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Changes in Psychological, Morphological, and Performance Characteristics in Preparation for a National Weightlifting Competition

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Changes in Psychological, Morphological, and Performance Characteristics in Preparation for a National Weightlifting Competition

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ABSTRACT

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The primary aim of this study was to examine the time course of change in muscle morphology and vertical jump performance in weightlifters preparing for a national competition. The secondary aim of this study is to examine how perceived recovery and stress state corresponds with alterations in training load leading up to competition. Eleven Olympic Training Site weightlifters completed a 4-week peaking phase for a national competition. Body mass, stress and recovery psychometric measures, and unloaded/loaded (20kg) squat jump height (SJH) were measured weekly and at the competition site. Vastus lateralis cross-sectional area (CSA), muscle thickness (MT) and pennation angle (PA) ultrasound measurements were taken prior to and following the training protocol. In competition, 6 athletes set a personal best in snatch, clean and jerk and/or total. These results suggest that improvements in the loaded SJ and psychometric measures correspond to successful competition performance in some weightlifters. Notably, most weightlifters appeared to be peaked within 3 days of competition.

DEDICATION

To my mother and father, for their support and love.

To my wife, Christianna, for your strength.

To my friends, for sharing these years with me.

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CHAPTER 1

INTRODUCTION

Problem Statement

Sports performance programs attempt to improve an athlete's physical abilities and performance to yield the best possible outcome during competition. One approach to manage the training process is periodization, which attempts to integrate the multiple components of the training process to successfully converge the summative effects of training and allow for the optimal expression of fitness at the desired time. The fitness-fatigue paradigm is an instructive framework for this goal. It states that training produces both fitness and fatigue aftereffects and that fatigue masks the expression of the athlete's fitness (Bannister 1982; Zatsiorsky 1995). One strategy to reduce fatigue and maximize preparedness, or the expression of fitness, is tapering. A taper is a planned reduction in training volume and/or intensity prior to competition, which allows fatigue to dissipate thereby maximizing preparedness at competition (Mujika & Padilla, 2003). The difference between winning and losing in a sports event can often come down to small differences in performance (< 2 %) (Mujika et al., 2002; Mujika et al., 2000), and a properly executed taper has been shown to cause improvements approximately equivalent to this difference (~3%) (Le Meur et al., 2012). Thus, the taper can prove vital to realizing peak performance.

Block periodization is a commonly used approach to order training in a timely manner and elicit phasic training adaptations (hypertrophy, max strength, speed, etc.). Block periodization uses concentrated workloads with emphasis on specific technical, motor, and physical characteristics which allow for the implementation of phasic potentiation (DeWeese et al. 2015 a and b; Issurin, 2008). This requires the application of a progressive overload stimulus, with the intent to disturb biological homeostasis and return physiological and performance outcomes greater than the previous state (Bompa & Haff, 2009; Cunanan et al. 2018). The application of the overload stimulus results in accrued fatigue, followed by the dissipation of fatigue and potential to express new training-induced adaptations (Meeusen et al., 2012). Further, this approach culminates in a 'peak', during which training induced stressors are manipulated, via a taper, in order to optimize the chance of success in competition (Mujika and Padilla 2003). The peak/taper literature has primarily examined the effects of peak/taper strategies in endurance/aerobic sports. However, peaking and tapering strategies, nor their effects, in strength/power sports are not as well characterized. Given the differences in physiological demands and training for aerobic vs. strength/power sports, it's reasonable to presume that optimal peak/taper strategies may differ between both types of sport. Weightlifting coaches may benefit from better understanding the taper timeline in the context of strength-power athletes, so that the correct implementation of a taper strategy can increase the chance of success in competition.

Athlete monitoring enables the coach and sport scientist to assess, via a multitude of measures, an athlete's response to training and subsequent effects on performance (Stone, Stone, & Sands, 2007). Prior related studies on high-level weightlifters have employed such athlete monitoring measures, including ultrasonography (Bayzler et al. 2018; Suarez et al., 2019), vertical jump testing (Hornsby et al. 2017), and psychometric questionnaires (Travis et al. 2018; Perkins et al., 2018) to evaluate acute and chronic changes in the athlete's performance capabilities due to training. However, the use of these indices as they relate specifically to the effects of tapering on performance in weightlifters remain unresolved. Given the general usefulness of such measures to evaluate training-induced changes, it is reasonable to expect that they may also be useful to examine the effects during a peak and taper period. Therefore, the primary purpose of this study was to examine the time course of changes in muscle morphology and vertical jump performance in weightlifters preparing for a national competition. The secondary aim of this study was to examine how perceived recovery and stress state corresponds with alterations in training load leading up to competition. Our hypothesis was that jumping performance would be peaked the day of competition, which would correspond to an improved mood state and preserved muscle cross-sectional area, muscle thickness, and pennation angle.

CHAPTER 2

COMPREHENSIVE REVIEW OF THE LITERATURE

Review of the Training Process

Training for competitive sport has long-standing historical roots, reaching back to physical and philosophical culture in ancient societies and culminating in modern concepts of training theory. A number of 20th century authors laid the groundwork for contemporary discussion of training theory, including works by Kotov, Pihkala, Matveyev, and others (Issurin, 2014; Kotov, 1916; Matveyev, 1964; Pihkala, 1930). In modern times, coaches and sport scientists seek to understand the training process from a scientific perspective to enhance sport performance outcomes. However, in terms of tapering practice for strength-power athletes, coaches often rely on unscientific, anecdotally shared methods which may stifle outcomes in competition (Mujika, Padilla, & Pyne, 2002). Thus, it is necessary to conduct research to elucidate best training practices, particularly within tapering for strength-power athletes.

The purpose of training is to develop the physical, tactical, and psychological characteristics necessary for an athlete to compete in the highest levels of competitive sport (Harre, 1982). Each athlete's highest potential level of competitive ability will be largely dependent on their genetic capabilities; thus, training attempts to maximize development within the athlete's genetic limitations and manage all alterable aspects of the process. (M.H. Stone, Stone, & Sands, 2007; Stebbing, 2015; Yessalis, 1993). Further, given that it is not possible to maintain peak physiological and psychological abilities throughout the training year, it is imperative to sequence training in a logical fashion to ensure that the athlete is prepared at the correct times throughout the competition schedule (Bompa & Haff, 2009).

Mechanistic Models

Several models have proven to be highly applicable to the training process and are ubiquitous among coaches and sport scientists. Among these models is Selye's General Adaptation Syndrome (GAS), which provides a framework to understand the biological basis of the application of training stressors (Cunanan et. al 2018; Selye, 1982). GAS is generally believed to be the primary model from which other key concepts of periodization stem from (Stone, Stone, & Sands, 2007). This mechanistic model consists of three stages, following the application of a stressor- alarm reaction, stage of resistance, and stage of exhaustion (Selye, H., 1936). System-stress will be proportional to the strength of the stimulus and duration, and will determine the extent of each stage. Further, Seyle suggested that GAS has broad implications regarding adaptation and the avoidance of exhaustion (Selye, H., 1976). The relationship described in GAS relates highly to observed response to training stressors. Building from the biological basis for adaptation described in GAS, Yakovlev's stimulus-fatigue-recovery-adaptation (SFRA) model gives additional information regarding the functional response from training and subsequent adaptation (Yakovlev, 1967). The SFRA model relates to fatigue accumulation specifically; following the application of a stimulus, protein synthesis is acutely enhanced, but fatigue is accumulated. With rest, fatigue dissipates, and performance adaptations ensues, resulting from the effects of supercompensation (Rowbottom, 2000). Notably, this effect on performance has been observed following a high-volume overreach phase, specifically within strength-power athletes and weightlifters (Fry et al. 2000a; Stone and Fry 1998; Stone et al. 2003). Finally, the most prominent modern model is the fitness-fatigue paradigm (FFP), which states that the interaction between the two aftereffects of training, fatigue and fitness, influences the expression of the athlete's preparedness (Bannister 1982; Zatsiorsky 1995). While the SFRA implicates a cause-effect relationship between fatigue and improvement in fitness due to the effect of the stressor, the FFP describes opposing effects of these factors (Zatsiorsky, 1995). Generally speaking, fatigue has a larger magnitude and shorter duration, whereas fitness has a smaller magnitude and longer duration (Bannister, 1982). General fitness is represented by the state of the athlete at rest, with all prior after-effects of training dissipated.

Periodization

Periodization is founded on the understanding developed in the previously discussed mechanistic models: general adaptation syndrome, stimulus-fatigue-recovery-adaptation, and the fitness-fatigue paradigm (Plisk and Stone, 2003; Turner, 2011). Periodization has previously been defined as ‘a logical phasic method of manipulating training variables in order to increase the potential for achieving specific performance goals’ (Plisk & Stone, 2003; Stone et al., 1999). In Bompa and Haff’s (2009) prolific text, they define periodization as “the logical integration and sequencing of training factors into mutually dependent periods of time designed to optimize specific physiological and performance outcomes at predetermined time points.” Periodization may be discussed within two primary contexts: (a) the division of the annual plan into smaller, more manageable subunit periods, which ensures peak performance at the correct time, and (b) the structure of sequential phases targeting specific biomotor abilities, allowing for the highest development of strength, speed, power, or whichever properties are crucial most for the given sport (Bompa & Haff, 2009; Bonderchuk, 1986). Regarding the sequenced phases of training, there have been significant differences in the terminology used to define and characterize these periods of training. Matveyev (1981) defined a periodized macro-structure as consisting of three primary periods: preparatory, competition, and transition. Throughout the preparatory stage, emphasis is placed on general, higher volume and lower intensity activities. The application of extensive volume loads is known to enhance work capacity, muscular endurance/hypertrophy, and potentially influence the duration and nature of subsequently gained adaptations (Abe et al., 2000; Charniga et al., 1987a; Hakkinen et al., 2003; Plisk & Stone, 2003). This preparatory phase lays the physiological foundation which later phases capitalize upon. This model was subsequently appended by Stone et al. (1981) to include a special preparation phase prior to the competition period. During this transitional period, emphasis shifts towards more sport-specific activities and the development of basic strength (Bompa and Haff, 2009; Counsilman, 1994). With a reduction in volume and a progressive increase in intensity, the athlete is more susceptible to significant strength and power development (Garhammer, 1993; Hornsby et al., 2017). This model culminates in the competition period, which is typically characterized by a marked decrease in volume, increase in intensity, and stabilization of technique and performance in the competition lifts (Brännström, Rova, & Yu, 2013; Mujika, 2009). Additionally, given that competition in weightlifting will take place on a specific day, it is logical to employ a peaking phase during the competition period to achieve peak performance at the appropriate time (Pritchard et al., 2015).

Block Periodization

Block periodization implements a sequence of concentrated training loads. Generally, a concentrated load has a strong emphasis on the development of one physiological characteristic (e.g. maximal strength, muscular endurance, power, etc.) (Stone, Stone, & Sands, 2007). Suchomel et al., (2018) defines retaining loads as the minimal dose needed to prevent involution of a specific fitness characteristic. Retaining loads are used in conjunction with concentrated loads to maintain previously acquired fitness characteristics, while allowing for the disturbance of homeostasis and development of new characteristics. Concentrated loads results in residual effects, which persist into the following training phase. These effects may potentiate or augment the emphasized characteristic of the next concentrated load (Deweese et al., 2015). Implementation of sequenced training (i.e. block periodization), in a variety of studies, has shown superior increases in speed, rate of force development, and power in comparison to non-sequenced training (Bartolomei et al., 2014; Breil et al., 2010; Garcia-Pallares et al., 2010; Harris et al., 2000; Issurin et al., 1988; Issurin & Sahrobajko, 1985; Mallo, J., 2011; Painter et al., 2012; Rønnestad et al., 2014). Painter et al., (2012) directly compared a block model vs. a daily undulating model (DUP). The authors found that the block model was more efficient in improving maximal strength and the rate of force development in college trained athletes. Notably, the findings of this study showed that the block model made statistically equal gains with fewer repetitions (52%) and less work (35%), compared to the DUP model. Further, other research indicates that block periodization may be a preferable approach to manage fatigue and prevent the onset of overtraining syndrome (Foster, C., 1998; Issurin 2008; Meeusen et al., 2013; Stone, Stone, & Sands, 2007).

Programming

Periodization provides the phasic timeline for training, wherein programming addresses the specifics of training (exercise selection, exercise order, manipulation of training load, rate of progression, etc.). Programming actualizes the plan laid out within the periodized model by driving the expected phasic adaptations, managing fatigue, and preparing the athlete psychologically (Coutts et al., 2007; Deweese et al., 2015; Stone, Stone, & Sands, 2007). Stone et al. (1982) honed observations made within the literature (O'Bryant, 1982) and provided a more comprehensive set of programming recommendations (See Table 1). This table represents an initial conception of block periodization; however, substantial evolution has occurred since this time (Carroll et al., 2018; Cunanan et al., 2018; Deweese et al., 2015 a; Deweese et al., 2015 b; Harris et al., 2000; Hornsby et al., 2013; Hornsby et al., 2017; Kirksey et al., 1998; Painter et al., 2012; Painter et al., 2018; Plisk & Stone, 2003; Stone et al., 1998; Stone et al., 1999 a; Stone et al., 1999 b; Stone et al., 2000; Stone et al., 2006 a; Stone et al., 2006 b; Suarez et al., 2019) which has culminated in the formulation of a more robust model (Carroll et al., 2018; Deweese et al., 2015 a and b).

Table 2.1

Hypothetical Model of Strength Training (adapted from Stone et al. 1982)

Preparation	**Transition 1**	**Competition**	**Transition 2**	
Phase	Hypertrophy	Basic Strength	Strength & Power	Peaking or Maintenance
Sets	3-5	3-5	3-5	1-3
Reps	8-20	2-6	2-3	1-3
Days/Wk	3-4	3-5	4-6	1-5
Times/Day	1-3	1-3	1-2	1
Intensity Cycle (weeks)	2-3/ 1	2-4/ 1	2-3/ 1	-
Intensity	low	high	high	very high to low
Volume	high	moderate to high	low	very low

Exercise selection and order are equally important components of programming which the coach must consider. Although exercises may be classified according to many different criteria, considering the number of joints involved may be most appropriate. Doing so will result in two groups: multi-joint or single-joint exercises (Haff & Triplett, 2015). By their nature, single-joint exercises involve smaller muscle masses, will generally have less impact on sport performance, and have minimal risk of injury (Bompa & Haff, 2009). Conversely, multi-joint exercises involve two or more primary joints and recruit large muscle masses. Multi-joint exercises are usually axially loaded and will induce higher degrees of training stress compared to single-joint exercises (Haff & Triplett, 2015). There have been disparate results within the literature recently regarding the effects of including both multi-joint and single-joint exercises, compared to multi-joint alone, on muscular strength (Gentil et al., 2015; Paoli et al., 2018). Paoli et al. (2018) noted that training with multi-joint exercises produced superior strength gains in all exercises tested, likely due to the greater muscular recruitment involved in multi-joint compared to single-joint exercises. Contrary to these findings, Gentil et al. (2015) found similar improvements in muscle strength in multi-joint and single-joint exercises, however the difference between studies may be attributable to differences in testing procedures (Gentil et al., 2017; Paoli et al., 2018). However, several studies have noted that, when combined, single-joint exercises have not contributed to increased strength compared to multi-joint exercises alone (Gentil et al., 2017; Paoli et al., 2018). While these discrepancies within the literature are noted, it is still generally agreed upon that multi-joint exercises should serve as the primary constituent of a resistance training program. Single-joint exercises may be useful to correct for muscular imbalances or strengthen smaller muscle groups specific to the sport (Gentil et al., 2017; Paoli et al, 2018).

