8-2018

An Investigation into Fatigue Management: Effects of Two Different Loading Protocols on Markers of Inflammation and the Endocrine Response

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An Investigation into Fatigue Management: Effects of Two Different Loading Protocols on Markers of Inflammation and the Endocrine Response

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A dissertation

presented to

the faculty of the Department of Sport, Exercise, Recreation, & Kinesiology

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Doctor of Philosophy in Sport Physiology and Performance

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August 2018

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Keywords: Fatigue, Inflammation, Resistance Training

ABSTRACT

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The purposes of this dissertation were to 1) determine the effectiveness of the neutrophil-lymphocyte ratio (NLR) as an athlete monitoring tool in resistance training and 2) determine if repetition maximum or relative intensity loading scheme is superior in managing fatigue through the hormonal, inflammatory, and performances response throughout a 10-week periodized resistance training program. Results from the dissertation give merit to continued research regarding the use of NLR as a monitoring tool to help determine the degree of recovery. Furthermore, results from this dissertation lead to questioning the effectiveness of using a repetition maximum (RM) loading scheme within a periodized training model. Results indicated statistical significant time x group interaction effects for training strain and T:C, statistical main effects for time for NLR, IPF, and IPFa. Under an identical programming model, RM loading subjects experienced a 48.7% increase in training strain over the course of ten weeks. This intensification in training strain likely contributed to the increased negative immune and endocrine response the RM subjects experienced when compared to the relative intensity (RI_{SR}) group. When dissecting the individual pre-post performance results, the three largest decreases in static jump height (out of four) participated in the RM loading group. Additionally, only two subjects experienced decreases in their maximal strength (based on isometric mid-thigh pull), both of which participated in the RM loading group. Lastly, it is highly likely that one subject from the RM group was at exceedingly high risk of entering a state overtraining. At a minimum,

the subject entered a state of a nonfunctional overreach, based on an increase in cortisol concentrations, NLR, T:C levels, along with decreases in testosterone concentrations and maximal strength performance. When combined, results suggest that using an RM loading scheme and a periodized model may not allow for adequate recovery, especially during phases where recovery is of utmost importance (e.g. a taper).

DEDICATION

I would like to dedicate this dissertation to the humble scientist who quietly works to perfect his/her craft. In the subtle absence of dogmatism, there lays a common ground for scientific knowledge to grow and flourish.

ACKNOWLEDGMENTS

I would like to thank my family and friends for their continued support throughout my education.

Thank you to the ETSU staff and student body for driving me to grow as a professional as well as a person.

Finally, thank you to the subjects who dedicated an extraordinary amount of time, effort, and agony for this study to be possible.

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CHAPTER 1

INTRODUCTION

The theory of periodization aligns a system of consecutive training goals to maximize fitness characteristics and, therefore, preparedness during specific time points throughout the year (DeWeese, Gray, Sams, Scruggs, & Serrano, 2013). Not to be confused with periodization, the programming techniques used with a periodized model are what make up the sets, repetitions, and exercises the athlete completes to achieve specific training outcomes (DeWeese, Hornsby, Stone, & Stone, 2015a; Stone, Stone, & Sands, 2007). Beyond the programming technique implemented, the individual must also decide on a loading strategy used throughout the programming model. Various programming and loading techniques alter the sets, repetitions, and intensity at various time points throughout the year to ensure the athlete is most prepared directly before a competition.

Integral to many programming and loading strategies is the variation and specificity that occurs with the alteration of the sets, repetitions, and intensities. A common programming strategy found in the periodization literature and practice is phase potentiation (DeWeese et al., 2015a; DeWeese, Hornsby, Stone, & Stone, 2015b). Phase potentiation (Cunanan et al. 2018) is a programming method constructed so that volume and intensity create residual and after effects that potentiate the programming in the following phases (blocks) (DeWeese et al 2015a; DeWeese et al. 2015b; Issurin 2008; Issurin 2010). Phase potentiation typically incorporates a relative intensity (RI_{SR}) loading scheme utilizing heavy and light training days within a concentrated block. A percentage of a set x rep best value determines the weight used. This programming and loading strategy aim to improve a specific fitness characteristic at a specific phase within the periodization model (DeWeese et al., 2015a, 2015b). Furthermore, the incorporation of heavy and light training days may enhance fatigue management within a microcycle and across a mesocycle.

Regardless of the programming strategy applied, the most common loading strategy found in training literature is the use of repetition max (RM) values (Buford, Rossi, Smith, & Warren, 2007; Hartmann, Bob, Wirth, & Schmidtbleicher, 2009; Hoffman, Wendell, Cooper, & Kang, 2003; Kok, Hamer, & Bishop, 2009; Prestes, De Lima, Frollini, Donatto, & Conte, 2009; Rhea, Ball, Phillips, & Burkett, 2002). RM loading often takes advantage of individual RM training zones and prescribes different repetition ranges based on the day's training goals. For example, when training for muscular hypertrophy, the athlete would perform repetitions of eight to twelve with a load that can be lifted a minimum of eight times but no more than twelve (Hoffman, 2002). In turn, this loading strategy continually prescribes a relative maximum load, leading to the athlete training to failure for one or more sets per exercise. Use of an RM strategy is likely to result in little time to recover from the accumulated fatigue that occurs from an extensive training program outside of days off and may put the athlete at risk of overtraining (Meeusen et al., 2013; Moran-Navarro et al. 2017).

As the principles of phase potentiation promote a balance between stimulus and fatigue levels, employing a loading scheme such as RM may alter the theoretical response (DeWeese et al., 2013). Regardless of the training phase, the athlete may also experience an endurance component through the relative maximum loading scheme. This unaccounted endurance component can likely result in reduced fatigue management. Thus, physiological and performance response to training will likely be affected.

