructed the athlete to perform a squat to 90° knee angle, measured using a handheld goniometer, and hold the position until the force-time trace was stable. Once the force-time trace was stable, the tester shouted "3,2,1...jump" and the athlete performed a maximal effort jump. All jump trials were recorded and analyzed using a custom program (LabView 8.5.1, 8.6, and 2010, National Instruments Co., Austin, TX). Voltage data from the force platforms were converted to vertical ground reaction forces using laboratory calibrations and were smoothed using a 4th order Butterworth filter. Jump height was estimated from flight time using the formula: g·flight time^2·8^{-1}, where "g" is a constant of 9.81 m·s^{-2} for the acceleration due to gravity. Peak power was determined as the maximal value during the concentric phase obtained from the product of the velocity-time and force-time trace and was allometrically scaled for the athlete's body mass

(PPa). The average of the two best trials within a 2 cm difference in JH was used for analysis. Additional trials were performed when the difference between two trials was greater than 2cm. Intra-session reliability of this method has been previously established in our laboratory (ICC: 0.96-0.99) (Kraska et al., 2009).

Dynamic Mid-Thigh Pulls. Following a standardized dynamic warm-up, dynamic MTPs were performed in a custom built power rack on dual uniaxial force plates (Rice Lake Weighing Systems, Rice Lake, WI) synchronized with 4 string potentiometers (2 on each side of the bar) (Celesco Measurement Specialties, Chatsworth, CA) collecting at a sampling frequency of 1000 Hz using a BNC 2110 connector with an analog to digital converter (DAQCard-6063E, National Instruments, Austin, TX) as described previously (Cormie, McBride, & McCaulley, 2007). The same absolute loads and bar height were used for each testing session to assess changes over time. The athlete performed the MTPs in the following order for each testing session: 1 set of 3 repetitions (1x3) at 50% of estimated 3RM (150kg) from training, 1x3 at 70% of 3RM, and 1x3 at 90% of 3RM. These loads were chosen because they are similar to what the athlete used on this exercise during training. The athlete was allowed to wear straps for all sets and was instructed to rest the bar on the rack between repetitions. All MTP trials were recorded and analyzed using a custom program (LabView 8.6, and 2010, National Instruments Co., Austin, TX). Concentric peak force was determined as the maximal value obtained from the concentric force-time trace and was allometrically scaled for body mass (PFa). Maximal concentric vertical displacement (VD) was calculated by triangulating the position of the barbell relative to the front and back linear position transducers given the known distance between the two linear position transducers in conjunction with their displacement data. The mean PFa and VD of three repetitions for each load were used for analysis. Intra-session reliability of this method has been

previously established in our laboratory (ICC: 0.99 for both measures) (Goodin, DeWeese, Sato, Mizuguchi, & Kavanaugh, 2015).

Statistical Analyses

The precision (probability) of weekly changes relative to pre-OR values during each competition phase was determined using previously described methods (Hopkins, 2000). Qualitative terms corresponding to the probability values associated with weekly changes relative to pre-OR for each competition phase were classified as almost certainly not (< 1%), very unlikely (< 5%), unlikely (< 25%), possibly (25-75%), likely (>75%), very likely (> 95%), and almost certain (> 99%). Cohen's d effect sizes were calculated for the mean differences between pre-OR and subsequent weekly testing sessions during each competition phase using the pooled standard deviation across sessions. Effect sizes were classified as trivial (<0.25), small (0.25-0.5), moderate (0.5-1.0), and large (>1.0) (Rhea, 2004). The smallest worthwhile change (SWC) was used to determine whether changes were meaningful relative to pre-OR values. Smallest worthwhile change was calculated for each dependent variable by multiplying the pooled standard deviation of all time points over ten months of training by 0.3 (Halperin et al., 2016; Hopkins, 2004). Alpha level for all analyses was set at $p \leq 0.05$. Probabilities of clinically meaningful changes were calculated using a published online spreadsheet (Hopkins, 2000). All other analyses were performed using Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA).

RESULTS

Volume-Load

Average training VL during COMP1 was reduced by 59% from the first week to the final week of the phase. Average training VL during COMP2 was reduced by 47% from the first week to the final week of the phase. Average training VL during COMP3 was reduced by 71% from the first week to the final week of the phase. Changes in average training VL for each competition phase relative to normal average training VL during the corresponding macrocycle were -28% for COMP1, -10% for COMP2, and –19% for COMP3.