Exercise order refers to the sequence of exercises to be performed within a training session (Haff & Triplett, 2015). The ACSM position stand on progression models of resistance training recommends that large muscle group exercises, or multi-joint exercises, should be completed first in a training session (ACSM, 2002; ACSM, 2009). However, determining exercise order based solely on the degree of muscle mass involved by the movement may be overly simplistic. Exercise order may affect chronic adaptation, as several studies have shown greater increases in maximal strength in exercises performed at the beginning of training sessions (Dias et al., 2010; Simăo et al., 2010; Spineti et al., 2010). Effect size analysis of these studies suggests that differences in regional hypertrophy aligned with the specific exercise order (Simăo et al., 2012). Coaches also typically order power exercises (snatch, jerk, clean, etc.) prior to other strength exercises (back squat, presses, etc.). Multiple joint power exercises are often highly technical and require precise execution (Fleck & Kraemer, 2014), and are therefore more susceptible to degradation due to fatigue. However, a high-power movement proceeded with a biomechanically similar high-force movement may capitalize on the effects of post-activation potentiation (PAP), and thus augment the desired training goals of the phase (enhanced rate of force development, peak power, etc.) (Baker, D., 2003; Suchomel et al., 2016). While all of these considerations factor into exercise order, they should be ancillary compared to the specific needs of the athlete and movements patterns in need of greatest improvement (Simăo et al., 2010).

The manipulation of training load is key to eliciting favorable adaptation within the athlete. Training load is defined as the product of frequency, repetition volume, and training intensity. The measurement of training load has been further categorized in two ways: internal training load and external training load. Internal training load describes the biological response to the imposed stressors, and are typically assessed using methods such as changes in heart rate, oxygen consumption, psychological stress, etc. (Bourdon et al., 2017). External training load describes the objective work completed and is independent of the biological response to the stressor. Generally, external training load will be assessed using the pertinent objective measure for the given task (accelerometry, power output, etc.) (Halson, 2014). In the context of resistance training, volume load may serve as a corollary of the degree of training load.

Volume

Volume is an estimate of the total work (Force * displacement) completed and energy expended (M.H. Stone, Stone, & Sands, 2007). Given the association between the amount of work completed and energy expenditure (Stone et al., 1999), it is logical to use volume estimates as a surrogate measure of the degree of imposed stress from resistance training. To this end, volume load (VL) (repetitions *sets * mass lifted) is generally considered an appropriate measure of accomplished work within training (Stone et al., 1999). VL is a useful tool for coaches as they navigate the training process. However, it assumes equal displacement between movements and similar displacement in the same exercises between athletes. For this reason, VL calculations which exclude displacement may significantly underestimate or overestimate the amount of work done, either due to a specific exercise with a large displacement, or an athlete with atypical anthropometric features (e.g. long femurs, short torso). To remedy this, it has been suggested that the inclusion of displacement into VL calculations (VL * displacement: VLd) can enhance the sensitivity to subtle alternations in training load, and thus, potential training adaptations (Hornsby et al., 2018; Haff, 2010). While a VL calculation may suffice for the purpose of a coach tracking accomplished work, VLd is preferable for more accurate monitoring and research purposes (Hornsby, 2013; Haff, 2010; McBride et al., 2009). Diligent monitoring practices will inform and enhance training-related decisions.

Training

Training is a multi-factorial process which prepares the athlete for the highest level of performance possible. Fundamental to this process is the application of the overload principle, which drives physiological and performance adaptations (Deweese et al., 2015 a and b; Stone, Stone, & Sands, 2007). Overload consists of applying a training stimulus which is of greater intensity than the athlete is currently adapted to (Shepard and Triplett, 2016). In the context of resistance training, this is typically accomplished by a progressive increase in load, however it may also be accomplished by increasing the frequency of training, adding exercises, sets, or increasing range of motion, among other methods. The application of an overload is essential to eliciting improvement. However, if overload is applied in a linear format (i.e., constant progression without variation or periods of recovery), non-functional overreach or overtraining is likely to result (Deweese et al., 2015). Overtraining is a result of high levels of accumulated fatigue and inhibits performance and further adaptation (O'Toole, 1998). Thus, it is key to implement an overload in a systemic manner. When properly used, overload, in tandem with the other principles of training (variation, specificity, and reversibility), resultant adaptation is optimized, and fatigue is managed (Mujika, 2009). To ensure an adequate recovery period following an overload, an unload period is used typically spanning one microcycle (i.e. a period of a few training days, or more often one week) (Deweese et al., 2013). Microcycles often consist of concentrated workloads and alter the intensity and volume of training to bring about specific adaptations (Deweese et al., 2015). Microcycles can be ordered sequentially to form a summated microcycle (i.e. block) and often use a 3:1 format (3 weeks of overload and 1 week unload) (Stone and Pierce 2006 a and b; Turner, 2011). This format allows for an effective application of an overload stimulus while being less likely to result in overtraining.

Overreach

As previously mentioned, it is critical to manipulate training load to elicit adaptations at key points in time. To this end, a period of overreach training is commonly used by coaches in an attempt to elicit a supercompensation following a subsequent taper period (Hellard et al., 2013). A ubiquitous definition of overreaching describes it as "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 et al., 1998). It has been suggested that overreaching is actually an early stage of overtraining, with the primary differentiation being the length and severity of the performance decrement (Fry & Kraemer, 1997, Stone et al., 1991 Stone, Stone, & Sands, 2007). Overreaching is further subdivided based on the athlete's response; functional (FOR) or non-functional (NFOR) (Aubry et al., 2014; Fry & Kraemer, 1997). A functionally overreached state means that, following a decrement in performance and period of recovery, performance will supercompensate and acutely increase beyond previous levels (Meeusen et al., 2012). In comparison, a non-functional overreach means that, even with a period of recovery, there will be no supercompensation and a stagnation or decrease in performance (Meeusen et al., 2012). If the application of the overreach is continued once the athlete has reached a NFOR-state, overtraining will occur. The effects of overtraining are far more severe and chronic than NFOR, including motor and hormonal effects which may be long-lasting. Further, if overtraining occurs, it may reduce the sensitivity of the athlete to subsequent training (Fry & Kraemer, 1997, Stone, Stone, & Sands, 2007). While it is difficult to elicit a state of overtraining, the balance between FOR and NFOR is more tenuous and presents a challenge to coaches. A successful FOR must be subsequently followed by a period of reduced training, via a taper, to allow for recovery and optimal performance outcomes in competition (Pritchard et al., 2015).

Taper

Mujika and Padilla (2003) have previously defined a taper 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”. In more simple terms, a taper has been defined as a “time of reduced training volume and increased intensity that occurs prior to a competition” (McNeely & Sandler 2007). There has been extensive research performed on the implementation of a taper with endurance athletes, demonstrating a marked improvement in performance (Bonifazi et al., 2000; Cavanaugh & Musch, 1989; Costill et al., 1985; D’Acquisto et al., 1992; Mujika et al., 2002). These improvements have been attributed to a variety of physiological factors, such as improvements in the neuromuscular (Raglin et al., 1996), hormonal (Bonifazi et al., 2000; Costil et al., 1991; Mujika et al., 1996), and psychological (Hooper et al., 1998; Raglin et al., 1996) state of the athlete, as well as increased ability to produce muscular force and power (Cavanaugh et al., 1989; Costill et al., 1985; Hooper et al., 1998; Johns et al., 1992; Raglin et al., 1996; Trappe et al., 2001). These performance improvements made during the taper period are critical to an optimal outcome in competition, as the difference between Olympic placements is often minute (Pritchard, 2015). Consequently, the overall success of the program may depend on the proper manipulation of the training variables which constitute a taper.

While it is generally agreed upon that a taper is critical to optimize the chance of peak performance in competition, the specific construction of the taper procedure has been more contentious (Mujika & Padilla, 2003). Many taper strategies to reduce training stress have been explored in the literature, and most have shown some degree of improvement in performance and/or the state of the athlete (Houmard, 1991; Houmard, 1994; Mujika, 1998; Mujika, 2004;

Neufer, 1989). However, there is disagreement in terms of the optimal taper strategy for peak performance (Bosquet, 2007). The disparity in conclusive outcomes between studies requires further investigation. Thus, the manipulation of training variables (volume, intensity, frequency, duration) throughout the taper has been an area of research among sport scientists, with the intent of elucidating best practices. Various approaches have been studied; each with different alterations in training intensity, volume, and duration (Mujika & Padilla, 2003). An early study on the taper period showed that amongst a group of elite swimmers (n=18), performance outcomes were most highly correlated to mean training intensity (r=.69) throughout the season, yet not with frequency or volume (Mujika et al., 1995). Additionally, a meta-analysis on tapering practices showed that the most efficient variable to alter during the taper is training volume (Bosquet et al., 2007). The authors demonstrated that endurance performance had the largest magnitude of change within a 2-week taper with a 41-60% exponential reduction in volume, while training intensity and frequency were held constant (Bosquet et al., 2007). The trend amongst these studies is that training intensity should be maintained or marginally increase throughout the taper, while volume is exponentially reduced (Bosquet et al., 2007).

While the extent of the literature on taper practices has provided useful information for sport scientists and coaches, most studies have pertained to endurance athletes (Aubry et al., 2014; Le Meur et al., 2012; Mujika & Padilla, 2003). However, the few studies which have pertained to strength-power athletes have provided similar suggestions (Pritchard et al., 2015) where volume should be decreased throughout the taper while intensity remains high (O'Bryant, 1982; Stone et al., 1981; Stone et al., 1982). It is of note that Pritchard et al. (2015) suggests a volume reduction of 30-70% for strength power athletes, while Bosquet et al. (2007) recommends a volume reduction between 41-60%. Nonetheless, Pritchard et al. (2015) reported findings consistent with prior conclusions made in the literature, suggesting that a taper with reductions in volume and maintenance/increase in intensity proved favorable for strength-power athletes. Future research may consider alterations in training intensity in a more comprehensive manner. Training intensity is the rate of ATP use and thus, take typically two forms in the context of resistance training- high force (e.g. powerlifting) and higher velocity power outputs (e.g. ballistic, weightlifting). Alterations in training intensity should be considered within the context of the sport.

In addition to properly manipulating training variables in a taper, the timing and scope of the taper must align with the competition schedule. Differences in individual response to the overreach and subsequent taper protocol may result in different peaked performance timelines, which could impact performance at competition (Avalos et al., 2003; Hellard et al., 2005; Mujika et al., 1996a, Wallace et al., 2009). Previous research has suggested that there may be two primary patterns of response to an overreach and subsequent taper (Mujika et al., 1995, Mujika et al., 1996a). The first pattern is characterized by an acute decrease in performance followed by a steady improvement in performance as fatigue dissipates. The second pattern is characterized by a rapid improvement in performance without the initial acute decrease. While these patterns may be innate to the athlete, there is some evidence to suggest that the pattern of response to the overreach and taper period may change throughout the course of the athlete's career. Years of intense training may alter the pattern of response and as a result the athlete may require longer periods of recovery to optimally enhance performance (Avalos et al., 2003; Gaskill et al., 1999; Thomas & Busso, 2005; Thomas et al., 2008). This variance in response to the overreach and taper period may result in a misaligned timeline of peaked performance; in other words, the athlete may peak too soon or too late in relation to competition. If this response timeline were better understood, it would enable the coach to account for inter-individual variability and make the necessary adjustments to their training, as is advocated in the literature (Avalos et al., 2003; Hellard et al., 2005, Steward & Hopkins, 2000a). Further research is needed on the timeline of response to the overreach and taper period, particularly as to whether performance peaked at the appropriate time.

Monitoring the Training of Weightlifters

Training, especially with high level athletes, is a more complex process than the simple implementation of a series of planned sessions. While forethought of training is crucial to the overall success of the athlete, it is equally important to monitor the athlete's response to training and make the necessary adjustments (Siff, 2003). Monitoring throughout the training process offers feedback on the nature, timing, and degree of individual differences in the athlete's response (Medvedyev, 1986; Mujika et al., 1996a). Observations made from monitoring data may correspond with positive or negative adaptations and can help differentiate between potential confounding variables. In the context of the overreach and taper period prior to competition, this information may prove to be especially impactful, given the proximity to competition.

Monitoring tools may vary from daily measures (training load logged in a journal, psychometric questionnaires, heart rate and blood pressure, changes in body mass, etc.) to more periodic laboratory measures (isometric and dynamic force plate testing, body composition testing, ultrasonagraphy etc.) which provide in-depth data related to performance and training induced adaptations. Taken separately, these measures may not provide sufficient information to describe the athlete's state and response to training. In comparison, a comprehensive testing battery provides a holistic view of the athlete's preparedness and may determine whether the expected adaptations from each phase are actually occurring. For this reason, it is important to ensure that the testing battery is comprised of appropriate tests for the sport and the frequency of testing aligns with expected fluctuations in performance and planned sequence of phases (Hornsby et al., 2013; Hornsby et al., 2017).

Short Recovery and Stress Scale

Daily questionnaires have become prevalent among sport scientists and coaches due to their ease of use, low cost, and ability to quantify subjective stressors experienced by the athlete (Nässi et al., 2017). Of these, the Short Recovery and Stress Scale (SRSS) has proven to be an economic, valid and reliable psychometric measure (Hitzschke et al., 2015). The SRSS was developed to be a shorter alternative to the related long-form questionnaire, the Acute Recovery and Stress Scale (Nässi et al., 2017). There is also some evidence to suggest that a correctly implemented psychometric measure may be able to detect alterations in internal load more sensitively and earlier than many physiological measures (Auersperger et al., 2014; Raglin & Wilson, 2000; Saw et al., 2016). It is imperative to intervene as quickly as possible if a maladaptive response is noted by the monitoring protocol. Therefore, it is beneficial to use a daily questionnaire as a frequent, initial indicator of changes in internal training load. The SRSS is a suitable choice as it is brief enough to complete frequently without risking poor compliance from athletes.

Ultrasonography

Ultrasonography (US) has been shown to be a valid and reliable method of assessing muscle size, measured as anatomical cross-sectional area (CSA), compared to gold standard measurements such as magnetic resonance imaging and dual energy X-ray absorptiometry (Hides et al., 1995; Raadsheer et al., 1994; Waltonet al.,1997). Additionally, ultrasound measurement of muscle thickness and pennation angle provide a more comprehensive characterization of training-induced changes. Peak force and rate of force development may be influenced by alterations in muscle architecture or size (Folland, et al., 2014, Zaras et al., 2016). Muscle thickness (MT) and pennation angle (PA) is collected within 3 images anterio-medial of the halfway point of the thigh, as measured by the rater. MT serves as a simple way to assess changes in muscle size, which is largely established in the literature to result from extensive training loads (Scanlon et al., 2014). During peaking phases, volume reductions are often strategically implemented to dissipiate fatigue and peak the athlete on the day of competition. However, if this reduction in volume load is too severe, it may result in an undesirable loss of muscle tissue or an atrophied state of the muslce. Changes in MT may serve as a sport scientist's initial indication of an important phyiological response to reductions in training load throughout the pre-competition period. PA increases are often associated with an increase in muscular hypertrophy, and theoretically increase the force production capabilities of the muscle (Ahtiainen et al., 2010). However, the timeline of morphological changes have not been well established. Acute alterations in either MT or PA may be more related to a temporary loss of body mass rather than a substantive training-induced adapation (Suarez, et al., 2019). Further research, particularly throughout the taper period, should investigate this topic to further enhance our understanding of these measures. CSA is collected with a panoramic sweep of the muscle from the medial to lateral portion of the thigh, directly between the origin and insertion of the muscle (Ahtiainen, et al., 2010). A few studies have used this technology to examine training-induced changes in muscle size and have found associations between alterations to the muscle and certain performance variables such as strength, jump height, and sprinting speed (Bazyler et al., 2017; Nimphius et al., 2012; Scanlon et al., 2014; Zaras et al., 2016). Additionally, vastus lateralis

CSA has shown associations with pertinent movements to weightlifters, such as deadlifts, squats, and power cleans (Bazyler, et al., 2018, Brechue & Abe, 2002; McMahon, Turner, & Comfort, 2015). Given that the relationship between changes in CSA and maxium strength appears to be linear, it is appropriate to use US as a monitoring method to characterize the athlete's adaptation to training and readiness for competition (Scanlon, et al., 2014).