Several metabolic alterations associated with inflammation accompanies fatigue accumulated by exposure to training and other stressors. These can include, alterations in white blood cell count, testosterone and cortisol concentration, the testosterone to cortisol ratio (T:C) and several potential proinflammatory cytokine concentrations (Bessa et al., 2016; Fry et al., 2000; Pedersen & Toft, 2000; Smilios, Pilianidis, Karamouzis, & Tokmakidis, 2003). Such alterations often reflect the severity of the resulting fatigue and loss of performance (Angeli, Minetto, Dovio, & Paccotti, 2004; Fry et al., 1994; Gleeson, 2002; Smith, 2000).

To compare the effects of employing an RM loading scheme into a periodized model, the investigator must prescribe identical exercise selection and fitness goals throughout the training program. This type of observation allows for an accurate comparison of various physiological and performance alterations that stem from the different loading strategies ability to manage fatigue adequately. To the authors' knowledge, this has yet to be accomplished.

Purpose

Therefore, the purpose of this dissertation was to determine if the fatigue and performance response differed when comparing RM and RI_{SR} loading strategies under an identical phase potentiation programming model. Specifically, this dissertation served to;

1. Determine the effectiveness of the neutrophil-lymphocyte ratio (NLR) as an athlete monitoring tool in resistance training

2. Determine if repetition maximum or relative intensity loading scheme is superior in managing fatigue through the hormonal, inflammatory, and performances response.

Operational Definitions

1. Periodization- A logical phasic method of manipulating training variables to increase the potential for achieving specific performance goals. Plisk, S. S., & Stone, M. H. (2003)
2. Programming – The sets, repetitions and exercise selection that make up the various phases of the periodized plan (DeWeese, Hornsby, Stone, & Stone, 2015).
3. Loading – The method of prescribing the intensity of the resistance training program through alteration of the load prescribed
4. Relative Intensity Loading (RI_{SR}) – A loading scheme where individuals are provided a percentage of their set x repetition maximum dependent on the day's training goal
5. Relative Maximum Loading (RM) – A loading scheme where individuals are provided a zone dependent on the day's training goal (i.e., 8-12). The prescribed load must be lifted a minimum of the lower end of the range and no more than the upper end.
6. Failure – The inability of an individual to contract past the "sticking point" of an exercise
7. Biomarker – Substance measured in serum that indicates the concentration of a protein, hormone, etc.
8. Endocrine: Relating to glands or hormones which secrete hormones directly into the blood
9. Inflammatory – Relating to or causing inflammation within the body
10. Rating of perceived exertion (RPE) – a measure of the athlete's perception of training intensity
11. Session Ration of perceived exertion (sRPE) – RPE quantified on a modified Borg scale (1-10) and multiplied by the duration of the training session.

12. Allometric scaling – The absolute value of a variable divided by the subject's body mass raised to the power of two thirds (Jaric, Mirkov, & Markovic, 2005).
13. Volume-load displacement (VL_d) – resistance training load (sets x reps x load) for an exercise multiplied by the concentric bar displacement measured using OpenBarbell following the completion of training.
14. Non-functional Overreach – An accumulation of training and non-training stress resulting in a decrement in performance capability which takes longer than the intended desire (Meeusen et al., 2013).
15. Fatigue – The inability to maintain the required or expected force (or power) outputs (Edwards, 1983).
16. Fatigue management – Strategies inherent to the training program to help manage the accumulation of excessive fatigue
17. Performance – A laboratory assessment outcome that relates to athletic performance

CHAPTER 2

LITERATURE REVIEW

As sport scientists continually expand our understanding of the response and adaptations to various stimuli, training methods continue to evolve to develop the most efficient way to train. Such training methods aim to incorporate activities that target specific physiological and performance characteristics, both of which can be modulated to have direct training outcomes (Bompa & Haff, 2009). These results can, therefore, be manipulated to improve athletic readiness. To improve an athlete’s readiness, a strength coach must first have a sound understanding of the sport's physiological properties. Additionally, a thorough understanding of how a training plan may influence an individual's fitness characteristics and physiological adaptations, both acutely and chronically, must be known. The acute responses and chronic physiological adaptations become the foundation of increased performance during competition, but only if fatigue is adequately managed.

There has been considerable debate as to which programming model is the most effective in maximizing neural and morphological adaptations (Baker, Wilson, & Carlyon, 1994; Buckner et al. 2017; Cunanan et al. 2018; Haff, 2001; Prestes et al., 2009; Turner, 2011). Central to any strength training program is the recovery-adaptation process in conjunction with an athlete’s level of preparedness (summation of two after effects of training: fatigue and fitness) at a given competition (Stone et al., 2007). Without properly accounting for the recovery process, the exercise stimulus will produce diminished performance due to increased levels of fatigue. Furthermore, if fatigue has not adequately dissipated the previously increased fitness characteristics cannot be expressed, and performance will likely be diminished (Banister, 1991).

Alterations to the training stimulus, including a proper progression of volume, load, and exercise selection, may determine the athlete's level of fitness and fatigue in the short- and long-term (Kavanaugh, 2014). Therefore, the success of any training program is dependent on the integration of adequate recovery periods that allow for adaptations to the training stimulus to occur. This review examines the current understanding fatigue plays in the success of a training program and consequently, performance in competition.

Training Theory

Training is a process which prepares an athlete, technically, tactically, psychologically, physiologically, and physically for the highest possible levels of performance (DeWeese et al., 2015a; Stone et al., 2007). A thorough understanding of training principles along with how and when to apply those principles can be the difference between a successful offseason of training and under-stimulating or over-fatiguing an athlete. Both of which lead to the athlete underperforming when it matters most. When developing, and implementing a training program, various core principles must be taken into consideration: overload, variation, specificity, and reversibility. When correctly applied in the training process, adaptation is optimized, fatigue management is enhanced, chances of overtraining become minimized, and the potential for superior performance is augmented (DeWeese et al., 2015a).