Anthropometrics and Cross-Sectional Area

The athlete was characterized as an endomorphic mesomorph (3.5-6.9-0.4). Her standing height was 162cm, femur length was 41cm, and her initial body fat percentage calculated from the sum of skinfolds was 15.4%. She met performance goals for the first competition (total: 200kg) and the second (total: 193kg), but not the third (total: 196kg). Body mass very likely increased following COMP2 (99%, ES=2.61), and very likely decreased following COMP3 (99%, ES=1.87) compared to pre-OR values. Similarly, sum of skinfolds very likely increased following COMP2 (99%, ES=0.9), and very likely decreased following COMP3 (99%, ES=1.18). Vastus lateralis CSA very likely decreased following COMP3 (99%, ES=1.93) (Figure 6.4).
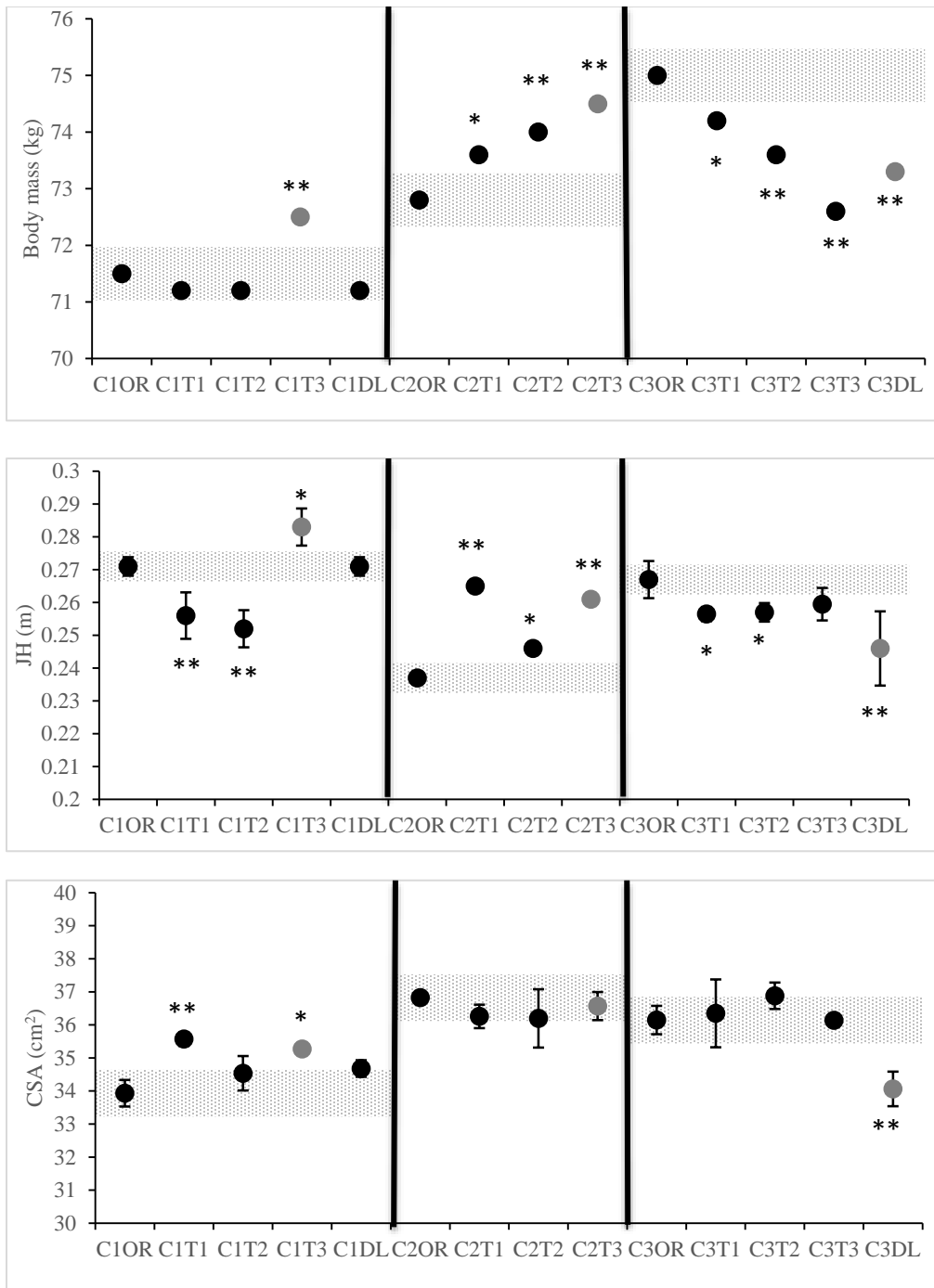
Figure 6.4: Weekly changes in body mass, CSA, and unloaded JH during each competition phase. Shaded region represents smallest worthwhile change (SWC) from pre-overreach values for each competition phase. Gray marker represents week of competition. *precision>75% (likely) and **precision>95% (very likely) change from pre-overreach values. CSA-cross-sectional area, JH-unloaded squat jump height, OR-overreach, T1-taper week 1; T2-taper week 2, T3-taper week 3, DL- de-load week.

<u>Biomarkers</u>

Baseline values for all biomarkers were as follows: total testosterone (127.50 ± 17.68 ng/dl), SHBG (95.25 ± 30.76 nmol/L), bioavailable testosterone (27.33 ± 10.92 ng/dl), cortisol (13.45 ± 4.45 ug/dl), T:C ratio (10.26 ± 4.71 A.U.), IL-6 (0.28 ± 0.06 pg/ml), TNFα (10.44 ± 0.30 pg/ml), decorin (5573.26 ± 336.95 pg/ml), myostatin (4554.51 ± 599.72 pg/ml). Total testosterone likely decreased following COMP2 (89%, ES=1.5) and likely increased following COMP3 (82%, ES=1.17). Sex hormone binding globulin likely increased following COMP3 (76%, ES=1.08). Bioavailable testosterone likely decreased following COMP2 (85%, ES=1.23), and possibly increased following COMP3 (72%, ES=0.81). Cortisol likely decreased following COMP1 (75%, ES=0.96), very likely decreased following COMP2 (97%, ES=1.84) and possibly decreased following COMP3 (70%, ES=0.88). The T:C ratio possibly decreased following COMP2 (67%, ES=1.25), and likely increased following COMP3 (88%, ES=2.64). Interleukin-6 and TNFα concentrations likely decreased following COMP3 (79%, ES=2.47, 81%, ES=3.59, respectively). Decorin concentrations very likely decreased following COMP2 (99%, ES=1.95). Myostatin concentrations very likely increased following COMP1 (99%, ES=1.21) and very likely decreased following COMP2 (99%, ES=1.96) (Figure 6.5).
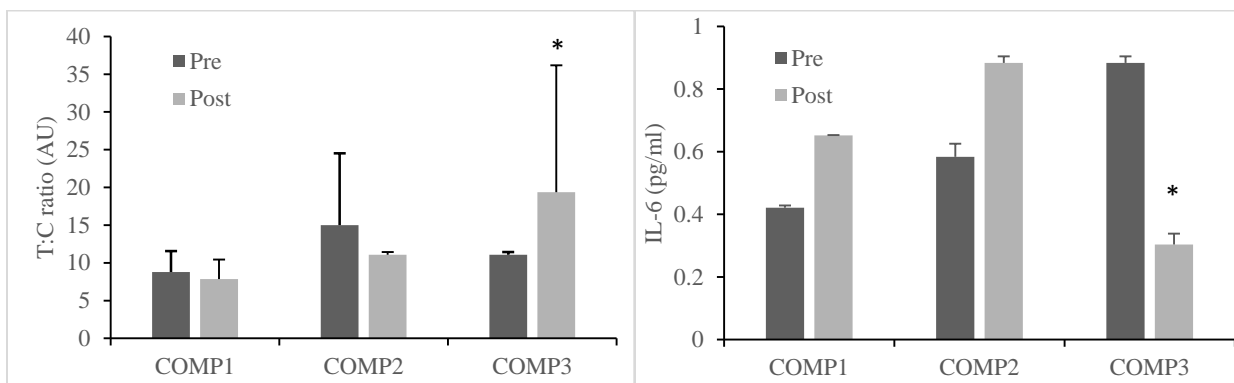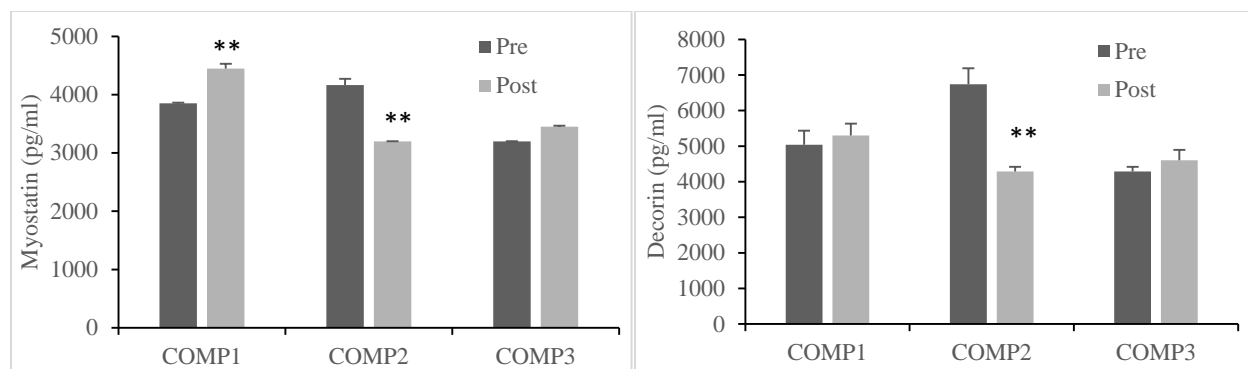
Figure 6.5: Changes in biomarkers pre- to post-competition phase. *precision>75% (likely) and **precision>99% (almost certain) change from pre-overreach value. T:C-testosterone to cortisol ratio, IL-6-interleukin 6, COMP-competition