Jump Height

Coaches and sport scientists recognize the need for an index measure of weightlifting performance. Theoretically, increases in strength and power output should coincide with an athlete's preparedness for competition (Beckham et al., 2013b; Carlock et al., 2004; Haff et al., 2005, Häkkinen et al., 1986, 1987; Mcbride, Triplett-Mcbride, Davie, & Newton, 1999). Testing such abilities prior to competition may indicate whether the programming has successfully prepared the athlete. However, frequent testing of these abilities using the competition lifts may expose the athlete to unnecessary risk of injury and burnout, and otherwise predispose the athlete to sub-optimal performance outcomes in competition. To this end, jump performance, specifically the squat jump (SJ), has been researched and identified as a useful index measure of performance and preparedness in weightlifters. SJ are often performed under both unloaded and loaded (20kg) conditions. Carlock et al. (2004) found that unloaded SJ height (SJH) and peak power (PP) are correlated with weightlifting performance. Hornsby et al. (2017) found that, in competitive weightlifters, loaded SJH responded to fatigue in a more predictable manner than unloaded conditions and may be a more sensitive measure for monitoring purposes. Sport scientists and coaches may use both the unloaded and loaded SJ conditions as a monitoring tool to indicate the preparedness of the athlete and whether fatigue has dissipated. Further, in the context of a taper, use of the SJ may indicate whether the taper timeline was adequately aligned with the competition date and if the athlete peaked at the correct time.

Conclusion

The purpose of this review was to provide an overview of the training process, pre-competition period of training (i.e. overreach and taper), and monitoring methods in strength-power sports, particularly weightlifting. The primary findings of this review include: 1) coaches and sport scientists cam use an overreach and subsequent taper prior to competition to dissipate fatigue and unmask preparedness 2) peak/taper literature has primarily examined the effects of peak/taper strategies in endurance/aerobic sports, with comparatively little research being completed in strength/power sports 3) athlete monitoring measures, such as ultrasonography, vertical jump testing, and psychometric questionnaires, can effectively characterize acute and chronic changes in an athlete's performance capabilities due to training. This study aims to contribute to the literature by examining the effects of an overreach and taper in competitive weightlifters, and better characterize the timeline of response in relation to competition.

CHAPTER 3

CHANGES IN PSYCHOLOGICAL, MORPHOLOGICAL, AND PERFORMANCE CHARACTERISTICS IN PREPARATION FOR A NATIONAL WEIGHTLIFTING COMPETITION

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Abstract

Coaches are interested in knowing when their athletes are peaked relative to competition. The purpose of this study was to investigate the time course of psychological, morphological, and performance measures following an overreach and taper period in weightlifters preparing for a national competition. Olympic Training Site weightlifters (N=11) completed a 5-week peaking phase for a national competition. Body mass, stress and recovery psychometric measures, and unloaded/loaded (20kg) squat jump height (SJH) were measured weekly and at the competition site. Vastus lateralis cross-sectional area (CSA) ultrasound measurements were taken prior to and following the training protocol. One-way repeated measures ANOVAs with post-hoc comparisons were used for analysis ($p \leq 0.05$). Statistically significant time effects were found for overall recovery ($p<0.001$), overall stress ($p<0.001$), and loaded SJH ($p=0.01$). Post-hoc comparisons revealed a statistical increase in overall recovery ($p<0.001$) and decrease in overall stress ($p=0.02$) the day of competition compared to baseline. 9 athletes achieved their best psychometric score within 3 days of competition. There was an increase in loaded SJH ($p=0.06$); 7 athletes achieved their best performance within 3 days of competition. There was a statistically significant decrease in CSA ($p=0.04$), but no statistically significant changes in body mass. In competition, 6 athletes set a personal best in snatch, clean and jerk and/or total. These results suggest that improvements in the loaded SJ and psychometric measures correspond to successful competition performance in some weightlifters. Notably, most weightlifters appeared to be peaked within 3 days of competition.

Introduction

A primary goal of periodization is to converge the summative effects of training in a way that allows for the optimal performance at the time of competition. A theoretical underpinning of this concept can be explained in the *fitness-fatigue* paradigm, which states that the interaction between the two aftereffects of training, fatigue and fitness, influences the expression of the athlete's preparedness (Bannister 1982; Zatsiorsky 1995). In order for accrued fitness to be expressed, fatigue must first be reduced. In the context of competition preparation, coaches strategically utilize a taper to dissipate fatigue and optimize performance at the right time (Meeusen et al. 2013; Stone et al. 2007). While tapering research with strength athletes is scarce in comparison to aerobic athletes, a recent review recommended a taper that is at least 1-4 weeks in length and maintains or increases intensity while reducing training volume as being most effective for enhancing maximal strength (Pritchard et al., 2015). The challenge presented to coaches is in determining the correct approach to peak at the right time (Bosquet et al. 2007). Several authors have suggested that there is an optimal taper strategy for most competitive athletes (Mujika and Padilla 2003; Pyne et al. 2009). However, effective strategies for weightlifters are not well characterized in the literature.

In addition to the lack of empirical evidence for effects of tapering in weightlifting, there is limited knowledge of practical tools to monitor responses to on-going tapering for weightlifting. Sport scientists have utilized a variety of approaches to further investigate the taper-induced effects on performance, including hematological, psychological, metabolic, neuromuscular, and hormonal changes (Mujika and Padilla 2003; Mujika et al. 1997; Hooper et al. 1999; Bannister et al. 1999; Trappe et al. 2001; Bonifazi et al. 2000). One practical aspect of responses to on-going tapering may be psychological responses. Athletes appear to experience increased irritability and emotional distress during an overreach and taper period (Nässi et al. 2017; Aubry et al. 2014). Such a variability in mood state may affect performance outcomes and adversely impact the physiological benefits of a taper. Therefore, it may beneficial to utilize a quasi-objective assessment of recovery, stress and mood state throughout the training process, but especially during the taper periods. Nässi and colleagues have researched the utilization of the Short-Recovery and Stress Scale (SRSS) as an appropriate self-reported questionnaire measure to monitor the athlete's perception of their performance readiness (Nässi et al. 2017). Other studies have examined the morphological changes throughout the taper period. For example, Bayzler and colleagues utilized ultrasound measurements to quantify muscle cross-sectional area (CSA) alterations in a National Level Female Weightlifter as she peaked for a competition, amongst other measures (Bayzler et.al, 2017). Zaras et al. (2016) examined alterations in rate of force development (RFD), muscle architecture (pennation angle-PA, muscle thickness-MT) in relation to performance in competitive track and field athletes. Additionally, a recent study from Suarez et al (2019) examined phase-specific changes in RFD and muscle morphology in weightlifters training in a block periodized training program. Collectively, changes in CSA, PA, MT provide a more comprehensive characterization of alterations in muscle morphology in response to training.

Other studies have focused on assessing optimal taper lengths to produce maximal strength expression and effects on weightlifting performance. For example, Stone et al. (1996) observed the effects of different taper lengths in ten elite weightlifters. Both groups completed a similar training program for the first 8 weeks but tapered differently throughout the last 4 weeks. 'Group L' utilized a 4-week taper; 'Group S' a 1-week taper. They did not find any significant differences between groups in resting measures (blood pressure, testosterone, cortisol, sex hormone binding globulin (SHBG)). It was observed that 'Group L', which utilized a lower volume and statistically significant higher relative intensity during the taper period, had increased their competition total by 17.5kg, compared to an 8kg increase in 'Group S'

While psychological responses can be valuable information, such knowledge may not necessarily reflect physical performance responses to tapering. Carlock et al. (2004) investigated the usefulness and reliability of vertical jump performance as a correlate of weightlifting performance and found a strong correlation between static vertical jump and both snatch and clean & jerk (r=0.64). Given this relationship, vertical jump performance may be used to infer about a weightlifter's physical performance responses to tapering. Should further evidence supporting such use of vertical jump performance be presented, a coach's ability to evaluate the efficacy of an on-going peaking strategy may be enhanced.

The primary aim of this study was to examine the time course of changes in muscle morphology and vertical jump performance in weightlifters preparing for a national competition. The secondary aim of this study was to examine how perceived recovery and stress state corresponds with alterations in training load leading up to competition. We hypothesized that jumping performance would be peaked the day of competition, which would correspond to an improved mood state and preserved muscle cross-sectional area, muscle thickness, and pennation angle.

Methods

Participants

Eleven well-trained weightlifters (8 females and 3 males) volunteered for the study. All participants were members of the ETSU Olympic Training Site (OTS) Program and had at least one-year competition experience. The study was approved through the university's institutional review board (IRB) for the use of human subject's data. Two female participants were excluded from the study; One due to missing the post-peaking cycle testing session, and one due to a shoulder injury which prevented her from competing.

Table 3.1 Descriptive Characteristics

	Height (cm)	Body Mass (kg)	Age (yrs)	Snatch (kg)	C&J (kg)	Total (kg)
Male (n=3)	175.7 ± 4.0	91.4 ± 5.2	24.8 ± 0.5	112.7 ± 8.0	150.7 ± 9.3	262.3 ± 15.6
Female (n=8)	158.2 ± 4.6	61.5 ± 7.9	20.9 ± 2.2	67.1 ± 8.2	88.1 ± 10.3	153.9 ± 17.2

Procedure

The study duration was 5 weeks. Athletes completed a 4-week peaking phase for a national weightlifting competition (University Nationals; USA). The athletes followed one of three similar training programs, in accordance with their competitive level and training history. Week 1 was a deload week, where training loads were reduced to facilitate recovery. Week 2 was an overreach during which training load, measured as VLd, was substantially increased by 88.7% compared to the deload week. Weeks 3-5 comprised the taper where training load was reduced exponentially until competition. There was a 36.8% decrease in VLd between the deload week and last week of the taper. It should be noted that the load, repetitions and number of warmup sets were not dictated by the coach. Thus, this may affect the distribution of volume over the 5-week peaking phase.

In conjunction with an ongoing monitoring program (hydration, ultrasound, SRSS), athletes completed static jump (SJ) testing every Saturday morning prior to their training session throughout weeks 1-4 (Figure 3.1) and more frequently during the week of competition (Figure 3.2) for a total number of 9 testing sessions, excluding the regularly scheduled testing session upon return. Testing session 1 (T1) and T2 occurred on Monday and Wednesday of Week 1, respectively. T3-T5 occurred on the subsequent three Saturdays, as detailed in in Figure 3.1. Figure 3.2 details the timeline of T6-T10.

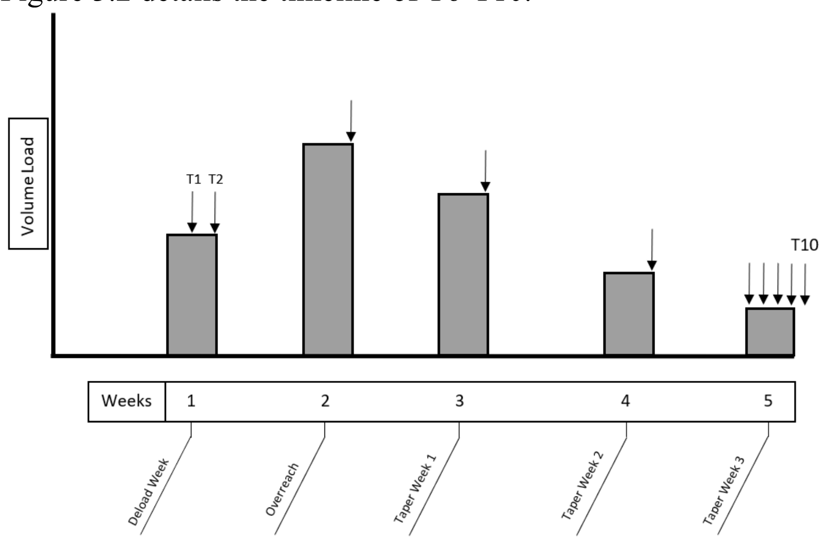


Figure 3.1: Overview of the Testing Schedule (Weeks 1-5)

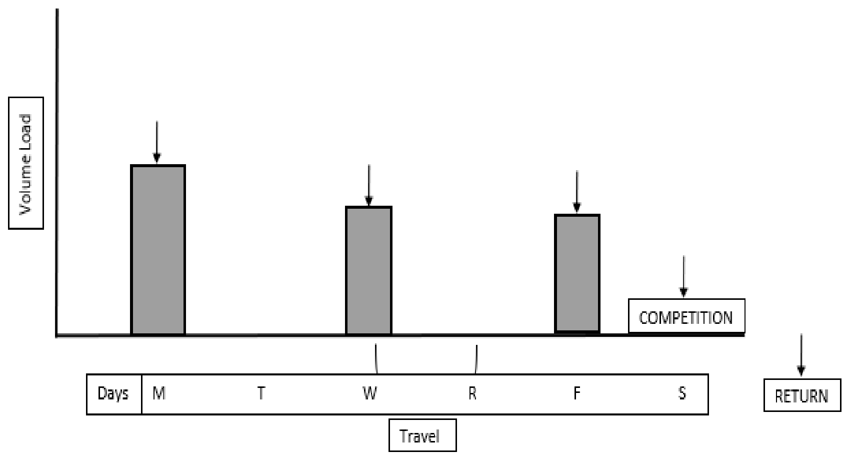


Figure 3.2: Testing Schedule during Week 5

Descriptive information

Descriptive information was collected throughout the study. Body mass was measured using a digital scale prior to each training session (Cardinal Scale Manufacturing Co., Webb City, MO). All work completed from each strength training session was recorded by the athlete and coach in their training journal and log book, respectively. Performance outcomes of the meet was recorded in comparison to the athlete's most recent and comparable competition total. Athletes were instructed to complete a 24-hour dietary log prior to the first testing session and replicate it prior to each testing session. Dietary logs were reviewed prior to each testing session to check for an irregular dietary intake. Athletes were instructed to maintain their current diet throughout the testing period and to avoid the ingestion of stimulants prior to each testing session.

Hydration

Hydration status was assessed prior to each testing session by measuring urine specific gravity (USG) with a handheld refractometer (Atago 4410 PAL-10S, Tokyo, Japan). Athletes were not able to proceed with any other tests until providing a urine sample with USG < 1.020.

Questionnaire

The Short Recovery and Stress Scale (SRSS) questionnaire was used to assess the self-reported stress-recovery response state of the athlete prior to each training (and testing) session. This measure consists of eight items and relates to physical, mental, emotional and general factors of recovery. The items consist of: muscular stress (MS), lack of activation (LA), negative emotional state (NES), overall recovery (OR), physical performance capability (PPC), mental performance capability (MPC), and emotional balance (EB). Each measure lists a series of descriptive synonyms to explain each measure. Measures are rated on a scale of 0 (does not apply at all) to 6 (fully applies) and is to be self-reported by the athlete (Nässi et al., 2017). The SRSS has shown satisfactory internal consistency in all scales (Cronbach's alpha between $\alpha = 0.84$ and $\alpha = 0.96$).