Two additional considerations when developing a training plan include volume and intensity. Training volume is a measure of the total work performed during training and is strongly related to the total energy expenditure and subsequent metabolic alterations (Burleson, O'Bryant, Stone, Collins, & Triplett-McBride, 1998; McCaulley et al., 2009; Phillips, Mitchell, Currie-Elolf, Yellott, & Hubing, 2010). While it is not practical to measure the exact training volume for each training session, a commonly used metric used in research and practical settings for resistance training is the volume load displacement (VL_d). Calculated via:

$$VL_d = \text{reps} * \text{load} * \text{displacement}$$

The volume load displacement is a much more accurate measurement of the total work completed when compared to the common volumeload metric: reps x load, as it considers the distance an individual is moving the mass (Hornsby, 2013). The VL_d can be computed to estimate the amount of work accomplished for specific exercises during each training session, microcycle, mesocycle, and macrocycle.

Training intensity is associated with the velocity of movement, the rate of performing work (power), and the rate at which energy is expended (Stone, Fleck, Triplett, & Kraemer, 1991). A typical metric used to plan intensity during a training program is commonly known as relative intensity. Relative intensity can be defined as a percent of one repetition maximum (1RM) for each exercise and is often used as a prescription method in various programming strategies. Relative intensity can also be calculated in terms of the maximum load for sets and repetitions (RI_{SR}) (Stone et al. 2007). Use of the RI_{SR} is beleieved to better account for differences in the number of possible repetitions that can be accomplished for a given set and repeitition range (Stone et al. 2007). Training with relative intensities can be broken into the relative daily intensity, the average weekly relative intensity, and the block's average relative intensity. Tracking the relative intensity throughout the training program can ensure the athlete is achieving the proper stimulus to force adaptation and help manage fatigue. Moreover, tracking the intensity can also contribute to ensuring the athlete is not overstimulated and at risk for non-functional overreaching or overtraining.

Essential to training theory is the concept of periodization. Periodization can be defined as the overall long-term cyclic structuring of training and practice to maximize or stabilize performance coinciding with essential competitions (DeWeese et al., 2015a; Verkhoshansky & Siff, 2009). Periodization deals with timelines and fitness phases (Cunanan et al. 2018; DeWeese et al. 2015a; Stone et al. 2007). A periodization plan structures the training phases to target physiological and performance characteristics allowing the athlete to develop the highest levels of speed, strength, power, agility, and endurance possible (Bompa & Haff, 2009). Regardless of the training model implemented, for a training plan to be effective, it must reflect an increasing level of variation and micromanagement as the athlete's development progresses (Stone et al., 2007).

Block Periodization

Block periodization (Block) consists of a stage(s), containing three “blocks”: accumulation, transmutation and realization (DeWeese et al. 2015a; DeWeese et al. 2015b.) Each block typically lasts 3–4 weeks. Conceptually, Block periodization depends upon “phase potentiation” programming, in which each individual block theoretically potentiates the next, through residual effects (Issurin 2008; Issurin 2010; DeWeese et al. 2015a; DeWeese et al. 2015b). Accumulation, is focused on higher volume and less specific training such that alterations in characteristics such as body composition, work capacity, and basic strength, are emphasized. Transmutation (or Transition) moves to more specific exercises, lower volumes and higher intensities of training, and can result in substantial increases in maximum strength for specific exercises. For strength-power athletes, realization is associated with task-specific, power-oriented exercises and typically involves a taper (volume reduction) to reduce accumulated fatigue.

As noted, programming for a block periodization model includes phase potentiation. Phase potentiation uses the idea of linking together a sequence of concentrated loads (summated microcycles) at appropriate time points to help potentiate a subsequent block's fitness phase and ultimately produce superior results (DeWeese et al., 2015b). Potential outcomes of the emphasis placed on the concentrated load will then be expressed at a later time due to after-effects, and perhaps a long-term delayed training effect (Verkhoshansky & Siff, 2009). Following the removal of the initial stimulus, physiological, performance-related characteristics known as after-effects can persist for several weeks. The expression of the after-effects can allow one phase of training to potentiate the subsequent block (DeWeese et al., 2015b, 2015a). Theoretically, this could enable the athlete to handle a higher stimulus than they could have formerly endured without the risk of overtraining. Furthermore, the attempt to simultaneously develop multiple components is often counterproductive (DeWeese et al., 2015b; Jones, Howatson, Russell, & French, 2016; Terzis et al., 2016; Verkhoshansky & Siff, 2009).

These occurrences were illustrated through a study completed by Harris et al. (2000) where a high force concentrated training block before a high power concentrated block produced superior improvements in the rate of development, peak isometric force, and 1RM squat when compared to high power or high-velocity training alone. In the study, Harris et al. (2000) examined the effectiveness of three separate training programs for 51 American football players. Training programs included high force focused training, high power focused training, and training consisting of summated blocks of combined high force and high-power training for a nine-week period. Results indicated that the summated blocks allowed for superior adaptations, when compared to both high force training and high power focused training alone, in improving squat strength, midthigh pull, vertical jump (height and power), and 10-yard sprint time (Harris et al., 2000).