Squat Jumps

Squat JH with 0kg likely increased the third week of the taper during COMP1 (89%, ES=0.95), very likely increased the third week of the taper during COMP2 (99%, ES=1.83), and possibly decreased the third week of the taper during COMP3 (69%, ES=0.99). There were no worthwhile changes in PPa with 0kg during the third week of the taper for any competition. Squat JH with 20kg likely decreased the third week of the taper during COMP3 (82%, ES=1.52). Squat jump peak power allometrically scaled with 20kg likely decreased the third week of the taper during COMP1 (86%, ES=2.1) and COMP2 (88%, ES=1.19).

Dynamic Mid-Thigh Pulls

Concentric VD50% likely increased following COMP1 (94%, ES=0.81) and very likely increased following COMP3 (97%, ES=0.95). Concentric VD70% likely increased following COMP1 (81%, ES=0.84). Concentric VD90% likely increased following COMP1 (93%, ES=0.84), and likely decreased following COMP2 (83%, ES=0.61), and COMP3 (94%, ES=0.87). Concentric PFa50% very likely decreased following COMP2 (98%, ES=1.47), and possibly decreased following COMP3 (70%, ES=0.54). Concentric PFa70% likely increased following COMP1 (85%, ES=0.84), and likely decreased following COMP2 (94%, ES=1.14).

Concentric PFa90% likely increased following COMP1 (81%, 0.6), and very likely decreased following COMP2 (99%, ES=1.39).

<div align="center">DISCUSSION</div>

The purpose of this investigation was to examine changes in anthropometric, muscle CSA, biochemical, and performance measures in a national level female weightlifter following three separate competition phases. The primary results of this investigation include: a) weightlifting performance goals were met for COMP1 and COMP2, but not COMP3, b) vastus lateralis CSA increased or was preserved following each competition phase except for COMP3, c) the T:C ratio likely increased, IL-6 and TNFα likely decreased following COMP3, whereas myostatin and decorin very likely decreased following COMP2, d) unloaded squat JH likely increased the final week of COMP1 and COMP2, whereas unloaded and loaded squat JH possibly and likely decreased the final week of COMP3, e) MTP concentric VD90% likely increased following COMP1 and likely decreased following COMP3.

Descriptive Characteristics

The athlete's somatotype (endomorphic mesomorph) matched previous descriptions of high level female weightlifters (Stone, Pierce, Sands, & Stone, 2006). She was younger (21.82 y) than the average age of a group of seven U.S. elite female weightlifters (23 ± 4 y) (Stone et al., 2006). Her height (162 cm) was similar (161.1 ± 5.8 cm), whereas her initial body mass (70.8 kg) was slightly higher than the average reported in this group (68.9 ± 7.5 kg). Her baseline body fat percentage (15.4%) was lower than the average reported in this group (19.6 ± 4.4%). Her baseline maximal snatch (90 kg) and clean and jerk (110 kg) were similar to the average reported from a group of six U.S. female weightlifters (90.8 ± 8.0 kg, 110 ± 16 kg) who had a higher average body mass (82.8 ± 18.9 kg) (Haff et al., 2005). Her baseline unloaded squat JH (0.24 m)

and PPa (177.57 W/kg$^{0.67}$) were slightly lower than those reported in this same group (0.29 ±

0.05 m, 185.53 ± 37.45 W/kg$^{0.67}$). Her baseline total (127.5 ng/dl) and bioavailable testosterone

concentrations (27.33 ng/dl) were greater than the normal ranges reported for pre-menopausal

females (8-60 ng/dl, 0.8-10 ng/dl, respectively) (Mayo Clinic, 2016c). Her baseline serum

cortisol (13.45 ug/dl) and SHBG (95.25 nmol/L) concentrations were within the normal range for

females (7-25 ug/dl, 18-144 nmol/L, respectively) (Mayo Clinic, 2016a, 2016b). Interleukin-6

and TNFα, were similar to normal physiological values (<5 pg/ml, <22 pg/ml) (ARUP, 2014;

Fayad et al., 2001). While concerns have been raised about detecting mature myostatin in serum

due to poor specificity of previous assays, the athlete's serum myostatin concentration (4,554.54

pg/ml) was similar to those reported for young females using a mass-spectrometry based assay

(5,500 ± 2,100 pg/ml) (Bergen et al., 2015). Normative serum decorin concentrations have not

been established. Nonetheless, the athlete's (5,573.26 pg/ml) concentrations were higher than

previously reported values in healthy control subjects (1,514.9 ± 391.2 pg/ml) (Tanino et al.,

2014).

Anthropometrics and Cross-Sectional Area Changes

Changes in her sum of skinfolds following each competition corresponded with the

changes in body mass and varied between competition periods. Body mass increased weekly

during the competition phase leading up to COMP2; however, she was training through this

competition so weight loss was not attempted. Despite the large decrease in training VL during

each competition phase, there were no worthwhile reductions in vastus lateralis CSA. The

overreaching microcycle implemented in the first week of each competition phase may have

helped preserve CSA during the following tapering weeks. A decrease in CSA was observed

following COMP3, which may be due to the large, abrupt decreases in body mass over this

competition phase (-6.0 kg) compared to the others (COMP1: -2.5 kg, COMP2: +2.2 kg), particularly during the final week (-3.5 kg). An alternative explanation could be the larger decrease in average training VL across this competition phase (71%) compared to the others (COMP1: 59%, COMP2: 47%). The poor weight loss strategy used coupled with the decreases in CSA following COMP3 could at least partially explain why she did not meet performance goals for this competition.

Biomarker Changes

Changes in testosterone, cortisol, T:C, and SHBG were consistent with previous studies on overreaching and tapering with weightlifters (Busso et al., 1992; Fry et al., 1994; Hakkinen et al., 1987). Total and bioavailable testosterone only increased following the competition phase with the largest decrease in VL (COMP3), whereas moderate to large decreases in cortisol were observed following each competition phase. Increases in the T:C ratio following COMP3 were primarily due to increases in total testosterone rather than decreases in cortisol. Despite very likely decreases in cortisol following COMP2, there was a possible decrease in T:C due to the likely decrease in total testosterone. Considering she was training through COMP2, reductions in T:C are likely due to the greater training stress during this period. The large reduction in VL leading up to COMP3 likely explains the increased T:C. As expected, SHBG mirrored changes in total testosterone with increases observed following COMP3 indicating a homeostatic regulation of free testosterone. Despite the greater testosterone bioavailability, CSA was not preserved following COMP3 demonstrating that changes in testosterone concentrations over this period were more indicative of changes in training stress than changes in hypertrophic signaling. We also acknowledge that changes in these biomarkers may be due to normal variation throughout her menstrual cycle; however, none of the blood draws occurred around her ovulation

window, which decreases the probability that testosterone changes were due to a luteinizing hormone surge.