Ultrasound

Standing Ultrasound measurements were taken according to the procedure described by Wagle et al. (2017). The practitioner used a 7.5 MHz ultrasound probe (LOGIQ P6, General Electric Healthcare, Wauwatose, WI) to measure CSA. Anatomical landmarks (greater trochanter, lateral epicondyle) were used to locate halfway point of the right femur and place a marking. The athlete was instructed to stand and bear weight on their left leg with their unweighted right leg positioned off a standing platform. Cross-sectional area (CSA) measurements of the vastus lateralis (VL) were taken in a panoramic sweep in the transverse plane perpendicular to the muscle. Three CSA images were obtained in this fashion, and the best two images were selected based on their uniformity and clarity of the region of interest. Images were analyzed using an image processing software (ImageJ 1.52a, National Institutes of Health, Bethesda, MD, USA) to outline the intermuscular portion of the region of interest. Muscle thickness (MT) and pennation angle (PA) images were collected from 5cm anterio-medially at the mid-point of the thigh, as identified from anatomical landmarks. MT and PA were measured as the average of values from 3 consecutive images. All images were collected and analyzed by the same practitioner on the same computer. Measurements were taken according to the monitoring schedule dictated by the OTS staff, which coincided with the end of Week 1 and the end of Week 5. One subject was excluded from ultrasound measurements due to non-compliance with the protocol. An additional subject's MT and PA measurements were excluded due to a computational error preventing analysis of the image.

Squat Jump

Per the testing session schedule detailed in Figures 1 & 2, the athletes performed Static Squat Jumps (SJ) with unloaded (PVC used; see Figure 3.3) and 20kg conditions. The SJ was performed on a dual uniaxial force plates sampling at 1000Hz (PASPORT force plate, PS-2141, PASCO Scientific, California, USA). Upon instruction, the athlete stepped onto the force plates and placed a PVC pipe onto their back as if they were going to perform a Back Squat. The athlete was instructed to squat down to a knee angle of 90°, as measured by the rater using a handheld goniometer. They held this position until a stable force-time trace was measured. Following this, the rater shouted "3,2,1 Jump!" and the athlete performed a maximal SJ (Figure 3). This procedure was then repeated with a 20kg barbell. A minimum of 2 jump trials was recorded and analyzed using ForceDecks software, a commercially available program (ForceDecks, London, UK). More trials were performed and recorded until there was less than 2 centimeter difference in jump height. SJ height (SJH) was derived from flight time. Peak power (PP) was estimated using the equations developed by Sayers et al. (1999) and used by Carlock et al. (2004). PP was allometrically scaled for analysis.

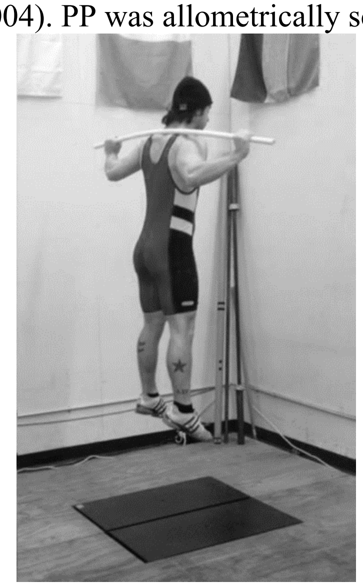


Figure 3.3: An athlete completing a SJ on a dual force plate platform

Training

Data collection for this study occurred over a five-week period prior to the USA Weightlifting University Nationals competition. The training period consisted of the following: Week 1 was representative of a deload week of training, Week 2 Overreach, Weeks 3-5 Taper until competition.

Training was split into seven training sessions over four training days per week (Table 2). Monday and Thursday sessions were split into an AM/PM session with squat in the AM, jerks and other pressing variations in the PM. Wednesday sessions were split into an AM/PM session consisting of a variety of pulling and weightlifting derivatives. Saturday was a sport specific day, similar to the structure of Wednesday but with the competition lifts as a primary focus. Wednesday and Saturday both qualified as pull days, however Saturday training consisted of one session. External Training Load (TL) was calculated for each session using volume load (weight x sets x reps) x Displacement (Stone et al., 1998; Haff, 2010). Displacement in every movement utilized in the program was measured using 4 potentiometers (2 on each side of the barbell) and analyzed with a custom Labview program (Lab View 2010, National Instruments Co., Austin, TX). Each athlete's coach supervised and conducted each training session without involvement from the researchers.

Table 3.2 Representative Training Block prior to University Nationals

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
AM	Back Squat*	Rest	Snatch tech	Back Squat*	Rest	Snatch tech	Rest
			CGSS			SGSS	
			CGP from PP			Snatch	
						C&J	
						SG SLDL	
						DB BOR	
PM	Jerk		Clean tech	Jerk			
	DSP Squat**		SGSS	DSP Squat**			
	BNP		SGP	BNP			
	DBP*		CG SLDL*	DBP*			
			DB BOR*				

Note: DSP Squat= dead stop parallel squat, BNP= behind the neck press, DBP= dumbbell press, CGSS= clean grip shoulder shrugs, CGP from PP= clean grip pull from power position, SGSS= snatch grip shoulder shrugs, SGP= snatch grip pull, CG SLDL= clean grip straight legged deadlift, DB BOR= dumbbell bent over row, SG SLDL= snatch grip straight legged deadlift; *=drop exercise after Week 3, **= drop exercise after Week 1

Statistics

Following an initial data screening, a one-way repeated measures ANOVA was calculated for each variable. A statistical time effect was followed by post-hoc comparisons. Alpha level for all analyses was set at $p \leq 0.05$ and a Benjamini-Hochberg adjustment was used to correct for familywise error. The magnitude of within-athlete changes between testing sessions was interpreted using 0.3, 0.9, 1.6, 2.5, and 4.0 of the within-athlete coefficient of variation (CV) from T1-T2 as thresholds for small, moderate, large, very large, and extremely large, respectively. As recommended by Hopkins et al., (2009), 0.3*CV was selected to represent the smallest worthwhile change (SWC). Analyses were performed using SPSS software version 23 (IBM Co., New York, NY, USA), and Microsoft Excel 2018 (Microsoft Corporation, Redmond, WA, USA).

Results

Statistically significant time effects were found for overall recovery ($p<0.001$), overall stress ($p<0.001$), physical recovery ($p<0.001$), mental recovery ($p<0.001$), muscular stress ($p=0.002$), activation stress ($p=0.036$), and loaded SJH ($p=0.01$). There were no statistically significant time effects for allometrically scaled peak power with 0kg or 20kg, muscle thickness (MT), or pennation angle (PA). Post-hoc comparisons revealed a statistical, large increase in overall recovery ($p<0.001$, percent change=23.9%), moderate increase in physical recovery ($p=0.008$, 18.1%), large increase in mental recovery ($p=0.008$, 23.9%) and moderate decrease in overall stress ($p=0.02$, -50%) the day of competition compared to baseline. 9 athletes achieved their best psychometric score (lowest overall stress and highest overall recovery) within 3 days preceding or on the day of competition. There was a near significant, moderate increase in loaded SJH ($p=0.06$, 4.13%) on competition day compared to baseline with 7 athletes achieving their highest performance within 3 days preceding or including the day of competition. There was a significant, moderate decrease in CSA ($p=0.04$, -2.88%) following the 5-week peaking phase, but no statistically significant changes in body mass. In competition, 6 of 11 athletes achieved a personal best in snatch, clean and jerk and/or total.

Figure 3.4: Loaded SJ Height (cm) vs. Days from competition; * indicates statistical significance

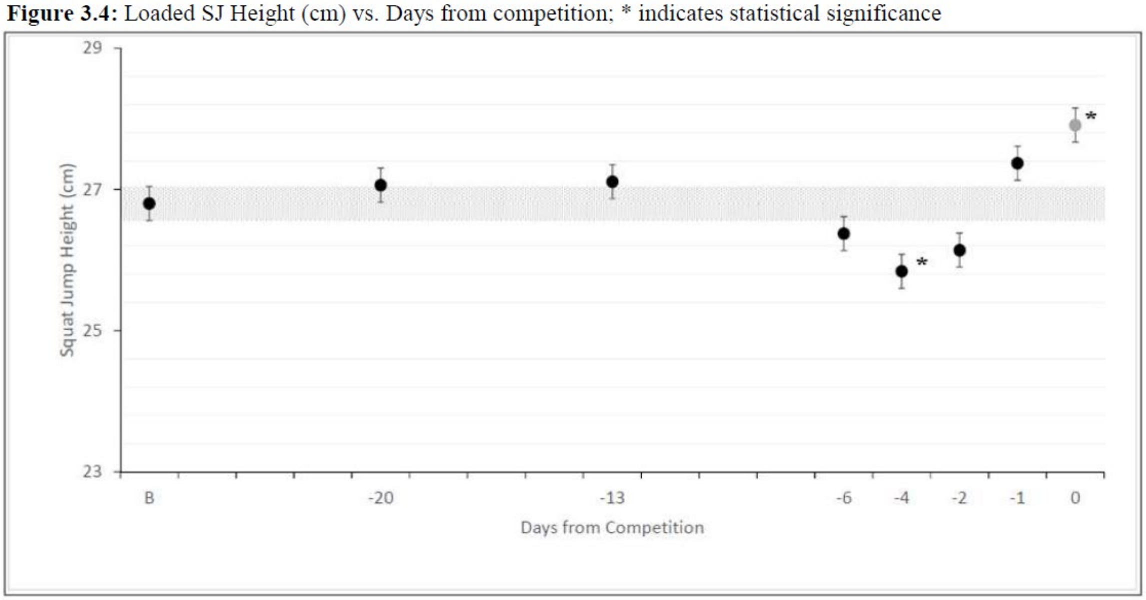


Figure 3.5: Overall Recovery (a.u.) vs. Days from competition; * indicates statistical significance

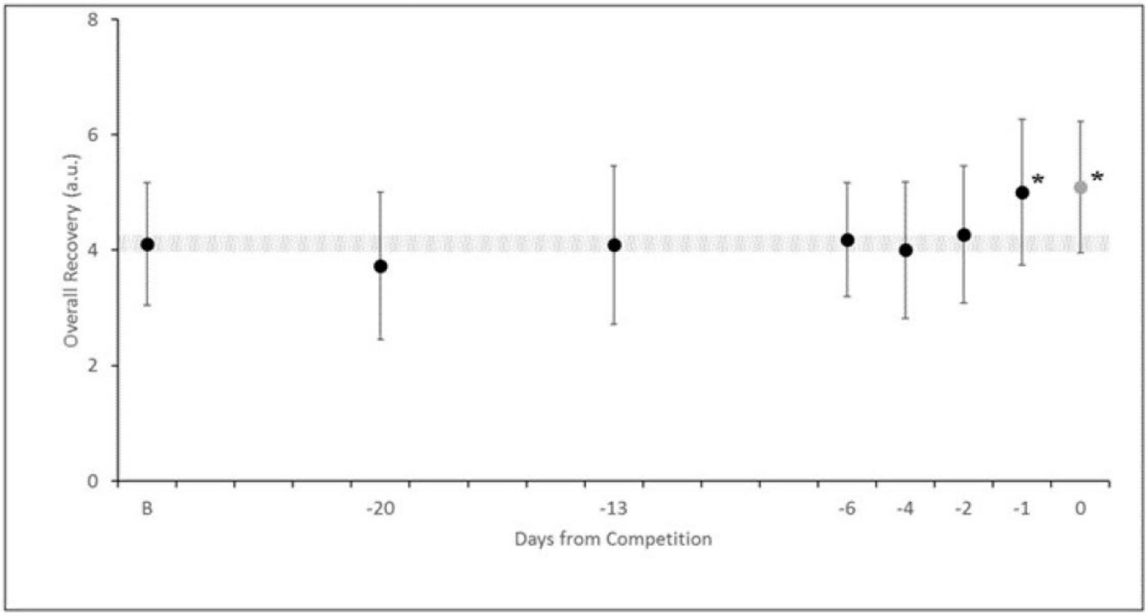


Figure 3.6: Overall Stress (a.u.) vs. Days from competition; * indicates statistical significance