Additional studies have also investigated the effectiveness of variations embodying block periodization and compared it to a multitude of other training protocols including traditional periodization, daily undulating periodization, force focused training, power-focused training, and traditional sports training. For example, Mallo (2011) investigated the effectiveness of block periodization on performance during competition for a Spanish professional soccer team over a four-year bout. A total of 77 male professional soccer players were included in the study. Over the course of the season, time points were broken down into three distinct training stages including; Accumulation, Transmutation, and Realization. Results favored the block form of periodization for speed endurance, 1RM (strength), and percentage of points obtained by the team in each match when compared to traditional soccer training. Additionally, competitive team performance was highest during the realization blocks, giving credence towards block periodization's superior fatigue management strategies (Mallo, 2011).

Garcia (2010) investigated the physiological and performance outcomes of traditional periodization vs. block periodization in world-class kayakers. Over the course of two years, block periodization was superior to traditional periodization in increasing $\dot{V}O_{2peak}$, peak paddling speed, peak power output, and a higher stroke rate when paddling at max capacity. Furthermore, when comparing the two training models side by side, block periodization showed a more significant improvement even though it lasted ten weeks and 120 training hours less than the traditional periodization design. The authors attributed the superior efficiency to the block periodization’s ability to allow for a higher workload accumulation over the selected training targets (Garcia-Pallare et al., 2010).

A key advantage in implementing a block periodized training model is the ability to manage fatigue. In block periodization, a planned variation of training methods, such as exercise selection/depletion, training intensities, and volume loads help to manage fatigue. This essential variation allows for a sufficient stimulus to force adaptation, but also adequate recovery to ensure the athlete does not enter a state of overtraining.

Overtraining Syndrome

When an imbalance between stimulus and recovery occurs, the athlete becomes at risk to enter a state of overtraining. Overtraining is the accumulation of training and non-training stress resulting in the long-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of overtraining in which restoration of performance capacity may take several weeks or several months (Kreider, Fry, & O'Toole, 1998). A fundamental difference between overreach and overtraining is the management of training volume and intensity. While an overreach can be advantageous to an athlete if adequately planned for (functional overreach), a state of overtraining almost always results in a decrease in performance for an extended period.

Once an athlete experiences OTS, it is too late to adjust in a timely fashion, and the athlete must decrease training until he/she can adequately respond to a stimulus again. Therefore, it is imperative that an individual's training program account for fatigue management at various times throughout the annual plan. It is important to note that both overreaching and overtraining are on the same continuum. When an athlete partakes in a single training session, there is an acute response. This acute response often results in "adaptive micro-trauma." As the athlete continues to increase training frequency (volume) and intensity they will also enhance their state of fatigue. Adaptive micro trauma leads to local acute inflammation and is followed by local chronic inflammation and if severe enough to a systemic immune/inflammatory response or otherwise known as overtraining syndrome (OTS) (Smith, 2000).

Currently, the most accepted concept regarding OTS is the cytokine hypothesis of overtraining developed by Dr. Lucille Smith. This conceptual overtraining model (2000) provided a unifying paradigm providing arguments that high volume/intensity training, with insufficient rest, will produce muscle and skeletal and joint trauma. Injury-related cytokines then activate various circulating monocytes, and, in turn, generate large quantities of proinflammatory IL-1β, and IL-6, and TNF-α producing systemic inflammation. It is suggested that the repetitive trauma to the musculoskeletal system, due to high volume/intensity training, associated with inadequate rest and recovery is the predominant cause of overtraining. Further, it is proposed that injury and the subsequent inflammatory response may be both the initiating and perpetuating cause of OTS (Smith, 2000).

In a more recent consensus statement released by the International Olympic Committee in 2004, the term “overtraining” has been combined with the “Female Athlete Triad” to define a single comprehensive term known as “Relative Energy Deficiency in Sport” (RED-S). The syndrome of RED-S refers to impaired physiological functions including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, and cardiovascular health caused by a relative energy deficiency for both males and females (Mountjoy et al., 2014). The underlying problem of RED-S is an inadequacy of energy available to support a broad range of physiological functions that are involved in optimal health and performance. Potential performance effects of RED-S include decreased muscle strength, training response, coordination, concentration, increased injury risk, irritability, and depression (Constantini, 2002).

A training program must adequately account for fatigue at specific time intervals throughout the year to prevent a nonfunctional overreach, overtraining, or RED-S. As mentioned earlier, if the summated fatigue that is developed throughout the training cycle is poorly managed, the athlete risks entering into a state similar in nature to the "exhaustion" stage of Selye's GAS and will likely underperform in competition (Cunanan et al. 2018; Fry et al., 1994; Fry, Webber, Weiss, Fry, & Li, 2000; Maso, 2004; Petibois, Cazorla, & Poortmans, 2003). Conventional monitoring tools have been used to help regulate an athlete's training program to ensure fatigue is under control.

Monitoring Fatigue

Monitoring throughout training and competition is an essential component of the training process. A sound monitoring system can aid in determining if an athlete is adapting to the training program and can help ensure fatigue is being adequately managed. As mentioned earlier, alterations in both volume and intensity are essential for a sound program to maximize adaptations over the course of a training cycle. These adjustments are made to alter the level of fatigue an athlete experiences and are dependent on the phase of training.

Fatigue is a complex and multifaceted phenomenon that has a variety of possible mechanisms (Halson, 2014). Currently, the most common definition of fatigue is the inability to maintain the required or expected force (or power) output (Edwards, 1983). Accumulative fatigue resulting from resistance training can be influenced by a variety of sources including the type of stimulus, type of contraction, duration of exercise, frequency, and intensity of exercise along with the kind of muscles involved (Sahlin, 1992). Fatigue can be partially managed throughout a training cycle by incorporating strategically placed reductions in training volume/intensity. However, it is important to remember that fatigue reflects an accumulation of all stresses affecting the athlete, not just what is experienced during training. Factors such as school, employment, social life, and so forth all combine into accumulative stress that will evidently affect the athlete's response to a training program and potentially competitive success (Stone et al., 2007). As such, there are specific monitoring metrics that can be used on a regular basis over the course of a training program to ensure the athlete is adapting to the training stimulus and not at risk for overtraining due to excessive levels of fatigue.