Serum myostatin has been shown to be inversely related with skeletal muscle mass and is a potent inhibitor of muscle protein synthesis (Bergen et al., 2015). Decorin has been shown to antagonize myostatin and serum levels have been found to increase following strength training (Kanzleiter et al., 2014). Therefore, these biomarkers may provide an indication of changes in hypertrophic/atrophic signaling following training. Serum decorin and myostatin changed in a similar manner following each competition phase, and the changes corresponded with training VL. Specifically, average training VL during COMP1 was 28% lower than her normal average training VL during this macrocycle, which corresponded with a very likely, large increase in myostatin. In contrast, average training VL during COMP2 was only 10% lower than her normal average training VL during this macrocycle with 3 of the 4 weeks having a similar VL to the macrocycle average. The relatively higher average VL during this competition phase corresponded with a very likely, large decrease in myostatin and decorin. These findings provide evidence that serum concentrations of these myokines may be related to changes in training VL. The large decreases in serum decorin and myostatin following COMP2 suggest a homeostatic regulation of these myokines. However, caution should be applied in interpreting these findings as changes in resting serum myostatin and decorin can be contributed to by tissue other than muscle. Changes in serum decorin could also be indicative of tendon restructuring as it has been shown to have a crucial role in the early repair process (Dunkman et al., 2014).

Interleukin-6 and TNF-ὰ are acute phase proteins that promote secretion of acute phase reactants (i.e. C-reactive protein, fibrinogen, plasminogen) in response to injury, infection, and tissue damage (Biffl, Moore, Moore, & Peterson, 1996; Smith, 2000). Systemic elevations of

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these cytokines have been observed following injury and various disease states (Peake, Della Gatta, Suzuki, & Nieman, 2015). They are also implicated in chronic fatigue syndrome and upper respiratory tract infections limiting athletic performance. Systemic inflammation can lead to "sickness behaviors" such as tiredness, drowsiness, and lethargicness, which promote return to homeostasis (Smith, 2000). Elevated IL-6 and TNFα have been observed following overreaching periods and are subsequently reduced following a taper (Farhangimaleki et al., 2009; Main et al., 2010). Worthwhile reductions in IL-6 and TNFα were only observed following COMP3. Considering the role of IL-6 and TNF-ὰ in the inflammatory response to training it is possible that decreases in these markers are related to the greater reduction in training VL during this competition phase compared to the others. While reduced inflammation is advantageous for recovery, reduced mechanical and metabolic stress also decrease hypertrophic signaling (Schoenfeld, 2013). Therefore, reduced training-induced inflammation may also explain the decreases in CSA observed following COMP3.

Furthermore, the observed decreases in IL-6 and TNFα coupled with increases in the T:C ratio following COMP3 provide evidence that these circulating cytokines influence the hypothalamic-pituitary-adrenal axis and hypothalamic-pituitary-gonadal axis in response to significant decreases in training VL. In support of this, IL-6 and TNF-ὰ have been found to increase glucocorticoid production via interaction with hypothalamic receptors resulting in the secretion of corticotropin releasing hormone (Schobitz, Reul, & Holsboer, 1994). There is also evidence that elevated IL-6 and TNF-ὰ disrupt hypothalamic secretion of gonadotropin-releasing hormone possibly leading to reduced testosterone secretion (Schobitz et al., 1994; Wu & Wolfe, 2012). Therefore, reductions in IL-6 and TNF-ὰ following COMP3 may have indirectly attenuated cortisol secretion and promoted greater testosterone secretion explaining the elevated

T:C ratio following COMP3. These findings demonstrate that training during a competition phase is as a balance between reducing training stress and inflammation (fatigue) while preserving and expressing previously accrued adaptations (fitness) to optimize performance (Stone, Stone, & Sands, 2007).

<u>Squat Jump and Mid-Thigh Pull Performance Changes</u>

Squat jump and MTP performance provide an indication of the athlete's explosive ability prior to and following the competition phase. Overall, squat jump and MTP performance changes correspond with weightlifting performance at each competition. Increases in unloaded squat JH were observed the final week of the competition phase prior to COMP1, whereas decreases in unloaded and loaded squat JH were observed the final week of the competition phase prior to COMP3. Similarly, MTP concentric VD90% increased following COMP1, and decreased following COMP3. Squat and MTP performance changes were inconsistent (positive and negative) following COMP2 making it difficult to characterize the athlete's response. However, MTP PFa was consistently reduced at all loads following COMP2, which is more likely reflective of the increase in body mass during this period rather than changes in peak force. Also, training VL during COMP2 was greater than her normal training VL except for the week of competition because she was not peaking. Overreaching periods have been shown to alter weightlifting technique and cognitive function (Dupuy et al., 2014; Stone et al., 1993), which may explain why changes in her squat jump and dynamic MTP performance were inconsistent following COMP2.

Interestingly, concentric VD50% increased although VD90% decreased following COMP3. These findings indicate that heavier loads may be necessary to identify sport-specific performance changes in weightlifters. Considering the relative ease, low fatigue, and low injury

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risk associated with performing dynamic MTPs, performing this test with heavier loads is not a concern from an athlete monitoring standpoint. The unloaded squat jump performance improvements and dynamic MTP performance improvements corresponded with increases in CSA and successful weightlifting performance during her first competition. In contrast, the decreases in unloaded and loaded squat jump performance and dynamic MTP performance corresponded with decreases in CSA and unsuccessful weightlifting performance during her third competition.

CONCLUSION

In summary, the athlete's competition weightlifting performance can be explained by changes in body mass, muscle CSA, biochemical, kinetic and kinematic factors following a competition phase. Specifically, these findings demonstrate that vastus lateralis CSA can be maintained following a competition phase in a high level weightlifter provided large changes in body mass are not attempted close to competition. Changes in circulating cytokines (IL-6 and TNFα) may explain the alterations in testosterone and cortisol concentrations corresponding with the changes in weightlifting training VL observed in the present study and in previous investigations following a taper. However, reduced muscle damage-induced inflammation can reduce hypertrophic signaling, which may have partially explained the observed decreases in CSA and corresponding decreases in squat jump and dynamic MTP performance following COMP3. Conversely, increases in squat jump and dynamic MTP performance likely explain successful performance during her first competition. The athlete trained through her second competition, which may explain the reductions in total and bioavailable testosterone, possible reductions in the T:C ratio, and corresponding decreases in loaded squat jump and dynamic MTP performance. Concurrent changes in serum decorin and myostatin suggest homeostatic

regulation and appeared to correspond with changes in training VL. Overall, these findings provide a biochemical, morphological, and biomechanical basis for alterations in performance outcomes following multiple competition phases in a national level weightlifter.