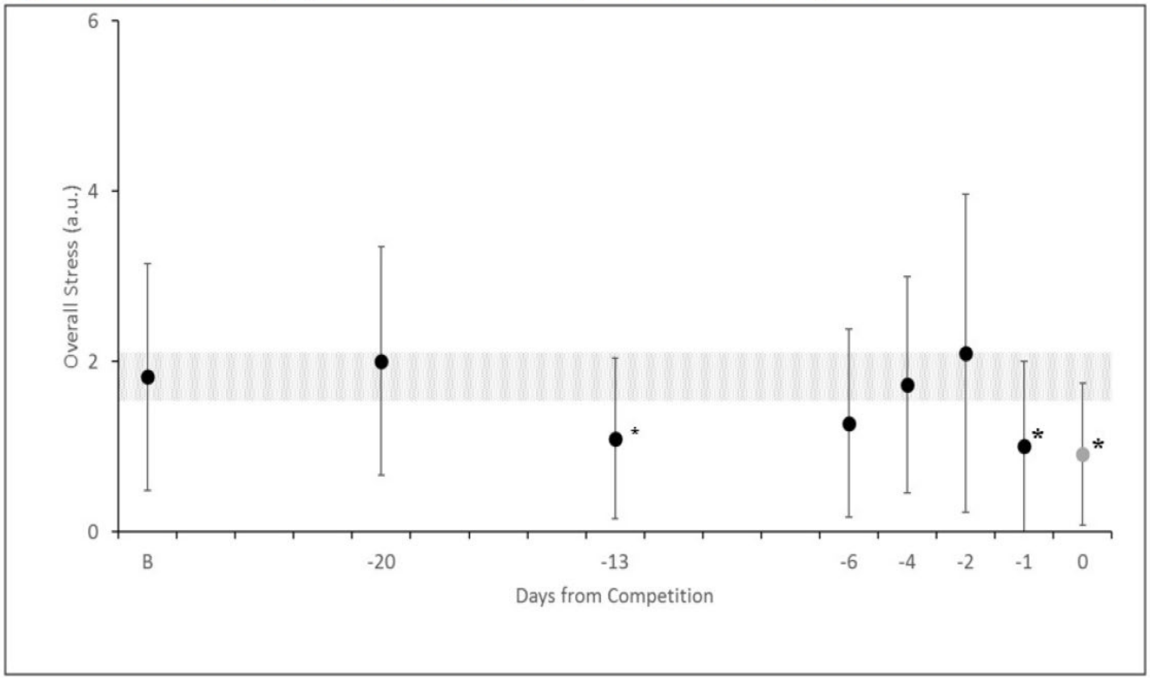


Figure 3.7: Volume Load · Displacement (kg · m) by Athlete and with Team Average

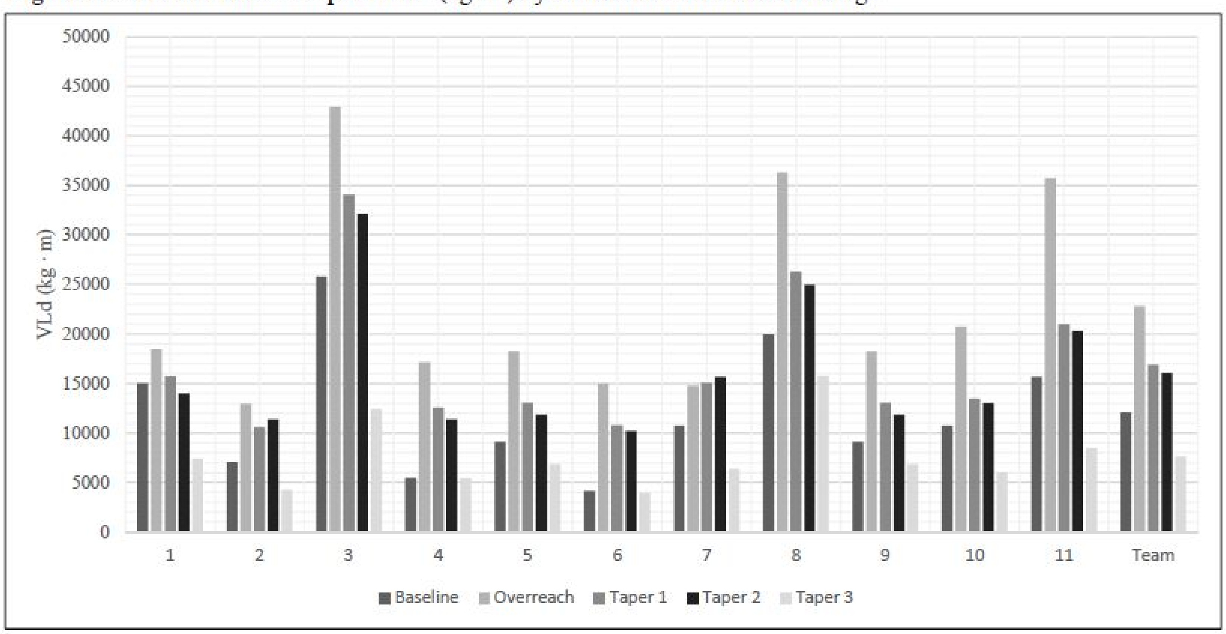


Table 3.3: Volume Load · Displacement (kg · m) by Athlete and with Team Average

Week	Athlete 1	2	3	4	5	6	7	8	9	10	11	Team
Baseline	15027.59	7047.53	25766.45	5458.90	9116.54	4125.29	10756.22	19941.42	9116.54	10746.32	15675.16	12070.72
Overreach	18437.30	12947.79	42930.71	17158.17	18270.65	15015.73	14768.35	36305.27	18270.65	20755.49	35701.53	22778.33
Taper 1	15696.69	10590.22	34079.68	12569.16	13050.84	10763.55	15068.36	26245.06	13050.84	13456.75	21003.62	16870.43
Taper 2	13992.65	11395.74	32120.13	11397.22	11840.25	10225.39	15670.66	24928.46	11840.25	13019.59	20310.13	16067.32
Taper 3	7409.84	4250.29	12420.36	5404.50	6876.13	3953.45	6411.79	15747.74	6876.13	6031.77	8511.16	7626.65

Table 3.4: Jumping Performance, Short Recovery and Stress Scale (SRSS) and Vastus Lateralis Cross-sectional Area (CSA) Results

Variable	Mean ± Standard Deviation								SWC
	B	T3	T4	T5	T6	T7	T8	T9	
Jump Performance									
SJH 0kg (cm)	34.69 ± 6.77	34.81 ± 6.69	35.33 ± 6.13	34.83 ± 5.96	33.49 ± 7.12	33.81 ± 6.15	35.25 ± 6.81	35.78 ± 7.15	0.29
PPa 0kg ($W/kg^{.67}$)	180.63 ± 44.26	186.77 ± 34.17	188.78 ± 31.98	187.45 ± 30.54	181.89 ± 35.64	183.42 ± 31.67	187.92 ± 33.92	189.54 ± 34.59	1.12
SJH 20kg (cm)	26.80 ± 6.21	27.06 ± 6.52	27.11 ± 6.00	26.37 ± 6.57	25.84 ± 6.61*	26.14 ± 6.16	27.37 ± 6.50	27.91 ± 7.08*	0.23
PPa 20kg ($W/kg^{.67}$)	153.37 ± 43.21	158.26 ± 37.87	158.48 ± 35.95	156.12 ± 37.16	153.84 ± 38.09	154.86 ± 36.34	158.57 ± 37.93	160.10 ± 39.3	0.89
SRSS									
Overall Recovery	4.11 ± 1.06	3.73 ± 1.27	4.09 ± 1.09	4.18 ± 0.98	4.00 ± 1.18	4.27 ± 1.19	5.00 ± 1.26*	5.09 ± 1.14*	0.15
Overall Stress	4.11 ± 1.33	2.00 ± 1.34*	1.38 ± 0.94	1.27 ± 1.10	1.73 ± 1.27	2.09 ± 1.87	1.00 ± 1.00*	0.91 ± 0.83*	0.28
Ultrasound									
CSA (cm^2)	32.04 ± 7.29							31.11 ± 7.24*	0.25
Body Mass (kg)									
	69.63 ± 15.56	69.91 ± 15.72	69.71 ± 15.29	69.96 ± 14.95	69.86 ± 15.00	69.65 ± 15.06	69.22 ± 15.40	69.04 ± 15.45	0.13

B- Baseline, T3- Testing Session 3, T4- Testing Session 4, T5- Testing Session 5, T6- Testing Session 6, T7- Testing Session 7, T8- Testing Session 8, T9- Testing Session 9, SWC- Smallest Worthwhile Change, SJH- Squat Jump Height, PPa- Peak Power allometrically scaled, CSA- Cross-sectional area, *- Statistical significance compared to baseline

Table 3.5: Pre-Competition Personal Records vs. Competition Outcome (kg)

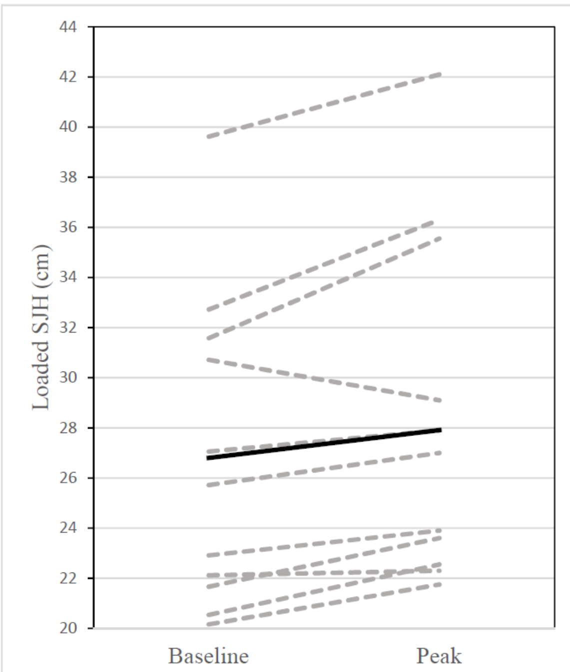
Athlete	Pre-PR Snatch	Pre-PR C&J	Pre-Total	Comp. Snatch	Comp. C&J	Comp. Total	Snatch % Change	C&J % Change	Total % Change
1	81	107	185	81	106	187*	0.00%	-0.93%	1.08%
2	61	78	137	63	78	141*	3.28%	0.00%	2.92%
3	121	161	279	121	164*	285*	0.00%	1.86%	2.15%
4	64	83	147	63	81	144	-1.56%	-2.41%	-2.04%
5	60	84	144	60	77	137	0.00%	-8.33%	-4.86%
6	60	79	139	58	83*	141*	-3.33%	5.06%	1.44%
7	69	91	160	70*	89	159	1.45%	-2.20%	-0.63%
8	115	140	255	109	140	249	-5.22%	0.00%	-2.35%
10	75	95	165	68	-	-	-9.33%	-	-
11	105	143	248	109*	-	-	3.81%	-	-

PR- Personal Record, C&J- Clean & Jerk, Comp.- Competition, *-indicates a new Personal Record, - indicates that the athlete did not make a successful attempt

Table 3.6: SRSS Non-Summary Variables and additional Ultrasound measures								
Variable	Mean ± Standard Deviation							
Items (a.u.)	B	T3	T4	T5	T6	T7	T8	T9
Physical Recovery	4.31 ± 1.14	4.00 ± 1.48	4.73 ± 0.90	4.64 ± 0.81	4.1 ± 1.14	4.55 ± 1.04	4.82 ± 0.98*	5.10 ± 0.83*
Mental Recovery	3.96 ± 1.13	4.45 ± 1.04	4.55 ± 1.04	4.64 ± 1.12	3.82 ± 1.47*	3.73 ± 1.62	4.36 ± 1.29	4.91 ± 0.94*
Emotional Recovery	4.15 ± 1.18	4.00 ± 1.41	4.55 ± 1.21	4.27 ± 1.35	3.64 ± 1.70	3.73 ± 1.50	4.27 ± 1.19	4.64 ± 1.21
Muscular Stress	1.35 ± 0.86	2.72 ± 1.35	1.55 ± 1.13	1.91 ± 1.38	2.00 ± 1.18*	1.27 ± 1.10*	1.45 ± 1.70	1.18 ± 1.78
Activation Stress	1.76 ± 1.25	2.10 ± 1.58	1.36 ± 0.92	1.27 ± 1.01	2.27 ± 1.62	1.91 ± 1.58	1.00 ± 1.18	1.10 ± 1.22
Emotional Stress	1.51 ± 1.05	1.64 ± 1.36	1.36 ± 1.03	1.27 ± 1.35	1.82 ± 1.60	1.91 ± 2.02	1.18 ± 0.87	0.82 ± 0.98
Muscle Thickness (cm)	2.77 ± 0.43							2.74 ± 0.45
Pennation Angle (∘)	19.18 ± 3.10							19.4 ± 3.50

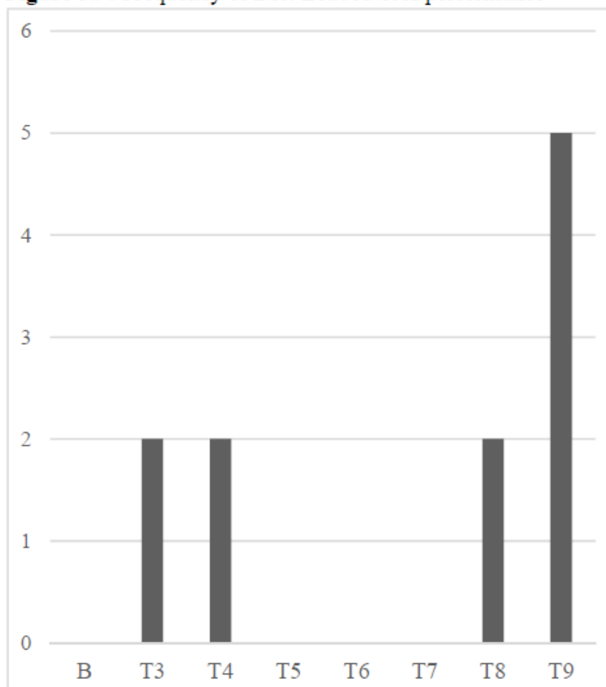
*- Statistical significant compared to baseline

Figure 3.8: Loaded SJH- Baseline vs. Peak



Baseline- average of T1 & T2, Peak- best Loaded SJH on day prior or day of competition. Gray dashed lines are individual changes and the black solid line is the group mean change. SJH- Static Squat Jump

Figure 3.9: Frequency of Best Loaded SJH performance



Discussion

The results from this study suggest that improvements in the loaded SJ and psychometric measures correspond to successful competition performance in some weightlifters. Notably, most weightlifters appeared to be peaked within 3 days preceding or including the day of competition. In agreement with Hornsby et al. (2017), loaded SJ, compared to unloaded SJ, presented as a more 'sensitive' measure of resultant preparedness in competitive weightlifters due to the taper procedure. However, contrary to Hornsby et al. (2017), there did not appear to be a difference in predictability in response between the men and women. There was a moderate, significant decrease in loaded jump height four days prior to competition. This testing session, compared to prior testing sessions which took place on Saturdays, occurred prior to a Wednesday training session. It is likely that there was an acute decrease in performance due to residual fatigue from Monday's training session.

It was expected that there would be a significant decrease in body mass considering that weightlifting is a weight class sport and athletes often train at a body mass over their weight class. Close to competition, athletes may strategically lose body mass to weigh in at the top end of their class and gain a competitive advantage. In actuality, only 5 of 11 athletes were overweight at baseline compared to their competitive weight-class. The remaining 6 athletes either needed to gain a negligible amount of weight or maintain the body mass throughout the peaking phase. An acute decrease in body mass may increase VJ performance because most of the lost weight is not contractile tissue (Ashley & Weiss, 1994). The results of this study, however, did not show any significant decrease in average body mass of the athletes. Given the decrease in CSA, but not in body mass, the increase in VJ performance may be due to changes in other unmeasured neuromuscular adaptations (e.g. shift towards faster myosin heavy chain isoforms, increased cortical motor output, reduced neural inhibition) following the taper (Thomas, et al., 2018). It should be noted that the statistical decrease in CSA may be due to acute glycogen depletion imposed from travel. Coaches may consider implementing strategies to better preserve CSA, such as noting individual differences in response to varying degrees of volume reduction throughout the taper. There were no findings for MT or PA in this study. This may be due to the fact that the image in question for MT and PA covers a substantially smaller surface area than a panoramic CSA image, and therefore minor alterations may be more difficult to detect. The statistical decrease in CSA is potentially less impactful due to the lack of a decrease in MT and PA as well. As would be expected, the pre-competition period did not result in the development of new morphological adaptations, but rather training in this period preserved muscle tissue.

The results of the psychometric measures indicates that the athlete's perception of alterations in training load corresponded with reductions in training volume. In other words, in a real-world setting, the recovery (overall, physical, mental) and stress (overall, muscular, activation) items proved useful as an early indicator of an improved mood state prior to competition partly resulting from a reduction in volume. This is generally in agreement with Perkins, et al. (2018). However, the lack of response in the other items (emotional recovery and stress) may indicate poor comprehension or limited application to weightlifting. The most general items of the SRSS, overall recovery and overall stress, demonstrated the largest changes relative to baseline. It may be that different training phases with a particularly focused emphasis (e.g. strength-endurance, strength, power) may elicit a higher degree of response in the more specific items (muscular stress, mental stress, etc.). Therefore, further research should investigate the relevance of more specific psychometric items compared to more general items during different training phases.

This study was novel for several key reasons. Testing occurred on a more frequent basis, particularly throughout the week of competition, than prior studies, thus providing impactful data on the timeline of response throughout the taper. Theoretical underpinnings of the pre-competition period imply a predictability of response, which was demonstrated in the applied setting within this study. Replication of a similar taper strategy may prove effective for other weightlifting athletes and provide coaches necessary data to adjust and improve the taper timeline on an individual basis. The use of loaded SJ monitoring and psychometric evaluations may prove useful as an index measure of weightlifting preparedness, and thus, address the overall effectiveness of the completed training program.

Practical Applications

These results suggest the pre-competition period, when correctly implemented, can favorably augment performance outcomes in competition for strength-power athletes, particularly weightlifters. The implementation of an overreach and taper in accordance with prior recommendations within the literature for strength athletes resulted in peaked performance for most athletes on the date of competition. Monitoring throughout this crucial period of training can demonstrate the timeline of fatigue dissipation and increased preparedness. Notably, loaded squat jumps performed on a force platform can be used to inform the training process throughout a peaking phase. Psychometric questionnaires can also be used to monitor the athlete's psychological state leading into competition. Coaches and sport scientists should consider these findings and carefully implement a similar monitoring program to optimize the chance of favorable competition outcomes.