Volume Load Displacement (VL_d). Volume load (VL) is an estimate of resistance training work per exercise, set, week, month etc. The volume load can be used to summate the estimated work for all training modalities an individual partakes in and represents an estimation of the work completed. While training loads will differ from sport to sport, a volume load can be calculated as reps x load x displacement (VLd) to monitor resistance training loads. The addition of displacement enhances the validity of the work estimate (Haff et al. 2010, Hornsby et al. 2017). Additional dosage-dependent monitoring variables can include the type of exercise completed, intensity/percentage of 1RM used, speed of the movement, range of motion of the movement, rest period between sets, the order of exercise, and time of the day. Each variable above contributes to the individual's training and ultimately, their response to training (Stone et al., 2007). With training methods becoming more and more critical in modern-day athletics (Gabbett & Seibold, 2013; Smith et al., 2014), monitoring the individual's volume load can be the difference between a successful training program and an athlete entering a state of overtraining.

Testosterone:Cortisol (T:C). One common monitoring tool used to track the anabolic/catabolic state of an athlete across a training cycle is the testosterone/cortisol ratio (T:C) (Adlercreutz et al., 1986). This ratio allows the coach and sport scientist to have a better insight into the training stress a program is having on an athlete. In a study completed by Fry (2000), high correlations were noted when comparing competitive weightlifting performances and T:C levels. Furthermore, both performance and the T:C ratio was associated with alterations of volume and intensity in the short-term training program. Results indicated positive correlations between pre-exercise T:C levels and weightlifting performance during the normal-volume training phase. Also, the "taper" phase of training appeared to permit recovery, indicated by the T:C, and was associated with enhanced performance with a correlation of $r = 0.92$ in elite weightlifters (Fry, Kraemer, et al., 2000). It is important to note, the T:C ratio and its response to training may not directly indicate if an athlete is overreached or overtrained, but rather is a measurement of training "strain" and preparedness. Thus, a high T:C ratio often corresponds to a high level of performance (Fry, Kraemer, et al., 2000; Plisk & Stone, 2003, Painter et al. 2018).

Cytokines (IL-1β, TNF-α, IL-6). The use of cytokines as a monitoring tool in conjunction with the training period can be vital for identification of an athlete being at risk of entering a state of overreaching or overtraining. By incorporating the measurement of cytokines into the monitoring program, a better understanding of the stress response the athlete is experiencing could be helpful in discovering a negative performance response stemming from inadequate management of fatigue. When the typical inflammatory response occurs, cytokine levels remain relatively low, however, when local inflammation transitions into a systemic inflammatory response, cytokine concentrations may become elevated (Cornish & Johnson, 2014; Smith, 2000; Ziemann et al., 2013). One reason for such a transition is the response to repetitive bouts of high volume/intensity training and insufficient rest. Monitoring the cytokine response can help ensure that fatigue is managed through ensuring the expected responses occur at various time point throughout the training program.

Neutrophil:Lymphocyte Ratio (NLR). Recent research in the medical field has pointed to the Neutrophil/Lymphocyte Ratio (NLR) as an indication of a strong immune response associated with acute systemic stress (Afari & Bhat, 2016; Venkatraghavan et al., 2015). The underlying theory of using the NLR as a means of determining the magnitude of systemic inflammation and the severity of muscle damage incurred by a given bout of exercise is the notion that inflammation is a fundamental part of muscle repair. This response occurs in a specific temporal pattern of neutrophils migrating most rapidly and lymphocytes migrating towards the cessation of the recovery process (Tidball, 1995). Much of the research investigating the use of NLR in a sport setting deals with endurance events. For example, Nieman (1998) investigated the effects of carbohydrate ingestion on the physiological stress and inflammation profile for triathletes. The authors concluded that the NLR was influenced by carbohydrate supplementation but not by the mode of exercise (Nieman, 1998). Typically, NLR returns to normal within 6-9 hours following exercise, however, following particularly prolonged and stressful exercise, NLR has been shown to still be an elevated 24-hours post (Robson, Blannin, Walsh, Castell, & Gleeson, 1999; Walsh, Blannin, Robson, & Gleeson, 1998). Currently, to the authors' knowledge, there has only been a single study investigating NLR as a function of an individual's metabolic recovery status following a single exercise bout, which included resistance training, which has been conducted. The authors concluded that the NLR could be used to indicate the relative post-exercise recovery status of an individual (Bessa et al., 2016). However, to the authors' knowledge, there has not been any research investigating NLR alterations to resistance training outside of the acute response. The NLR has the potential to be an extremely useful monitoring tool, although more research is first needed.

Irrespective of the evidence supporting block periodization (Cunanan et al. 2018, DeWeese et al. 2015a; DeWeese et al. 2015b), there is still debate about its effectiveness (Kiely, 2010; Koprivica, 2012; Mattocks et al., 2016). Skeptics of periodization argue that the theories that underpin the methodology are not based on scientific facts, and their application in practice may not be possible if the goal is to achieve an excellent result at the right time in the most significant competition. Additionally, others argue that critical concepts that provide a basis for periodization, such as Selye's General Adaptation Syndrome, have been misapplied in their application towards sport training (Buckner et al., 2017). Much of this controversy surrounding block periodization likely stems from a misunderstanding of the difference between the concept of periodization and programming. Periodization deals with timelines, fitness phases and conceptual alterations in long-term training variables (e.g. high to low volume alterations, less specific progressing to more specific) whereas programming deals with methods to "drive" the concept (e.g. exercise selection, sets, repetitions etc.) (Cunanan et al. 2018). Thus, one likely reason as to why there is still debate surrounding the effectiveness of block periodization may be due to programming methods and divergent loading strategies found within the literature.