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CHAPTER 7

SUMMARY AND FUTURE INVESTIGATIONS

The purpose of this dissertation was to examine changes following a peaking phase in individual event and team sport strength-power athletes. This purpose was addressed by conducting individual research investigations: 1) examining the effects of an ORT on individual-event strength-power athletes preparing for conference championships, 2) examining changes in team sport athletes throughout a competitive season in preparation for conference championships, 3) examining differences in the effects of a peaking phase between new and returning team sport athletes in order to identify variables that best explain the variation in performance changes, and 4) examining changes in a national level female weightlifter following three separate competition phases.

The results of study I demonstrated that pre/in-season training appeared to elicit increases in MT, whereas the ORT resulted in improved explosive ability in the absence of further detectable changes in muscle architecture. Additionally, the ORT appeared to augment throwing performance at conference championships and national ranking, which may have been due to the reduced RPETL and VLd. The findings of this study show that an overreaching week followed by a 3-week taper is an effective means of improving explosive ability and throwing performance in collegiate track and field throwers. Collegiate throwers and athletes in similar sports may benefit from an ORT phase where training load is exponentially reduced prior to an important competition.

In order to assess whether an ORT would benefit team sport athletes preparing for conference championships, we conducted two further studies (study II and III) with NCAA division I female collegiate volleyball athletes. In study II, we found positive alterations in

female volleyball athletes vastus lateralis muscle architecture and preserved explosive ability over the competitive season while performing a periodized training program. Additionally, the tapering period resulted in large decreases in body fat percentage and moderate decreases in vastus lateralis MT with no statistical changes in jumping performance. Large to very large, negative relationships were observed between maximal strength and changes in SJPPa and SJH with various loads (0kg to 40kg). One possible explanation is that the training stimulus may have been insufficient for the stronger athletes, which negatively affected their SJ performance. In support of this, the two athletes with the greatest relative strength decreased SJ performance over the course of the season suggesting an insufficient strength training stimulus. A solution we suggested was to perform an overreaching microcycle prior to the taper in an attempt to preserve previously accrued muscular adaptations.

In a follow up study with a similar team of volleyball athletes (study III), we had players perform an overreach microcyle prior to the taper and an abbreviated overreach the week of conference championships followed by a sharp reduction in training load. We found large to very large differences in age, trivial to large differences in vastus lateralis muscle architecture, trivial to very large differences in relative maximal strength and CMJ performance in favor of returners over new players at baseline. We also found moderate to very large, and trivial to very large differences in CMJ JH and PPa supercompensation during the peaking phase in favor of the returners over the new players. These findings of this study demonstrated that returners responded better to the ORT than the new players. Upon further examination, we found that the number of sets played during the peaking phase and athlete's baseline back squat 1RMa were the strongest correlates of JH supercompensation during the peaking phase. A possible explanation is that athletes who played more sets during the peaking phase had greater relative maximal

strength, which may have enhanced their ability to tolerate higher training loads resulting in greater CMJ performance supercompensation during the taper. These findings suggest that training prescription during the peaking phase should differ between athletes based on their relative maximal strength and time spent competing. Strength coaches should emphasize developing lower extremity muscle architectural characteristics to enhance strength of the musculature contributing to volleyball performance.

A fourth study was conducted to provide a more comprehensive evaluation of changes a strength-power athlete undergoes during and following a peaking phase. The national level female weightlifter had a similar somatotype and weightlifting total to those previously reported for high level U.S. weightlifters. The findings showed that vastus lateralis CSA can be maintained following a competition phase in a high level weightlifter provided large changes in body mass are not attempted close to competition. Changes in circulating cytokines (IL-6 and TNFα) may explain the alterations in T and C concentrations, which corresponded with the changes in weightlifting training VL. The athlete trained through COMP2, which may explain the reductions in total and bioavailable T, possible reductions in the T:C ratio, and corresponding decreases in loaded SJ and dynamic MTP performance. Changes in serum myostatin and decorin following the competition periods appeared to correspond with changes in training VL with increases in training VL leading to decreases in myostatin and decorin indicating a homeostatic regulation of these muscle growth-related markers in serum. The findings of this study provide a biochemical, morphological, and biomechanical basis for alterations in performance outcomes following multiple competition phases in a national level weightlifter.

Overall, the findings of these investigations support the use of an ORT for strength-power athletes and provide an underlying biochemical, morphological, and biomechanical basis for the

observed changes in performance. The investigations were, however, observational and did not control for multiple confounding variables that could influence the outcomes. Therefore, future research should use an experimental design and address changes in muscle architecture and sport performance in individual event and team sport strength-power athletes following a taper with or without a prior overreach. Future studies should also examine the effect of inflammatory cytokines on GnRH and subsequent production of LH and T following an ORT in male and female strength-power athletes. Additional mechanistic research should examine changes in the serum concentrations of decorin and myostatin in conjunction with expression of its receptor (Activin-II) on the myocyte surface following ORT phases. Providing additional information of the biochemical, morphological, and biomechanical changes following ORT periods will greatly enhance how these characteristics can be modified to optimize performance at crucial competitions with individual event and team sport strength-power athletes.

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APPENDICES

APPENDIX A: Institutional Review Board Approval Letters

IRB APPROVAL – Continuing Expedited Review

March 15, 2016

Caleb Bazyler

Re: The effects of a 4-week taper on throwing performance and measures of strength and explosiveness in Division I collegiate throwers
IRB#: 0314.22s
ORSPA#:

The following items were reviewed and approved by an expedited process:
- xform 107, narrative portion of new protocol submission xform, currently appproved ICD version 7/28/15 stamped approved 7/30/15 and clean copy of ICD version 7/28/15, attached article , Protocol history

On March 14, 2016, a final approval was granted for a period not to exceed 12 months and will expire on March 13, 2017. The expedited approval of the study will be reported to the convened board on the next agenda.

Note: This study is closed to accrual, therefore stamped, approved informed consent documents were not returned. However, should this study ever be open to accrual, revised informed consent documents will have to be submitted and approved by the IRB before enrollment of participants can restart.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
George Youngberg, M.D., Chair
ETSU/VA Medical IRB

Accredited Since December 2005

IRB APPROVAL – Minor Modification

July 7, 2014

Caleb Bazyler

RE: The effects of a 4-week taper on throwing performance and measures of strength and explosiveness in Division I collegiate throwers

IRB #: 0314.22s

On 07/07/2014, a final approval was granted for the minor modification listed below. The minor modification will be reported to the convened board on the next agenda.