REFERENCES

Ashley, C. D. & Weiss, L. W. (1994). Vertical jump performance and selected physiological characteristics of women. *Journal of Strength and Conditioning Research*, *8,* 5-11.

Aubry, A., Hausswirth, C., Louis, J., Coutts, A. J., & LE Meur, Y. (2014). Functional overreaching: the key to peak performance during the taper? *Medicine and Science in Sports and Exercise, 46,* 1769–77.

Bannister, E.W. (1982). Modelling elite athletic performance. In: J.D. MacDougall, H.A. Wenger, and H.J. Green (Eds.) Physiological testing of the high performance athlete (pp. 403-424). Champaign IL: Human Kinetics

Bazyler, C. D., Mizuguchi, S., Zourdos, M. C., Sato, K., Kavanaugh, A. A., DeWeese, B. H., … Stone, M. H. (2018). Characteristics of a National Level Female Weightlifter Peaking for Competition: A Case Study. *The Journal of Strength & Conditioning Research*, *Publish Ahead of Print*. https://doi.org/10.1519/JSC.0000000000002379

Bonifazi, M., Sardella, F., & Luppo, C. (2000). Preparatory versus main competitions: differences in performances, lactate responses and pre-competition plasma cortisol concentrations in elite male swimmers. *European Journal of Applied Physiology, 82,* 368–373.

Bosquet, L., Montpetit, J., Arvisais, D., & Mujika, I. (2007). Effects of tapering on performance: a meta-analysis. *Medicine and Science in Sports and Exercise, 39,* 1358-1365.

Carlock, J. M., Smith, S. L., Hartman, M. J., Morris, R. T., Ciroslan, D. A., Pierce, K. C., ... & Stone, M. H. (2004). The relationship between vertical jump power estimates and weightlifting ability: a field-test approach. *The Journal of Strength & Conditioning Research*, *18*(3), 534-539.

Haff, G. G. (2010). Quantifying workloads in resistance training: a brief review. *Strength and Cond.*, *10*, 31-40.

Hellard, P., Avalos, M., Hausswirth, C., Pyne, D., Toussaint, J. F., & Mujika, I. (2013). Identifying Optimal Overload and Taper in Elite Swimmers over Time. *Journal of Sports Science & Medicine, 12*(4), 668-678.

Hooper, S. L., Mackinnon, L. T., & Ginn, E. M. (1998). Effects of three tapering techniques on the performance, forces and psychometric measures of competitive swimmers. *European Journal of Applied Physiology, 78,* 258–263.

Hornsby, W. G., Gentles, J. A., MacDonald, C. J., Mizuguchi, S., Ramsey, M. W., & Stone, M. H. (2017). Maximum strength, rate of force development, jump height, and peak power alterations in weightlifters across five months of training. *Sports*, *5*(4), 78.

Hopkins, W. G., Marshall, S.W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41,* 3–13.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., ... & Urhausen, A. (2012). Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Medicine and science in sports and exercise*, *45*(1), 186-205.

Mujika, I., Busso, T., Lacoste, L., Barale, F., Geyssant, A. and Chatard, J.C. (1996a). Modeled responses to training and taper in competitive swimmers. *Medicine and Science in Sports and Exercise, 28,* 251-258.

Mujika, I., Chatard, J. C., Padilla, S., Guezennec, C. Y., & Geyssant, A. (1996). Hormonal responses to training and its tapering off in competitive swimmers: relationships with performance. *European Journal of Applied Physiology, 74,* 361–366.

Mujika, I., S. Padilla, A., Geyssant, J., & Chatard, C. (2003). Effects of tapering on performance: A meta-analysis. *Medicine and Science in Sports and Exercise, 39,* 1358-65.

Mujika, I., & Padilla, S. (2003). Scientific bases for precompetition tapering strategies. *Medicine and Science in Sports and Exercise, 35,* 1182–1187.

Nässi, A., Ferrauti, A., Meyer, T., Pfeiffer, M., & Kellmann, M. (2017). Development of two short measures for recovery and stress in sport. *European journal of sport science*, *17*(7), 894-903.

Pritchard, H., Keogh, J., Barnes, M., & McGuigan, M. (2015). Effects and mechanisms of tapering in maximizing muscular strength. *Strength & Conditioning Journal*, *37*(2), 72-83.

Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M.T. (1999). Cross-validation of three jump power equations. *Medicine and Science in Sports and Exercise, 31,* 572–577.

Stone, M. H., O'Bryant, H. S., Schilling, B. K., Johnson, R. I., Pierce, K. C., Haff, G.G., et al. (1999). Periodization: effects of manipulating volume and intensity. Part 1. *Strength Cond J., 21*(2): 56–62.

Stone, M. H. & Fry, A. C. (1998). Increased training volume in strength/power athletes. In: R.B. Kreider, A.C. Fry, and M.L. O'Toole (Eds.), *Overtraining in sport* (pp. 87-105). Champaign IL: Human Kinetics

Stone, M. H., Sanborn, K., O'Bryant, H.S., Hartman, M.E., Stone, M.E., Prouix, C., Ward, B. & Hruby, J. (2003). Maximum strength-power-performance relationships in collegiate throwers. *Journal of Strength and Conditioning Research, 17*, 739-745.

Suarez, D.G., Mizuguchi, S., Hornsby, W.G., Cunanan, A.J., Marsh, D.J., Stone, M.H. (2019). Phase-Specific Changes in Rate of Force Development and Muscle Morphology Throughout a Block Periodized Training Cycle in Weightlifters. Sports 7, 129.

Thomas, K., Brownstein, C. G., Dent, J., Parker, P., Goodall, S., & Howaston, G. (2018). Neuromuscular Fatigue and Recovery after Heavy Resistance, Jump, and Sprint Training. *Medicine and Science in Sports and Exercise.* PAP. Doi:10.1249/MSS.0000000000001733

Trappe, S., Costill, D., & Thomas, R. (2001). Effect of swim taper on whole muscle and single fiber contractile properties. *Medicine and Science in Sports and Exercise, 32,* 48–56.

Wagle, J.P., Carroll, K.M., Cunanan, A.J., Taber, C.B., Wetmore, A., Bingham, G.E., DeWeese, B.H., Sato, K., Stuart, C.A., & Stone, M.H. (2017). Comparison of the Relationship between Lying and Standing Ultrasonography Measures of Muscle Morphology with Isometric and Dynamic Force Production Capabilities. *Sports*, *5*.

Zaras, N. D., Stasinaki, A.-N. E., Methenitis, S. K., Krase, A. A., Karampatsos, G. P., Georgiadis, G. V., . . . Terzis, G. D. (2016). Rate of force development, muscle architecture, and performance in young competitive track and field throwers. The Journal of Strength & Conditioning Research, 30(1), 81-92.

Zatsiorsky, V.M. (1995). *Science and practice of strength training.* Champaign IL: Human Kinetics.

CHAPTER 4

SUMMARY AND FUTURE INVESTIGATIONS

The purpose of this study was to investigate the time course of psychological, morphological and performance measures in response to an overreach and taper period in weightlifters preparing for a national competition. The primary findings of this study were the significant time effects for overall recovery, overall stress, and loaded SJH, with 7 of 11 athletes having their best jump performance within 3 days preceding or including the day of competition. As was hypothesized, improved jump performance leading into competition coincided with improved mood-state, however there was a significant decrease in CSA. The findings of this study support the use of an overreach and taper period prior to competition to optimize competitive outcomes in competition.

The current study examined static jump performance, ultrasonography, and psychometric evaluation in an observational study over a five-week period of training prior to competition. The frequency of testing, particularly in the week of competition, was increased to characterize the timeline of response to training in the final days of preparation. This differs from prior investigations using similar monitoring methods in weightlifters, which primarily only tested in a pre-post manner (Hornsby et al. 2017, Carlock et al., 2004, Stone et al., 2006). Travis et al., 2018 conducted jump testing as a case study (one female, one male) with a similar frequency compared to the current study, however the current study pertained to a larger number of subjects (n=11). Thus, this study provides unique insight into the timeline of response to an overreach and taper within the context of a team of high-caliber weightlifters preparing for competition.

While this study did successfully demonstrate the time course of jump performance, psychometric and morphological measures, future research is needed to address optimal taper strategies for strength-power athletes. Studies may focus on the use of different taper strategies (step, linear, exponential) and its effects compared between athletes of various levels. Additionally, future research may investigate potential alterations in muscle architecture in response to various tapering strategies, with an emphasis on observing which strategy most effectively preserves CSA, MT and PA. These studies may also investigate potential differences in general and specific items of psychometric questions, with the goal of elucidating areas of focus for sport scientists during certain periods of training. Better understanding of the relevance of specific or general psychometric items throughout different periods of training would enhance the use of psychometric questionnaires as a monitoring tool. Further research may also focus on physiological effects of the pre-competition period and how these interact with performance and psychological measures.

REFERENCES

Abe, T., DeHoyos, D. V., Pollock, M. L., & Garzarella, L. (2000). Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. European Journal of Applied Physiology, 81(3), 174–180.

Ahtiainen JP, Hoffren M, Hulmi JJ, Pietikäinen M, Mero AA, Avela J, & Hakkinen, Keijo. (2010). Panoramic ultrasonography is a valid method to measure changes in skeletal muscle cross-sectional area. Eur J Appl Physiol. 108:273–9. 10.1007/s00421-009-1211-6

Ashley, C. D. & Weiss, L. W. (1994). Vertical jump performance and selected physiological

Aubry A, Hausswirth C, Louis J, Coutts AJ, LE Meur Y. (2014). Functional overreaching: the key to peak performance during the taper? Med Sci Sports Exerc;46:1769–77.

Auersperger, I., ˇSkof, B., Leskoˇsek, B., Knap, B., Jerin, A., Lainˇsˇcak, M., & Kajtna, T. (2014). Biochemical, hormonal and psychological monitoring of eight weeks endurance running training program in female runners. Kineziologija, 46, 30–39.

Avalos, M., Hellard, P. and Chatard, J.C. (2003) Modeling the training performance relationship using a mixed model in elite swimmers. Medicine and Sciences in Sports and Exercise 35, 838-846.

Baker, D. (2003). Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. J. Strength Cond. Res. 17, 493.

Baker, D., G. Wilson, and R. Carlyon. (1994). Periodization: the effect on strength of manipulating volume and intensity. J. Strength Conditioning Res. 8(4):235–242.

Bannister, E.W. (1982). Modelling elite athletic performance. In: J.D. MacDougall, H.A. Wenger, and H.J. Green (Eds.) Physiological testing of the high performance athlete (pp. 403-424). Champaign IL: Human Kinetics

Bartolomei S, Hoffman JR, Merni F, Stout JR. (2014). A comparison of traditional and block periodized strength training programs in trained athletes. J Strength Cond Res;28:990–7.

Bazyler, C. D., Mizuguchi, S., Zourdos, M. C., Sato, K., Kavanaugh, A. A., DeWeese, B. H., … Stone, M. H. (2018). Characteristics of a National Level Female Weightlifter Peaking for Competition: A Case Study. The Journal of Strength & Conditioning Research, Publish Ahead of Print. https://doi.org/10.1519/JSC.0000000000002379

Beckham, G., Mizuguchi, S., Carter, C., Sato, K., Ramsey, M., Lamont, H., … Stone, M. (2013). Relationships of isometric mid-thigh pull variables to weightlifting performance. The Journal of Sports Medicine and Physical Fitness, 53(5), 573–581.

Bompa, T. O., & Haff, G. (2009). Periodization: theory and methodology of training. In: Leeds: Human Kinetics, c2009.

Bonderchuk, A. Periodization of sport training.(1986). Legkaya Atletika 12:8-9

Bonifazi M, Sardella F, Luppo C. (2000). Preparatory versus main competitions: differences in performances, lactate responses and pre-competition plasma cortisol concentrations in elite male swimmers.Eur J Appl Physiol; 82: 368–373

Bosquet L, Montpetit J, Arvisais D, and Mujika I. (2007). Effects of tapering on performance: a meta-analysis. Med Sci Sports Exerc 39: 1358-1365

Bourdon PC, Cardinale M, Murray A, et al. Monitoring Athlete Training Loads: Consensus Statement. Int J Sports Physiol Perform. 2017;12(Suppl 2):S2161-S70.

Brännström, A., Rova, A., & Yu, J.G. (2013). Effects and Mechanisms of Tapering in Maximizing Muscular Power. International Journal of Human Movement and Sports Sciences, 1(1), 18–23. https://doi.org/10.13189/saj.2013.010103

Brechue, W. F., & Abe, T. (2002). The role of FFM accumulation and skeletal muscle architecture in powerlifting performance. European Journal of Applied Physiology, 86(4), 327–336.

Breil FA, Weber SN, Koller S, Hoppeler H, Vogt M. (2010). Block training periodization in alpine skiing: effects of 1-day HIT on VO2max and performance. Eur J Appl Physiol; 109:1077–86.

Carlock, J. M., Smith, S. L., Hartman, M. J., Morris, R. T., Ciroslan, D. A., Pierce, K. C., ... & Stone, M. H. (2004). The relationship between vertical jump power estimates and weightlifting ability: a field-test approach. The Journal of Strength & Conditioning Research, 18(3), 534-539.

Carroll, Kevin & Bernards, Jake & Bazyler, Caleb & Taber, Christopher & Stuart, Charles & DeWeese, Brad & Sato, Kimitake & Stone, Michael. (2018). Divergent Performance Outcomes Following Resistance Training Using Repetition Maximums or Relative Intensity. International Journal of Sports Physiology and Performance. 14. 1-28. 10.1123/ijspp.2018-0045.

Cavanaugh DJ, Musch KI. (1989). Arm and leg power of elite swimmers increase after taper as measured by biokinetic variable resistance machines. J Swimming Research; 5: 7–10 characteristics of women. Journal of Strength and Conditioning Research, 8, 5-11.

Charniga, A., Gambetta, V., Kraemer, W., Newton, H., O'Bryant, H. S., Palmieri, G., ... & Stone, M. H. (1987a). Periodization: Part 1. National Strength & Conditioning Association Journal, 8(5), 12-22.

Chiu LZF, Barnes JL. The fitness-fatigue model revisited: implications for planning short- and long-term training. Strength Cond J. 2003;25(6):42–51.

Costill DL, King DS, Thomas R, Hargreaves M. (1985). Effects of reduced training on muscular power in swimmers.Physician Sportsmed; 13: 94–101

Costill DL, Thomas R, Robergs A, Pascoe D, Lambert C, Barr S, Fink WJ. (1991). Adaptations to swimming training: influence of training volume.Med Sci Sports Exerc; 23: 371–377

Counsilman, J. E., & Counsilman, B. E. (1994). The new science of swimming. (pp. 229-244) Englewood Cliff, NJ: Prentice Hall.

Coutts, A. J., Wallace, L. K., & Slattery, K. M. (2007). Monitoring changes in performance, physiology, biochemistry, and psychology during overreaching and recovery in triathletes. International journal of sports medicine, 28(02), 125-134.

Cunanan, A. J., DeWeese, B. H., Wagle, J. P., Carroll, K. M., Sausaman, R., Hornsby, W. G., ... & Stone, M. H. (2018). The General Adaptation Syndrome: A Foundation for the Concept of Periodization. Sports Medicine, 1-11.