Relative Intensity Loading

A multitude of loading schemes can be used when prescribing a resistance-training program. Evidence indicates that when implementing a block periodized model, the use of relative intensity (RI_{SR}) loading paradigm is of primary importance (Carroll 2018; Cunanan et al. 2018; Moran-Navarro et al. 2017; Painter et al. 2012, Painter et al. 2018). In an RI loading scheme, the athlete is prescribed a percentage of their set x rep maximum dependent on the day's training goal.

As mentioned above, a vital component of the block periodization model is variation. The concept of variation involves manipulation of both the training intensity and speed of movement (DeWeese et al., 2015b). To accomplish the necessary variation within a training program, heavy and light days can be incorporated through manipulation of an athlete's relative intensity. It is thought that this variation enhances the management of fatigue throughout the resistance training program resulting in superior performance (Foster, 1998a; Stone et al., 2007).

For example, Foster (1998a) investigated the relationship of banal illnesses (a frequently cited marker of overtraining syndrome) to training patterns in 25 experienced athletes. Results from the study determined that training strain, calculated as training load x monotony, could explain 89% of illnesses by a preceding spike in training above the individual training threshold. Although heavy training loads are a necessary component to overload the system and cause adaptation, results from Foster (1998) suggest that strategies designed to minimize training strain, primarily the incorporation of light training days, allow a given training load to be accomplished with comparatively fewer adverse outcomes (Foster, 1998a).

Painter (2012) examined the effects of a block periodization (using heavy and light days) vs. daily undulating periodization (utilizing repetition maximum values necessitating a relative maximum intensity) in 31 track and field athletes spanning the course of a 10-week training cycle. While results from the study did not show statistical differences between the two groups, the data did indicate that the incorporation of heavy and light training days is more efficient, regarding volume, for producing strength gains compared to training at a relative maximum intensity exclusively. Additionally, when examining the effect sizes and percent change, the authors determined that the block periodization model was superior at increasing 1RM in the squat as well as both isometric peak force and rate of force development in the midthigh pull (Painter et al., 2012).

Repetition Maximum Loading

A shared loading scheme found in both the literature and in the field is the use of maximum repetition zones. In this loading strategy, individuals are provided a zone dependent on the day's training goal. For example, if an athlete is prescribed an 8-12 RM for the back squat, they must choose a load that can be lifted a minimum of eight times but no more than twelve. Subsequently, the load recommended for each workout is equivalent to the range of repetitions that is required (Hoffman, 2002).

Repetition maximum training zones are thought to provide an increased stimulus for the athlete apart from lifting a relative percentage of their 1RM. Instead of lifting based on a percentage of their 1RM for a set number of repetitions, the athlete has a range to continue working and will have a higher likelihood of reaching momentary failure. Whether the training program intends to reach concentric failure or not, RM training almost always results in momentary failure on one or all sets of the exercise. Because of this, athletes will have different RM loads for each repetition scheme throughout the training program. For example, dependent on the primary goal of the training session, an athlete may be prescribed a load range for 8-12, 4-6, or 1-3 repetitions. A load will be prescribed that allow the athlete to complete the lift a minimum number of repetitions dictated by the lower end of the range, but no more than the top end of the range. The resultant failure leads to the inability to contract past the "sticking point" of an exercise (Drinkwater et al., 2005; Van Den Tillaar & Ettema, 2010).

Morton et al. (2016) is one of the more recent investigations into the effectiveness of training to volitional failure. In their study, 49 male participants were assigned to either a high repetition or low repetition training program for a 12-week period. Results from the study failed to show differences at inducing skeletal muscle hypertrophy, maximal strength, or post exercise circulating hormone levels (Morton et al., 2016). Thus, the authors claimed that high- and low-repetition (low and high load, respectively) training paradigms elicit a comparable stimulus for the accretion of skeletal muscle mass when resistance exercise is performed until volitional failure.

Furthermore, previous research from the same group has indicated that maximal strength increases can be achieved with the use of either low or high loads as long as the exercise is completed to failure and periodic practice of lifting a heavier load is completed (Mitchell et al., 2012). For example, Mitchell et al. (2012) reported no differences between high load and low load training completed to failure in an unpracticed 5 second isometric maximum voluntary contraction using a dynamometer. Additionally, the authors claim that there is no apparent advantage of lifting with different loads on changes in muscle mass (Mitchell et al 2012). However, in the study design, subjects participated had their legs randomly assigned to the training conditions. Therefore, it is likely that there may have been a crossover effect causing interference.

Advocates of resistance training to failure cite its potential ability to maximize motor unit recruitment, increase metabolism, and produce muscle damage and repair process that accompanies the increased mechanical stress (Goldspink et al., 1992; Willardson, 2007). While empirical evidence of this phenomena is scarce, many papers advocating the use of training to failure base their conclusion on the size principle. Davies (2016) states the size-principle's relationship to training to failure;

> *"[D]uring a typical moderate to heavy set of resistance exercise, lower-threshold motor units composed of type I slow-twitch or type IIa fast-twitch muscle fibers are recruited first (Sale, 1987). As consecutive repetitions are performed, the lower-threshold motor units are fatigued, which results in recruitment of high-threshold motor units composed predominantly of type IIx fast-twitch muscle fibers. Once all of the available motor units have fatigued to a point where the load cannot be moved beyond a critical joint angle failure has occurred (Van Den Tillaar & Ettema, 2010). Therefore, training to failure might enable a lifter to maximize motor unit recruitment, which may be an important stimulus for muscular strength development (Fisher, Steele, & Smith, 2011)."*

Thus, it is thought that training to failure might enable a lifter to maximize motor unit recruitment, which may be a significant stimulus for muscular strength development (Davies et al., 2016; Schott, McCully, & Rutherford, 1995). However, the above definition regarding the size principle is misconstrued, as the size principle has very little to do with fatigue. An accurate explanation of the size principle involves the recruitment of higher threshold motor units as the intensity of muscle contraction is increased (Henneman, 1981). A critical difference between Davis' explanation of the size principle is the method by which the higher threshold motor units are recruited. One is the result of fatigue caused by a movement, while the original concept of the size principle deals with the intensity of a movement.