- xform modification request conduct a similar study with the women's volleyball players. The methods will be the same with the exception of a couple measurements; ICD for volleyball players version 6/30/2014

The **stamped, approved ICD(s)** listed below has been stamped with the approval and expiration date and must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document(s) (ICD version 6/30/2014 stamped 7/7/2014)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Accredited since December 2005

IRB APPROVAL – Minor Modification

July 30, 2015

Caleb Bazyler

RE: The effects of a 4-week taper on throwing performance and measures of strength and explosiveness in Division I collegiate throwers

IRB #:   0314.22s

On July 30, 2015, a final approval was granted for the minor modification listed below. The minor modification will be reported to the convened board on the next agenda.

- xform modification, previous approved ICD version 6/30/14, revised ICD version 7/28/15 highlighted changes, revised ICD version 7/28/15 clean copy

The **stamped, approved ICD(s)** listed below has been stamped with the approval and expiration date and must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document(s) (,ICD version 7/28/15 stamped 7/30/2015)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
George Youngberg, M.D., Chair

Accredited since December 2005

IRB APPROVAL PENDING MODIFICATIONS

March 16, 2015

Caleb Bazyler

Re: Longitudinal monitoring of a national level weightlifter: a one-year case study
IRB#: c0215.19s

The following items were reviewed and approved by an expedited process, ***pending*** the requested changes listed below:
- xform New Protocol Submission; ICD (version 6/30/2014); CV

CONTINGENT APPROVAL- REVISED ITEMS DUE: within 2 weeks from March 16, 2015

The requested changes are:

Informed Consent Document:
1) Please omit the reference to the VA IRB in the "confidentiality" section of the ICD.
2) In addition, at the end of the ICD just prior to the signatures please include a statement that the participant agrees he/she is at least 18 years of age.
3) Finally, please address how the confidentiality will be maintained when presenting or publishing results. In other words, given this participant is the only one, does that mean she will be directly identified in the publication/presentation? I believe the participant should know that up front if so.

Please submit to the IRB Office. A final approval letter will be issued when the changes have been approved.

Please note: As per 45 CFR 46, absolutely no research activity can be initiated until formal IRB approval has been granted.

Sincerely,
Stacey Williams, Ph.D., Chair
ETSU Campus IRB

Accredited Since December 2005

APPENDIX B: Informed Consent Documents

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of a 4-week taper on throwing performance and measures of strength and explosiveness in Division I collegiate throwers

Informed Consent Form

Introduction:

This Informed Consent will explain about being a participant in a research study. It is important that you read this material carefully and then decide if you wish to be a volunteer.

Purpose:

The purpose of this research project is to investigate the effectiveness of a 4-week tapering program on measures of strength and explosiveness in ETSU collegiate throwers. The study seeks to provide further insight to strength and conditioning professionals and coaches on how to peak for athletic performance.

DURATION:

The study will last 13 weeks including all training, testing sessions, and competitions. All participants will follow a similar training program throughout the duration of the study.

PROCEDURES:

Research:

1. Vastus lateralis muscle thickness and pennation angle (using ultrasound)
2. Backward overhead throw, squat underhand throw
3. TRIMP scores (session rating of perceived exertion * duration)
4. VLd = sets * reps * load * bar displacement
5. 48-hour dietary log prior to testing sessions
6. Competition wind resistance, humidity, barometric pressure and temperature

Non-research:

1. Anthropometrics (height and body mass)
2. Body composition (sum of seven skinfolds)
3. Countermovement and static jump with 0kg, 20kg and 40kg
4. Maximal isometric mid-thigh pull (at 125 degree knee angle)

The research procedures are additional measures included in the study. The non-research procedures listed are already part of the participant's regular training and testing program and will also be used for statistical analysis.

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of a 4-week taper on throwing performance and measures of strength and explosiveness in Division I collegiate throwers

ALTERNATIVE PROCEDURES/TREATMENTS:

There are no alternative procedures except not to participate

POSSIBLE RISKS/DISCOMFORTS:

Risks of the research procedures include the possibility of a cardiac event when doing a maximal effort test. There is also a possibility of a cardiac event after testing sessions. These risks could include abnormal blood pressure, fainting, disorders of heart rhythm, and very rare instances of heart attack. There is the possibility of muscle strains, tears and joint pain from the maximal tests. There is also the possibility of muscle soreness following the testing sessions. The testing sessions involve progressive stages of increasing effort and at any time the participant may terminate the test for any reason. Participant must complete a medical history questionnaire before participating in the study. If the participant has high blood pressure (greater than 140/90 mmHg), heart disease, has ever had a stroke, smoke, family history of heart attack or stroke, has any contraindications to exercise testing, neurological disorders, or orthopedic limitations then the participant cannot participate in this study.

Risks of non-research procedures include the aforementioned cardiac events and musculoskeletal injuries. Cessation of these testing procedures will be decided by the coach on an individual basis. Risks of allowing the use of data from the non-research procedures include greater cumulative fatigue from a longer testing battery, which may delay the recovery process. This risk will be minimized by the coach, who has decided to modify the training program to provide the recovery necessary for the participant following testing sessions.

The risks of research and non-research procedures will be minimized by using trained technicians and by teaching the participant proper technique in performing the tests. There is minimal risk involved in the testing sessions since the participants perform the research and non-research procedures on a regular basis and will be provided with careful instructions. To reduce the risk of muscular strains and tears and joint pain the participant will be told to perform the tests as instructed.

POSSIBLE BENEFITS:

Benefits of the research procedures include dynamic testing by certified strength and conditioning specialists (NSCA-CSCS), free muscular strength/power assessments, training load, and muscle architecture assessment. Additional benefits include laboratory and field based assessments of performance pre- and post-taper, which gives the participants insight into the effectiveness of their training program.

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of a 4-week taper on throwing performance and measures of strength and explosiveness in Division I collegiate throwers

Benefits of allowing the use of data from the non-research procedures include additional information on the participant's performance level as well as their body composition in relation to their training program. These procedures in conjunction with the research procedures provide the participant with a better indication of their preparedness for competition.

COMPENSATION FOR MEDICAL TREATMENT:

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury that may happen as a result of your being in this study. ETSU makes no commitment to pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6055.

FINANCIAL COSTS:

There are no financial costs to you.

COMPENSATION IN THE FORM OF PAYMENTS TO RESEARCH PARTICIPANTS:

There is no compensation for your participation in this research.

VOLUNTARY PARTICIPATION:

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. You may quit by calling or e-mailing Caleb Bazyler, whose phone number is 305-205-4462, and whose e-mail is bazyler@goldmail.etsu.edu or Dr. Satoshi Mizuguchi, (423) 439-5387, mizuguchi@etsu.edu.

CONTACT FOR QUESTIONS:

If you have any questions, problems or research-related injury or medical problems at any time, you may call or e-mail Caleb Bazyler at 305-205-4462, bazyler@goldmail.etsu.edu or Dr. Satoshi Mizuguchi, (423) 439-5387, mizuguchi@etsu.edu. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't

APPROVED
by the ETSU/VA IRB
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MAY 1 5 2015
By ___HP___
Chair/IRB Coordinator

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of a 4-week taper on throwing performance and measures of strength and explosiveness in Division I collegiate throwers

reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY:

Every attempt will be made to see that your study results are kept confidential. The only study personnel who will be allowed to view your data are Caleb Bazyler and Dr. Satoshi Mizuguchi, as well as your coach. As usual, feedback will be given back to the coach as soon as possible after each testing session to allow him to make the best decisions to enhance your performance. A copy of the records from this study will be stored in a locked file cabinet in the kinesiology lab for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the ETSU/VA IRB or ETSU IRB, and the Exercise and Sport Science department will have access to the study records. Your (medical) records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project.