D'Acquisto LJ, Bone M, Takahashi S, Langhans G, Barzdukas AP, Troup JP. (1992). Changes in aerobic power and swimming economy as a result of reduced training volume.In: Swimming Science VI.Lond on: E & FN Spon: 201–205

DeWeese B, Gray HS, Sams ML, Scruggs SK, Serrano AJ. (2013). Revising the definition of periodization: merging historical principles with modern concern. Olympic Coach Magazine;24:5–19.

DeWeese BH, Hornsby G, Stone M, Stone MH. (2015). The training process: planning for strength–power training in track and field. Part 1: theoretical aspects. J Sport Health Sci.; 4(4):308–17.

DeWeese BH, Hornsby G, Stone M, Stone MH. (2015). The training process: planning for strength–power training in track and field. Part 2: practical and applied aspects. J Sport Health Sci.;4(4):318–24.

Dias I, De Salles BF, Novaes J, et al. (2010). Influence of exercise order on maximum strength in untrained young men. J Sci Med Sport; 13: 65-9

Fleck, S. J., & Kraemer, W. (2014). Designing Resistance Training Programs, 4th Ed. Champaign, IL: Human Kinetics.

Foster C. (1998). Monitoring training in athletes with reference to overtraining syndrome. Med Sci Sports Exerc.;30:1164–1168. PubMed doi:10.1097/00005768-199807000-00023

Fry, A.C., W.J. Kraemer, M.H. Stone, L.P. Koziris, J.T. Thrush, and S.J. Fleck. (2000a). Relationships between serum testosterone, cortisol, and weightlifting performance. Journal of Strength and Conditioning Research 14: 338-343

Fry, A.C., W.J. Kraemer. (1997). Feb. Review Article: Resistance Exercise Overtraining and Overreaching- Neuroendocrine Responses. Sports Med. (2) 106-129: doi: 0112-1642/97/00J2.QI 06/S12.CXJ/O

Garcia-Pallares J, Garcia-Fernandez M, Sanchez-Medina L, Izquierdo M. (2010). Performance changes in world-class kayakers following two different training periodization models. Eur J Appl Physiol;110:99–107.

Garhammer, J. (1993). A review of power output studies of olympic and powerlifting: methodology, performance prediction, and evaluation tests. Journal of Strength and Conditioning Research, 7(2), 76–89.

Gaskill, S.E., Serfass, R.C., Bacharach, D.W. and Kelly, J.M. (1999). Responses to training in cross-country skiers. Medicine and Sciences in Sports and Exercise 31, 1211-1217.

Gentil, P., Fisher, J., and Steele, J. (2017c). A review of the acute effects and longterm

Gentil, P., Soares, S., and Bottaro, M. (2015). Single vs. Multi-Joint resistance exercises: effects on muscle strength and hypertrophy. Asian J. Sport. Med. 6:e24057. doi: 10.5812/asjsm.24057

Haff, G. G. (2010). Quantifying workloads in resistance training: a brief review. Strength and Cond, 10, 31-40.

Haff, G. G. (2015). Periodization. Haff, G. G., & Triplett, N. T. (Eds.), Essentials of strength training and conditioning 4th edition. (pp. 583-604) Human kinetics.

Haff, G. G., Carlock, J. M., Hartman, M. J., Kilgore, J. L., Kawamori, N., Jackson, J. R., … Stone, M. H. (2005). Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. The Journal of Strength & Conditioning Research, 19(4), 741.

Häkkinen, K., Komi, P. V., & Kauhanen, H. (1986). Electromyographic and force production characteristics of leg extensor muscles of elite weight lifters during isometric, concentric, and various stretch-shortening cycle exercises. International Journal of Sports Medicine, 7(3), 144–151. https://doi.org/10.1055/s-2008-1025752

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. Sports Medicine, 44(2), 139-147.

Harre, D. 1982. Principles of sports training. Berlin, German Democratic Republic. Sportverlag.

Harris GR, Stone MH, O'Bryant HS, Proulx CM, Johnson RL. (2000) Short term performance effects of high speed, high force or combined weight training. J Strength Cond Res;14:14–20.

Hellard P, Avalos M, Hausswirth C, Pyne D, Toussaint JF, Mujika I. (2013). Identifying Optimal Overload and Taper in Elite Swimmers over Time. J Sports Sci Med; 12(4):668-678.

Hellard, P., Avalos, M., Millet, G.Y., Lacoste, L. and Chatard, J.C. (2005). Modeling the residual effects and threshold saturation of training: a case study of Olympic swimmers. Journal of Strength and Conditioning Research 19, 67-75.

Hides, J. A., Richardson, C. A., & Jull, G. A. (1995). Magnetic resonance imaging and ultrasonography of the lumbar multifidus muscle. Comparison of two different modalities. Spine, 20(1), 54-58.

Hitzschke, B., Kölling, S., Ferrauti, A., Meyer, T., Pfeiffer, M., & Kellmann, M. (2015). Entwicklung der Kurzskala zur Erfassung von Erholung und Beanspruchung im Sport (KEB) [Development of the Short Recovery and Stress Scale for Sports (SRSS)]. Zeitschrift für Sportpsychologie, 22, 146–162. http://dx.doi.org/10.1026/ 1612-5010/a000150

Hooper SL, Mackinnon LT, Ginn EM. (1998). Effects of three tapering techniques on the performance, forces and psychometric measures of competitive swimmers. Eur J Appl Physiol; 78: 258–263

Hornsby, W. (2013). A Systematic Approach to the Monitoring of Competitive Weightlifters. Electronic Theses and Dissertations.

Hornsby, W. G., Gentles, J. A., MacDonald, C. J., Mizuguchi, S., Ramsey, M. W., & Stone, M. H. (2017). Maximum strength, rate of force development, jump height, and peak power alterations in weightlifters across five months of training. Sports, 5(4), 78.

Hornsby, W.G., Gentles, J.A., Comfort, P., Suchomel, T.J., Mizuguchi, S., Stone, M.H. (2018). Resistance Training Volume Load with and without Exercise Displacement. Sports, 6, 137

Houmard, J. A. (1991). Impact of reduced training on performance in endurance athletes. Sports Med. 12:380–393.

Houmard, J. A., and R. A. Johns. (1994). Effects of taper on swim performance. Practical implications. Sports Med. 17:224–232 https://doi.org/10.1007/s004210050027

Issurin V, Timofeyev V, Sharobajko I, Razumov G, Zemliakov D. (1988). Particularities of annual preparation of top-level canoe-kayak paddlers during the 1984–88 Olympic cycle. Scientific Report. Leningrad Institute of Physical Culture.

Issurin VB, Sahrobajko IV. (1985). Proportion of maximal voluntary strength values and adaptation peculiarities of muscle to strength exercises in men and women. Moscow: Academy of Sciences USSR. Hum Physiol; 11:17–22.

Issurin, V. (2008). Block periodization versus traditional training theory: a review. Journal of sports medicine and physical fitness, 48(1), 65.

Johns RA, Houmard JA, Kobe RW, HortobXgyi T, Bruno NJ, Wells JM, Shinebarger MH. (1992). Effects of taper on swim power, stroke distance and performance.Me d Sci Sports Exerc; 24: 1141–1146

K. Häkkinen, M. Kallinen, P. V. Komi, H. Kauhanen. 1991, Jan-Feb. Neuromuscular adaptations during short-term "normal" and reduced training periods in strength athletes. Electromyogr Clin Neurophysiol. Jan-Feb; 31(1): 35–42.

Kirksey, Brett & Stone, Michael. (1998). Periodizing a College Sprint Program: Theory and Practice. Strength and Conditioning Journal – Strength and Conditioning J. doi: 20. 10.1519/1073-6840

Kreider, R., Fry, A., & O'Toole, M. (1998). Overtraining in sport: terms, definitions, and prevalence. Overtraining in sport, 309e331.

Le Meur, Y., Hausswirth, C., & Mujika, I. (2012). Tapering for competition: A review. Science & Sports, 27(2), 77-87. doi: http://dx.doi.org/10.1016/j.scispo.2011.06.013

Mallo J. (2011). Effect of block periodization on performance in competition in a soccer team during four consecutive seasons: a case study. Int J Perf Anal Sport;11:476–85.

Matveev LP, Zdornyj AP. (1981). Fundamentals of sports training. Moscow: Progress

McBride JM, McCaulley GO, Cormie P, Nuzzo JL, Cavill MJ, Triplett NT. (2009). Comparison of methods to quantify volume during resistance exercise. J Strength Cond Res.; 23:106–110.

Mcbride, J. M., Triplett-Mcbride, T., Davie, A., & Newton, R. U. (1999). A Comparison of Strength and Power Characteristics Between Power Lifters, Olympic Lifters, and Sprinters. The Journal of Strength & Conditioning Research, 13(1), 58.

McNeely E, Sandler D. Tapering for endurance athletes. Strength Cond J (2007); 29: 18-24

Medvedyev, AS. (1986). A system of multi-year training in weightlifting. Moscow, Russia: Fizkultura I Sport, 1986.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., ... & Urhausen, A. (2012). Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. Medicine and science in sports and exercise, 45(1), 186-205.

Mujika I, Chatard JC, Padilla S, Guezennec CY, Geyssant A. (1996). Hormonal responses to training and its tapering off in competitive swimmers: relationships with performance. Eur J Appl Physiol; 74: 361–366

Mujika, I. (1998). Influence of training characteristics and tapering on the adaptation in highly trained individuals: a review. Int. J. Sports Med. 19:439–446.

Mujika, I., and S. Padilla. (2003). Scientific bases for precompetition tapering strategies. Med. Sci. Sports Exerc. 35:1182–1187.

Mujika, I., Busso, T., Lacoste, L., Barale, F., Geyssant, A. and Chatard, J.C. (1996a) Modeled responses to training and taper in competitive swimmers. Medicine and Sciences in Sports and Exercise 28, 251-258.

Mujika, I., Chatard, J. C., Busso, T., Geyssant, A., Barale, F., & Lacoste, L. (1995). Effects of training on performance in competitive swimming. Can J Appl Physiol, 20(4), 395-406.

Mujika, I., Padilla, S., & Pyne, D. (2002). Swimming performance changes during the final 3 weeks of training leading to the Sydney 2000 Olympic Games. International Journal of Sports Medicine, 23(8), 582–587. https://doi.org/10.1055/s-2002-35526

Mujika, I., S. Padilla, A. Geyssant, J.C.Chatard. Effects of Tapering on Performance: A Meta-Analysis. Medicine and science in sports and exercise. 39. (2003) 1358-65.

Mujika, I., S. Padilla, D. Pyne, and T. Busso. (2004). Physiological changes associated with the pre-event taper in athletes. Sports Med. 34:891–927.

Mujika, Iñigo. (2009). Tapering and Peaking for Optimal Performance (Illustrated). Champaign, IL: Human Kinetic.

Nässi, A., Ferrauti, A., Meyer, T., Pfeiffer, M., & Kellmann, M. (2017). Development of two short measures for recovery and stress in sport. European journal of sport science, 17(7), 894-903.

Neufer, P. D. (1989). The effect of detraining and reduced training on the physiological adaptations to aerobic exercise training. Sports Med. 8:302–321.

Nimphius, S., McGuigan, M. R., & Newton, R. U. (2012). Changes in muscle architecture and performance during a competitive season in female softball players. The Journal of Strength & Conditioning Research, 26(10), 2655-2666.

O'Bryant, H. S. (1982). Periodization: A Hypothetical Model for Strength and Power (Doctoral Dissertation). Retrieved from LSU Historical Dissertations and Thesis. Accession No. 3767.

O'Toole, M.L. (1998). Overreaching and overtraining in endurance athletes. In: Overtraining in Sport. R.B. Kreider, A.C. Fry, and M.L. O'Toole, eds. Champaign, IL: Human Kinetics

Painter KB, Haff GG, Ramsey M, McBride J, Triplett T, Sands WA. (2012). Strength gains: block vs. DUP weight-training among track and field athletes. Int J Sports Physiol Perform;7:161–9.

Painter, Keith & Haff, Guy & W Ramsey, Mike & Travis Triplett, N & Stuart, Charles & Hornsby, Guy & Bazyler, Caleb & Stone, Michael. (2018). Resting Hormone Alterations and Injuries: Block vs. DUP Weight-Training among D-1 Track and Field Athletes. Sports. 6. 10.3390/sports6010003.

Paoli A, Gentil P, Moro T, Marcolin G and Bianco A (2017) Resistance Training with Single vs. Multi-joint Exercises at Equal Total Load Volume: Effects on Body Composition, Cardiorespiratory Fitness, and Muscle Strength. Front. Physiol. 8:1105. doi: 10.3389/fphys.2017.01105

Plisk SS, Stone MH. (2003). Periodization strategies. Strength Cond J; 25(6); 19-37

Pritchard, H., Keogh, J., Barnes, M., & McGuigan, M. (2015). Effects and mechanisms of tapering in maximizing muscular strength. Strength & Conditioning Journal, 37(2), 72-83. Publishers.

Raadsheer, M., Van Eijden, T., Van Spronsen, P., Van Ginkel, F., Kiliaridis, S., & Prahl-Andersen, B. (1994). A comparison of human masseter muscle thickness measured by ultrasonography and magnetic resonance imaging. Archives of oral biology, 39(12), 1079-1084.

Raglin JS, Koceja DM, Stager JM, Harms CA. (1996). Mood, neuromuscular function, and performance during training in female swimmers. Med Sci Sports Exerc; 28: 372–377

Raglin, J. S., & Wilson, G. S. (2000). Overtraining in athletes. In Y. L. Hanin (Ed.), Emotions in sport (pp. 191–207). Champaign, IL: Human Kinetics.

Rønnestad BR, Hansen J, Ellefsen S. (2014). Block periodization of high-intensity aerobic intervals provides superior training effects in trained cyclists. Scand J Med Sci Sports; 24:34–42.

Rowbottom, D. (2000). Periodization of training. In: W.E. Garret and D.T. Kirkendall (Eds.), Exercise and sport science) pp. 499-512). Philadelphia: Lippincot Williams & Wilkins

Saw, A. E., Main, L. C., & Gastin, P. B. (2016). Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. British Journal of Sports Medicine, 50, 281–291. http://dx.doi.org/10.1136/bjsports-2015-094758

Sayers, S.P., D.V. Harackiewicz, E.A. Harman, P.N. Frykman, and M.T. Rosenstein. (1999). Cross-validation of three jump power equations. Med. Sci. Sports Exerc. 31:572–577.

Scanlon, T. C., Fragala, M. S., Stout, J. R., Emerson, N. S., Beyer, K. S., Oliveira, L. P., & Hoffman, J. R. (2014). Muscle architecture and strength: Adaptations to short-term resistance training in older adults. Muscle & nerve, 49(4), 584-592.

Selye H. (1936). A Syndrome produced by diverse nocuous agents. Nature; 138(3479): 32

Selye H. (1976). Forty years of stress research: principal remaining problems and misconceptions. Can Med Assoc J; 115(1):53–6.

Selye H. (1982). Stress: eustress, distress, and human perspectives. In: Day SB, editor. Life Stress. New York: Van Nostrand Reinhold; pp. 3–13.

Siff, M. C. (2003). Supertraining. Denver, CO: Supertraining Intistute.

Simăo R, Spineti J, De Salles BF, et al. (2010). Influence of exercise order on maximum strength and muscle thickness in untrained man. J Sport Sci Med; 9: 1-7

Simao, R., De Salles, B. F., Figueiredo, T., Dias, I., & Willardson, J. M. (2012). Exercise order in resistance training. Sports medicine, 42(3), 251-265.