Therefore, it appears the rationale of training to failure is based on a hypothesis that may be flawed and is instead detailing with the effects of fatigue. Studies investigating training to failure to non-failure can be separated into two subsets; heavy vs. light loading schemes or loading schemes that employ a similar intensity.

Failure vs. Non-failure: Heavy vs. Light. Looney (2015) examined EMG amplitudes in strength-trained individuals during a failure and non-failure condition in the squat movement. Results indicated that higher EMG amplitudes were achieved whenever repetitions were performed to failure compared to the submaximal repetitions completed at the same intensity. However, the motor unit activation was highest in the heavy loading condition when compared to lighter loading protocols. The authors suggested high-intensity resistance training to failure is necessary for maximal muscle activation and may be related to greater increases in muscular strength (Looney et al., 2015).

Contrary, Sundstrup (2012) using normalized EMG, found that motor unit recruitment of muscles involved in the raise reached maximum three to five repetitions before muscular fatigue. However, subjects participating in the study were untrained women completing a 15RM and a 3RM lateral raise with graded resistance bands. Furthermore Sundstrup (2012) compared the 15RM condiditon to a heavier 3RM banded condidtion and found that 15 RM caused greater muscle activation half way through the set compared to 3 RM. However, the mean power spetrum during the 15 RM ws considerably below that of the 3 RM suggesting that muscle conndution velocity was higher in the 3 RM, possibly reflecting recruitment of higher threshold motortor units (Rainoldi et al. 2008).

Failure vs. Non-failure: Similar Intensities. Rooney (1994) investigated the effects of incorporating a rest interval between each repetition of a 6RM load (non-failure) vs. completing the entire 6RM load continuously (failure) with an equal load. The use of a rest interval between each repetition allowed the subjects to complete all six repetitions without the need to go to momentary muscular failure while keeping the estimated volume of work completed identical. Results from the study revealed significantly larger mean increases in dynamic strength for the failure group when compared to the non-failure group. The authors suggested that high-intensity fatiguing protocols bring about larger activation of motor units than do high-intensity non-fatiguing protocols and that the degree of activation of motor units determines the magnitude of the strength training response (Rooney et al., 1994). However, results from the study warrant questioning as the non-training control group improved roughly half of what the not to failure group improved by (2.5kg vs. 5.1kg respectively) over the 6-weeks of training. Furthermore, the RM load was based on a traditional set x rep scheme. Thus, the "cluster" may have been underloaded.

In a study completed by Drinkwater (2005), training leading to repetition failure was directly compared to its non-failure alternative. Twenty-six trained junior basketball and soccer players completed either an 8 x 3 (not failure) or 4 x 6 (failure) bench press routine three days a week spanning six total weeks. The volume of work was equated on a repetition basis and rest intervals completed between each set. Results indicated the athletes performing to failure statistically improved both in strength and power more so than their non-failure counterparts. Conclusions were based on greater improvements in both the 6RM bench press (7.3 kg vs 3.6kg, $p < .005$) and bench throw (40.8 W vs 25W, $p < .05$). The authors attributed the added success of the RM group to the loading scheme's ability to maximize the recruitment of active motor units and therefore the magnitude of the adaptations made by the nervous system (Drinkwater et al., 2005). However, the study included apparent outliers in their regression analysis that most likely skewed the results, the testing measurement that was used included a 6RM test that favored the loading scheme used by the failure group putting them at an advantage, and there was no measure of work to quantify the amount each group completed. More recently, some evidence indicates that training to failure produces similar gains in hypertrophy and to an extent maximum strength independent of load (Fisher et al., 2017; Morton et al., 2016).

However, such studies suggesting that, when training to failure, hypertrophy and strength gains are similar, regardless of load, largely used untrained subjects. Use of untrained and minimally trained subjects likely reduces the probability of finding meaningful differences between groups (failure vs non-failure). Part of the reason for this reduction deals with the degree of "functional" hypertrophy realized in the early stages of training. For example, Damas et al. (2016) provides evidence that the majority of changes in CSA during early training is largely damage control and due to edema rather than accumulated protein. Furthermore, it may take months before substantial protein accumulates that would be detectable. As alterations in hypertrophy are likely related to strength gains, this finding would, at least in part, bring into question the results of these studies. Furthermore, considerable evidence indicates that when loads which are decreased below 80% of 1RM, as has been used in many studies to failure, a less effective stimulus for maximizing muscular strength adaptations likely results (Gonzalez-Badillo, Izquierdo, & Gorostiaga, 2006; Naclerio et al., 2013; Peterson, Rhea, & Alvar, 2004; Rhea, Alvar, Burkett, & Ball, 2003; Schoenfeld, Wilson, Lowery, & Krieger, 2016). Again, this difference in loading could alter the results of these studies.