_____   DATE
SIGNATURE OF PARTICIPANT

_____   DATE
PRINTED NAME OF PARTICIPANT

_____   DATE
SIGNATURE OF INVESTIGATOR

_____   DATE
SIGNATURE OF WITNESS (if applicable)

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of tapering on volleyball performance and measures of
strength and explosiveness in Division I women's volleyball players

Informed Consent Form

Introduction:

This Informed Consent will explain about being a participant in a research study. It is
important that you read this material carefully and then decide if you wish to be a
volunteer.

Purpose:

The purpose of this research project is to investigate the effectiveness of a tapering
program on measures of strength and explosiveness in ETSU women's volleyball players.
The study seeks to provide further insight to strength and conditioning professionals and
coaches on how to peak for athletic performance.

DURATION:

The study will last 18 weeks including all training, testing sessions, and competitions. All
participants will follow a similar training program throughout the duration of the study.

PROCEDURES:

Research:

1. Vastus lateralis muscle thickness and pennation angle (using ultrasound)
2. TRIMP scores (session rating of perceived exertion * duration)
3. Accelerometer and GPS data collected during volleyball matches and practice
4. VLd = sets * reps * load * bar displacement
5. 48-hour dietary log prior to testing sessions

Non-research:

1. Anthropometrics (height and body mass)
2. Body composition (sum of seven skinfolds)
3. Countermovement and static jumps with 0kg, 5kg, 11kg, 20kg, 40kg, and 60kg
4. Maximal isometric mid-thigh pull (at 125 degree knee angle)

The research procedures are additional measures included in the study. The non-research
procedures listed are already part of the participant's regular training and testing program
and will also be used for statistical analysis.

APPROVED
By the ETSU/VA IRB

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Ver. 07/28/15   Page 1 of 4   Subject Initials _____

By_____
Chair-IRB Coordinator

ETSU/VA IRB

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of tapering on volleyball performance and measures of
strength and explosiveness in Division I women's volleyball players

ALTERNATIVE PROCEDURES/TREATMENTS:

There are no alternative procedures except not to participate

POSSIBLE RISKS/DISCOMFORTS:

Risks of the research procedures include the possibility of a cardiac event when doing a
maximal effort test. There is also a possibility of a cardiac event after testing sessions.
These risks could include abnormal blood pressure, fainting, disorders of heart rhythm,
and very rare instances of heart attack. There is the possibility of muscle strains, tears and
joint pain from the maximal tests. There is also the possibility of muscle soreness
following the testing sessions. The testing sessions involve progressive stages of
increasing effort and at any time the participant may terminate the test for any reason.
Participant must complete a medical history questionnaire before participating in the
study. If the participant has high blood pressure (greater than 140/90 mmHg), heart
disease, has ever had a stroke, smoke, family history of heart attack or stroke, has any
contraindications to exercise testing, neurological disorders, or orthopedic limitations
then the participant cannot participate in this study.

Risks of non-research procedures include the aforementioned cardiac events and
musculoskeletal injuries. Cessation of these testing procedures will be decided by the
coach on an individual basis. Risks of allowing the use of data from the non-research
procedures include greater cumulative fatigue from a longer testing battery, which may
delay the recovery process. This risk will be minimized by the coach, who has decided to
modify the training program to provide the recovery necessary for the participant
following testing sessions.

The risks of research and non-research procedures will be minimized by using trained
technicians and by teaching the participant proper technique in performing the tests.
There is minimal risk involved in the testing sessions since the participants perform the
research and non-research procedures on a regular basis and will be provided with careful
instructions. To reduce the risk of muscular strains and tears and joint pain the participant
will be told to perform the tests as instructed.

POSSIBLE BENEFITS:

Benefits of the research procedures include dynamic testing by certified strength and
conditioning specialists (NSCA-CSCS), free muscular strength/power assessments,
training load, and muscle architecture assessment. Additional benefits include laboratory
and field based assessments of performance pre- and post-taper, which gives the
participants insight into the effectiveness of their training program.

Ver. 07/28/15   Page 2 of 4   Subject Initials _____

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of tapering on volleyball performance and measures of strength and explosiveness in Division I women's volleyball players

Benefits of allowing the use of data from the non-research procedures include additional information on the participant's performance level as well as their body composition in relation to their training program. These procedures in conjunction with the research procedures provide the participant with a better indication of their preparedness for competition.

COMPENSATION FOR MEDICAL TREATMENT:

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury that may happen as a result of your being in this study. ETSU makes no commitment to pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6055.

FINANCIAL COSTS:

There are no financial costs to you.

COMPENSATION IN THE FORM OF PAYMENTS TO RESEARCH PARTICIPANTS:

There is no compensation for your participation in this research.

VOLUNTARY PARTICIPATION:

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. Refusal to participate in the study will not impact your grades if you enroll in a class taught by sports science staff. You may quit by calling or e-mailing Caleb Bazyler, whose phone number is 305-205-4462, and whose e-mail is bazyler@goldmail.etsu.edu or Dr. Satoshi Mizuguchi, (423) 439-5387, mizuguchi@etsu.edu.

CONTACT FOR QUESTIONS:

If you have any questions, problems or research-related injury or medical problems at any time, you may call or e-mail Caleb Bazyler at 305-205-4462, bazyler@goldmail.etsu.edu or Dr. Satoshi Mizuguchi, (423) 439-5387, mizuguchi@etsu.edu. Caleb Bazyler will be obtaining your informed consent and is not one of the sport scientists for women's volleyball. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have

Ver. 07/28/15   Page 3 of 4   Subject Initials _____

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: The effects of tapering on volleyball performance and measures of strength and explosiveness in Division I women's volleyball players

any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY:

Every attempt will be made to see that your study results are kept confidential. The only study personnel who will be allowed to view your data are Caleb Bazyler and Dr. Satoshi Mizuguchi, as well as your coach. As usual, feedback will be given back to the coach as soon as possible after each testing session to allow him to make the best decisions to enhance your performance. A copy of the records from this study will be stored in a locked file cabinet in the kinesiology lab for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the ETSU/VA IRB or ETSU IRB, and the Exercise and Sport Science department will have access to the study records. Your (medical) records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project and acknowledge that you are at least 18 years of age.