Spineti J, De Salles BF, Rhea MR, et al. (2010). Influence of exercise order on maximum strength and muscle volume in nonlinear periodized resistance training. J Strength Con Res; 11: 2962-9

Stebbings, G. K. (2015, January). Genetics of skeletal muscle strength and its determinants in healthy, untrained males (doctoral). Manchester Metropolitan University. Retrieved from https://e-space.mmu.ac.uk/580126/

Steward, A.M. and Hopkins, W.G. (2000a). Consistency of swimming performance within and between competitions. Medicine and Sciences in Sports and Exercise 32, 997-1001.

Stone MH, O'Bryant HS, Schilling BK, Johnson RI, Pierce KC, Haff GG, et al. (1999).b Periodization: effects of manipulating volume and intensity. Part 1. Strength Cond J.; 21(2):56–62.

Stone, M. H., O'Bryant, H., Garhammer, J., McMillan, J., & Rozenek, R. (1982). A theoretical model of strength training. NSCA J, 4(4), 36-39.

Stone, M. H., O'bryant, H. S., Schilling, B. K., Johnson, R. L., Pierce, K. C., Haff, G. G., & Koch, A. J. (1999). Periodization: Effects Of Manipulating Volume And Intensity. Part 2. Strength & Conditioning Journal, 21(2), 56.

Stone, M. H., O'Bryant, H., & Garhammer, J. (1981). A hypothetical model for strength training. The Journal of sports medicine and physical fitness, 21(4), 342.

Stone, M. H., Stone, M., & Sands, W. A. (2007). Principles and practice of resistance training. Human Kinetics.

Stone, M.H., ad A.C. Fry. (1998). Increased training volume in strength/power athletes. In: R.B. Kreider, A.C. Fry, and M.L. O'Toole (Eds.), Overtraining in sport (pp. 87-105). Champaign IL: Human Kinetics

Stone, M.H., K. Sanborn, H.S. O'Bryant, M.E. Hartman, M.E. Stone, C. Prouix, B. Ward, and J. Hruby.(2003). Maximum strength-power-performance relationships in collegiate throwers. Journal of Strength and Conditioning Research 17: 739-745

Stone, Michael & Collins, David & Plisk, Steven & Haff, Guy & E. Stone, Margaret. (2000). Training Principles: Evaluation of Modes and Methods of Resistance Training. Strength & Conditioning Journal. 22. 65. 10.1519/1533-4295

Stone, Michael & Pierce, Kyle & Sands, William & Stone, Meg. (2006). Weightlifting: A Brief Overview. Strength & Conditioning Journal. 28. 10.1519/1533-4295

Stone, Michael & Pierce, Kyle & Sands, William & Stone, Meg. (2006). Weightlifting: Program Design. Strength and Conditioning Journal. 28. 10-17. 10.1519/1533-4295

Suarez, D.G., Mizuguchi, S., Hornsby, W.G., Cunanan, A.J., Marsh, D.J., Stone, M.H. (2019). Phase-Specific Changes in Rate of Force Development and Muscle Morphology Throughout a Block Periodized Training Cycle in Weightlifters. Sports 7, 129.

Suchomel, T.J.; Sato, K.; DeWeese, B.H.; Ebben, W.P.; Stone, M.H. (2016). Potentiation following ballistic and nonballistic complexes: The effect of strength level. J. Strength Cond. Res, 30, 1825–1833.

Thomas, K., Brownstein, C.G., Dent, J., Parker, P., Goodall, S., Howaston, G. (2018). Neuromuscular Fatigue and Recovery after Heavy Resistance, Jump, and Sprint Training. Medicine & Science in Sports & Exercise. PAP. Doi:10.1249/MSS.0000000000001733

Thomas, L. and Busso, T. (2005) A theoretical study of taper characteristics to optimize performance. Medicine and Sciences in Sports and Exercise 37, 1615-1621.

Thomas, L., Mujika, I. and Busso, T. (2008) A model study of optimal training reduction during pre-event taper in elite swimmers. Journal of Sports Sciences 26, 643-652.

Trappe, S., D. Costill, and R. Thomas. (2001). Effect of swim taper on whole muscle and single fiber contractile properties. Med. Sci. Sports Exerc. 32:48–56.

Travis, S.K., Mizuguchi, S., Stone, M.H., Sands, W.A., Bazyler, C.D. (2018). Preparing for national weightlifting championship: a case study. Presenting at the National Strength and Conditioning Association National Conference, Indianapolis, IN.

Turner, A. (2011). The science and practice of periodization: a brief review. Strength & Conditioning Journal, 33(1), 34-46.

Wagle, J.P.; Carroll, K.M.; Cunanan, A.J.; Taber, C.B.; Wetmore, A.; Bingham, G.E.; DeWeese, B.H.; Sato, K.; Stuart, C.A.; Stone, M.H. (2017). Comparison of the Relationship between Lying and Standing Ultrasonography Measures of Muscle Morphology with Isometric and Dynamic Force Production Capabilities. Sports, 5.

Wallace, L. K., Slattery, K. M., & Coutts, A. J. (2009). The ecological validity and application of the session-RPE method for quantifying training loads in swimming. J Strength Cond Res, 23(1), 33-38. doi:10.1519/JSC.0b013e3181874512

Walton, J., Roberts, N., & Whitehouse, G. (1997). Measurement of the quadriceps femoris muscle using magnetic resonance and ultrasound imaging. British journal of sports medicine, 31(1), 59-64.

Yakovlev NN. (1967). Sports biochemistry. Leipzig: Deutsche Hochschule fu¨r Korperkultur.

Yesalis, C.E. (1993). Introduction. In: C.E. Yesalis (Ed.), Anabolic steroids in sport and exercise (pp. xxiv-xxxiv). Champaign, IL: Human Kinetics.

Zaras, N. D., Stasinaki, A.-N. E., Methenitis, S. K., Krase, A. A., Karampatsos, G. P., Georgiadis, G. V., . . . Terzis, G. D. (2016). Rate of force development, muscle architecture, and performance in young competitive track and field throwers. The Journal of Strength & Conditioning Research, 30(1), 81-92.

Zatsiorsky, V.M. (1995) Science and practice of strength training. Champaign IL: Human Kinetics.

APPENDICES

Appendix A: Dietary Food Log

DIETARY LOG

1. Use the Dietary Record Forms provided to record everything you eat or drink for each day of this study.
2. Indicate the name of the FOOD ITEM, the AMOUNT eaten, how it was PREPARED (fried, boiled, etc.), and the TIME the food was eaten. If the item was a brand name product, please include the name. Try to be accurate about the amounts eaten. Measuring with measuring cups and spoons is best, but if you must make estimates, use the following guidelines:

   Fist is about 1 cup

   Tip of Thumb is about 1 teaspoon

   Palm of the hand is about 3 ounces of meat (about the size of a deck of cards) Tip of

   Thumb is about 1 ounce of cheese

3. Try to eat what you normally eat and record everything. The project will only be useful if you are HONEST about what you eat. The information you provide is confidential.
4. MILK: Indicate whether milk is whole, low fat (1 or 2%), or skim. Include flavoring if one is used.
5. VEGETABLES and FRUITS: One average serving of cooked or canned fruits and vegetables is about a half cup. Fresh whole fruits and vegetables should be listed as small, medium, or large. Be sure to indicate if sugar or syrup is added to fruit and list if any margarine, butter, cheese sauce, or cream sauce is added to vegetables. When recording salad, list items comprising the salad separately and be sure to include salad dressing used.
6. EGGS: Indicate method of preparation (scrambled, fried, poaches, etc.) and number eaten.
7. MEAT / POULTRY / FISH: Indicate approximate size or weight in ounces of the serving. Be sure to include any gravy, sauce, or breading added.
8. CHEESE: Indicate kind, number of ounces or slices, and whether it is made from whole milk, part skim, or is low calorie.
9. CEREAL: Specify kind, whether cooked or dry, and measure in terms or cups or ounces. Remember that consuming 8 oz. of cereal is not the same as consuming one cup of cereal. 1 cup of cereal generally weighs about 1 ounce.
10. BREAD and ROLLS: Specify kind (whole wheat, enriched wheat, rye, etc.) and number of slices.
11. BEVERAGES: Include every item you drink excluding water. Be sure to record cream and sugar used in tea and coffee, whether juices are sweetened or unsweetened and whether soft drinks are diet or regular.
12. FATS: Remember to record all butter, margarine, oil, and other fats used in cooking or on food.
13. MIXED DISHES / CASSEROLES: List the main ingredients and approximate amount of each ingredient to the best of your ability.
14. ALCOHOL: Be honest. Record amounts in ounces. Specify with "light" or "regular" beer.

DIETARY RECORD FORM

Day of the Week:

Date:

FOOD ITEM	AMOUNT	TIME

Express approximate measures in cups (C), tablespoons (T), teaspoons (t), grams (g), ounces (oz.), pieces, etc.

Appendix B: Short Recovery-Stress Scale

Short Recovery Scale

Below you find a list of expressions that describe different aspects of your current state of recovery. Rate how you feel right now in relation to your best ever recovery state.

Physical Performance Capability

e.g.
strong,
physically capable,
energetic,
full of power

does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Mental Performance Capability

e.g.
attentive,
receptive,
concentrated,
mentally alert

does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Emotional Balance

e.g.
satisfied,
balanced,
in a good mood,
having everything under control
stable,
pleased

does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Overall Recovery

e.g.
recovered,
rested,
muscle relaxation,
physically relaxed

does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Short Stress Scale

Below you find a list of expressions that describe different aspects of your current state of stress. Rate how you feel **right now** in relation to your highest ever stress state.

Muscular Stress

e.g.
muscle exhaustion,
muscle fatigue,
muscle soreness,
muscle stiffness

does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Lack of Activation

e.g.
unmotivated,
sluggish,
unenthusiastic,
lacking energy

does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Negative Emotional State

e.g.
feeling down,
stressed,
annoyed,
short-tempered

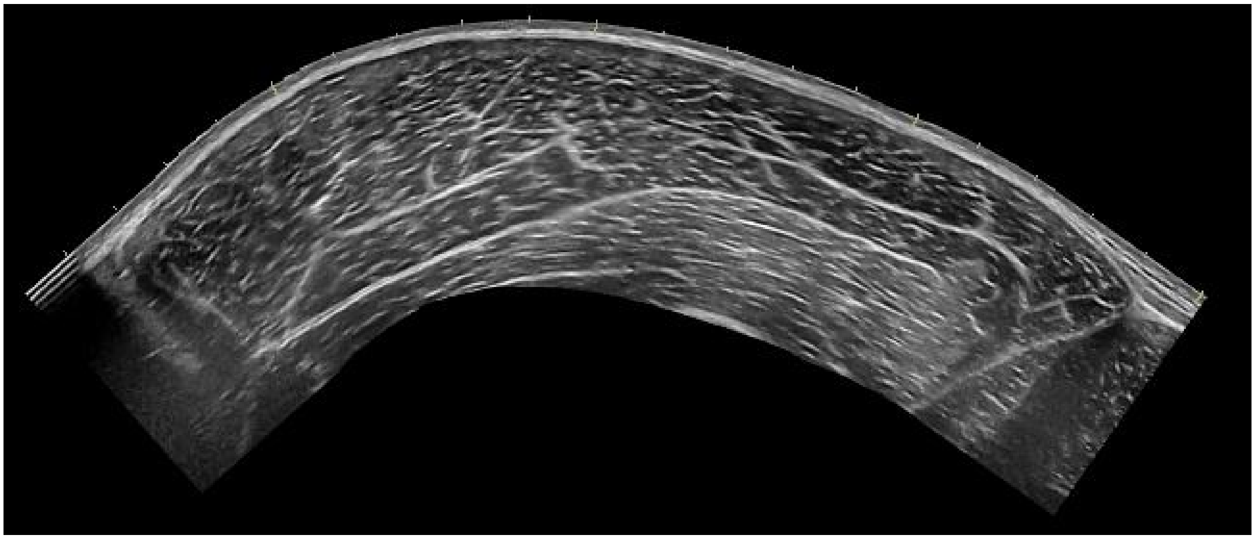
does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Overall Stress

e.g.
tired,
worn-out,
overloaded,
physically exhausted

does not apply at all ○—○—○—○—○—○—○ fully applies
0 1 2 3 4 5 6

Appendix C: Ultrasonography Image for Muscle Cross-Sectional Area



Appendix D: Sample Training Program

Repetitions

Wk1 - 5 x 5

Wk2 - 3 x 3 (1 x 5)

Wk3 – 3 x 3 (1 x 5)

Wk4 – 3 x 2 (1 x 5) – University Nationals

Relative Intensity (sets and reps)

	M	T	W	Th	F	Sat	S
Wk1	MH		M	L		VL	
Wk2	M		MH	VL		VL	
Wk3	MH		M	VL		VL	
Wk4	ML		L	VL	Meet	Meet	Meet

Monday and Thursday AM

1. Squats (drop after WK3)

Monday and Thursday PM

1. Jerk

WK1: 5x1 (#1 @ 85, #2 @ 80, #3 @ 85, #4 @ 75%, #5 @ 70%)

WK2: 3x1 (#1 @ 90%, #2 @ 85, #3 @ 90%)

WK3: 3x1 (#1 @ 80, #2 @ 75, #3 @ 80%)

WK4: 3x1 @ 75%

2. Dead stop parallel squat (drop after WK1)

3. BN Press

4. DB Press (drop after Wk3)

Wednesday AM

0. WU: Snatch tech 3x5

1. CGSS

2. CG pull from power position

Wednesday PM

0. WU: Clean tech 3x5 30-60% of goal

1. SGSS

2. SG pull from floor

3. CG SLDL (drop after WK3)

4. DB bent-over row (drop after WK3)

Saturday

0. WU: Snatch tech 3x5

1. SGSS

2. Snatch

    WK1: 5x1 (#1 @ 85, #2 @ 77.5, #3 @ 82.5, #4-5 @ 50-65%)

    WK2: 3x1 (#1 @ 90, #2-3 @ 50-65%)

    WK3: 3x1 (#1 @ opener, #2-3 @ 50-60%)

    WK4: University Nationals

3. C&J

    WK1: 5x1 (#1 @ 85, #2 @ 80, #3-5 @ 50-65%)

    WK2: 3x1 (#1 @ opener, #2-3 @ 50-60%)

    WK3: 3x1 (#1 @ 85, #2 @ 65, #3 @ 50%)

    WK4: University Nationals

3. SG SLDL

4. DB bent-over row (Drop after WK3)

VITA

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Assessing the Validity and Reliability of a Freehand Tool Method for Analysis of Ultrasound Cross-Sectional Area Images (Donald J. Marsh, Dylan Suarez, Luis Rodriguez-Castellano, Kyle Rochau, Ai Ishida, Caleb Bazyler, 2018)- Coaches College Conference

The Use of the Isometric Mid-thigh Pull in the Monitoring of Weightlifters: 25 Years of Experience. (M.H. Stone, G. Hornsby, A. Cunanan, S. Mizuguchi, D.J. Marsh, D.G. Suarez, M. South, G. Haff, M.W. Ramsey, G. Beckham, H. Santana, J.P. Wagle, M.E. Stone, K.C. Pierce). UKSCA

Phase-Specific Changes in Rate of Force Development and Muscle Morphology Throughout a Block Periodized Training Cycle in Weightlifters (Dylan Suarez, Satoshi Mizuguchi, William Hornsby, Aaron Cunanan, Donald Marsh, Michael Stone)- Published in Sports

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