_____   _____
SIGNATURE OF PARTICIPANT   DATE

_____   _____
PRINTED NAME OF PARTICIPANT   DATE

_____   _____
SIGNATURE OF INVESTIGATOR   DATE

_____   _____
SIGNATURE OF WITNESS (if applicable)   DATE

Ver. 07/28/15   Page 4 of 4   Subject Initials _____

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: Longitudinal monitoring of a national level weightlifter: a one-year case study

Informed Consent Form

Introduction:

This Informed Consent will explain about being a participant in a research study. It is important that you read this material carefully and then decide if you wish to be a volunteer.

Purpose:

The purpose of this study is to observe changes in your anthropometric, biochemical, physiological and performance measures over the next year. The primary focus will be on examining changes in these measures following various competition periods to examine the effectiveness of your tapering programs.

DURATION:

The study will last one year including all training, testing sessions, and competitions. No changes will be made to the training program your coach designs aside from the testing sessions used to monitor your progress.

PROCEDURES:

Research:

1. Muscle architecture, cross-sectional area and thickness (using ultrasound)
2. TRIMP scores (session rating of perceived exertion * duration)
3. Blood draws following an overnight fast
4. 48-hour dietary log prior to testing sessions
5. Dynamic mid-thigh pull

Non-research:

1. Anthropometrics (breadth, height and girth measurements)
2. Body composition (skinfolds)
3. Hydration (urine specific gravity)
4. Stress/mood state questionnaire
5. Resting heart rate and blood pressure
6. VLd = sets * reps * load * bar displacement
7. Squat jumps

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: Longitudinal monitoring of a national level weightlifter: a one-year case study

The research procedures are additional measures included in the study. The non-research procedures listed are already part of your regular training and testing program and will also be used for statistical analysis.

ALTERNATIVE PROCEDURES/TREATMENTS:

There are no alternative procedures except not to participate

POSSIBLE RISKS/DISCOMFORTS:

Risks of the research procedures include the possibility of a cardiac event when doing a maximal effort test. There is also a possibility of a cardiac event after testing sessions. These risks could include abnormal blood pressure, fainting, disorders of heart rhythm, and very rare instances of heart attack. There is the possibility of muscle strains, tears and joint pain from the maximal tests. There is also the possibility of muscle soreness following the testing sessions. The testing sessions involve progressive stages of increasing effort and at any time you may terminate the test for any reason. You must complete a medical history questionnaire before participating in the study. If you have high blood pressure (greater than 140/90 mmHg), heart disease, have ever had a stroke, smoke, have any contraindications to exercise testing, neurological disorders, or orthopedic limitations then you cannot participate in this study. There is a small risk of infection resulting from the blood draw. Risks also include greater cumulative fatigue from a longer testing battery, which may delay the recovery process. This risk will be minimized by the coach, who has decided to modify the training program to provide you the recovery necessary following testing sessions.

The risks of research procedures will be minimized by using trained technicians and by teaching you proper technique in performing the tests. The risk of infection during the blood draw will be minimized by sterilizing the partitioned area and disposing sharps and other material in a bio-hazard container. There is minimal risk involved in the testing sessions since you will be provided with careful instructions for all research procedures. To reduce the risk of muscular strains and tears and joint pain you will be told to perform the tests as instructed.

POSSIBLE BENEFITS:

Benefits of the research procedures include dynamic testing by certified strength and conditioning specialists (NSCA-CSCS), free muscular strength/power assessments, training load, muscle architecture, and blood biomarker assessment. Additional benefits include laboratory and field based assessments of performance pre- and post-taper, which gives you insight into the effectiveness of your training program. These procedures will provide you with a better indication of your preparedness for competition.

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: Longitudinal monitoring of a national level weightlifter: a one-year case study

COMPENSATION FOR MEDICAL TREATMENT:

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury that may happen as a result of your being in this study. ETSU makes no commitment to pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6055.

FINANCIAL COSTS:

There are no financial costs to you.

COMPENSATION IN THE FORM OF PAYMENTS TO RESEARCH PARTICIPANTS:

There is no compensation for your participation in this research.

VOLUNTARY PARTICIPATION:

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. You may quit by calling or e-mailing Caleb Bazyler, whose phone number is 305-205-4462, and whose e-mail is bazyler@goldmail.etsu.edu or Dr. Satoshi Mizuguchi, (423) 439-5387, mizuguchi@etsu.edu.

CONTACT FOR QUESTIONS:

If you have any questions, problems or research-related injury or medical problems at any time, you may call or e-mail Caleb Bazyler at 305-205-4462, bazyler@goldmail.etsu.edu or Dr. Satoshi Mizuguchi, (423) 439-5387, mizuguchi@etsu.edu. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research participant. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY:

Every attempt will be made to see that your study results are kept confidential. The only study personnel who will be allowed to view your data are Caleb Bazyler and Dr. Satoshi

APPROVED
By the ETSU IRB

DOCUMENT VERSION EXPIRES

Ver. 03/16/15   MAR 1 9 2015   Page 3 of 4   MAR 1 8 2016   Subject Initials _____

By____
Chair/IRB Coordinator

ETSU IRB

PRINCIPAL INVESTIGATOR: _____Caleb Bazyler_____

TITLE OF PROJECT: Longitudinal monitoring of a national level weightlifter: a one-year case study

Mizuguchi. As usual, feedback will be given back to the coach as soon as possible after each testing session to allow him to make the best decisions to enhance your performance. A copy of the records from this study will be stored in a locked file cabinet in the kinesiology lab for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as the participant. Although you will not be directly named as the participant, your competition results will likely be included in the publication and/or presentation. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, ETSU IRB, and the Exercise and Sport Science department will have access to the study records. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project and acknowledge that you are at least 18 years of age.

SIGNATURE OF PARTICIPANT	DATE
PRINTED NAME OF PARTICIPANT	DATE
SIGNATURE OF INVESTIGATOR	DATE
SIGNATURE OF WITNESS (if applicable)	DATE

Bazyler, C.D.; Abbott, H.A.; Bellon, C.R.; Taber, C.B.; Stone, M.H. Strength Training for Endurance Athletes: Theory to Practice. *Strength Cond J* 37(2): 1-12, 2015.

Bazyler, C., Bailey, C., Chiang, C.Y., Sato, K., Stone, M.H. The effects of strength training on isometric force production symmetry in recreationally trained males. *Journal of Trainology* 3(1), 6-10. 2014

Honors and Awards:

Clemmer College of Education Outstanding Graduate Student Award, 2016

GPSA Travel Award: $500 for NACSM annual meeting, 2016

GPSA Travel Award: $500 for NACSM annual meeting, 2015

1st place coaches education poster presentation at Sports Science and Coach's College, Johnson City, TN, 2014

ASUN Champions ETSU Women's Tennis, strength coach and sport scientist, Johnson City, TN, 2014

ASUN Champions ETSU Men's Tennis, strength coach and sport scientist, Johnson City, TN, 2012 and 2013

National Strength and Conditioning Association, Certified Strength and Conditioning Specialist (CSCS), 2011

Hortense Glenn Award, Florida State University, Tallahassee, FL, 2010

Bess H. Ward Honor's Thesis Award, Florida State University, Tallahassee, FL, $1,000, 2009