Potentially, the downfall for RM zone training leading to failure is the struggle to include highly trained individuals. When resistance-trained individuals are included, results tend to trend against the use of RM zone loading leading to subsequent failure. For example, Izquierdo (2006) examined training to failure vs. not to failure in professional Basque ball players and determined to perform each set, not too muscular failure led to enhanced gains in muscle power output of the lower extremity, although not significant. Additionally, repetition to failure did not provide a better stimulus for improving muscle power and may lead to reduced power output during long-term strength training. The authors hypothesized that not training to failure may reduce the overall stress of resistance training; consequently, the cortisol response may be attenuated and the anabolic status of skeletal muscle enhanced (Izquierdo et al., 2006).

In a later investigation conducted by Izquierdo (2010), arguments against the use of training to failure were again found. Forty-three trained male rowers were divided into four separate conditions, all of which performed the same endurance training but differed in the resistance training protocol. The four resistance training protocols incorporated; four exercises leading to repetition failure, four exercises not leading to failure, two exercise not to failure, and a control group who did not participate in any resistance training. Results from the investigation revealed that those who abstained from training to failure experienced increased gains in maximal strength and maximal power output in both absolute and relative terms and improvements in anaerobic rowing performance. Furthermore average power output during a 20-minute all-out test when was higher for subjects not training to failure when compared to higher training volumes to failure (Izquierdo et al., 2010).

Because fatigue can mask the expression of fitness characteristics, excessive levels of fatigue will negatively impact performance during competition (Banister, Calvert, Savage, &

Bach, 1975). Without a thoughtfully planned strategy to mitigate fatigue at specific time points throughout a training program, an athlete increases their risk of entering a state of overtraining. The use of an RM loading scheme in the periodized training model makes it extremely difficult to adequately manage fatigue due to consistently training at the relative maximum intensity. As the athlete consistently trains to a relative maximum (failure) on one or all sets, true heavy and light days are obviated, and fatigue can increase exponentially. Therefore, using an RM loading scheme may be inappropriate when employing a resistance training program designed to enhance strength, power and explosiveness.

Physiological Basis of Fatigue and Adaptation

Selye's General Adaptation Syndrome (GAS) describes an organism's changing ability to adapt to stress throughout its lifetime (Cunanan et al. 2018). In the concept, a stressor is defined as any physical or emotional factor that produces a stress response. It is proposed that all stressors result in similar physiological responses, and only the magnitude of the response is altered depending on the intensity and volume of the stressor(s) stimulus (Selye, 1950). Selye's GAS theory can be used to understand how training may affect the athlete. During training, an athlete is exposed to various stimuli that can result in three separate phases including an alarm phase, a resistance phase, and potentially an exhaustion stage. During the alarm phase a stressor, an initial exercise stimulus during training, will diminish performance. It is only during the resistance phase that positive adaptations may occur that allow the athlete to return to baseline, and often a higher state. This higher state is known as supercompensation (Stone et al., 2007). Fundamental to the supercompensation occurrence is the resistance or recovery-adaptation phase.

Rowbottom (2000) proposed that the application of a stimulus activate mechanisms leading to enhanced protein synthesis while additionally creating fatigue. To a point, both the enhanced protein response and fatigue accumulate in proportion to the stimulus' strength and duration of the stimulus. However, the inclusion of post-exercise rest allows for the recovery-adaptation process to begin, concurrently providing time for and fatigue to diminish. This is commonly known as the stimulus-fatigue-recovery-adaptation (SFRA) model (Rowbottom, 2000). Generally, the stronger the initial stimulus placed on the athlete, the longer the recovery period must be, however, adequate recovery periods are also dependent on an individual's age, training status, etc. If the recovery phase is insufficient, due to a strong single stimulus or the accumulation of the stimulus and other outside stressors (i.e., school, social life, environmental factors, etc.) the athlete may enter the exhaustion stage of GAS. Once the athlete enters the exhaustion stage a state of a nonfunctional overreach or overtraining is reached, depending on the severity (Halson & Jeukendrup, 2004).

The symbiotic nature of fitness and fatigue as it relates to performance can be described by the fitness-fatigue model developed by (Banister et al., 1975). The theory suggests that the athlete is a system with a training impulse as the input and performance as the output. The functional relationship between training impulse and the system's response is divided into two antagonistic effects called fitness and fatigue (Pfeiffer, 2008). Training increases the fitness effect and ultimately results in a positive effect on performance. Additionally, fatigue is increased as a result of the training stimulus, though, fatigue will negatively affect performance. The two effects, fitness, and fatigue, can be used in tandem to determine an athlete's level of preparedness. Preparedness can be calculated through the summation of the positive (fitness) and negative (fatigue) effects that result from a training stimulus (Banister et al., 1975). Early in the training process, the stimulus is typically high and causes both an increase in fitness and an increase in fatigue. As the training load decreases, both fitness and fatigue also decrease.

However, the fatigue component tends to fall off at a faster rate, increasing preparedness and, subsequently, performance. Therefore, with proper planning, preparedness can be optimized with strategies (i.e., functional overreach with a taper) that maximize the fitness responses to the training stimuli while attempting to minimize and manage levels of fatigue (Bazyler et al., 2017; Stone et al., 2007).

Inflammatory Response to High-Intensity Resistance Training

Following a training session, acute micro-trauma to the tissue(s) occur. The trauma results in an inflammatory response to protect the tissue from further injury by reducing additional damage, prevent infection of the injured tissue, and promote healing (Smith, 2000). The cellular components of inflammation include red blood cells, platelets, and leukocytes which include granulocytes, monocytes, and lymphocytes. Basophils, eosinophils, and neutrophils are all subsets of granulocytes. Monocytes act as precursors of macrophages and are found in the blood (Huether & McCance, 2008).

Every cell contains a set of cell-surface receptors that specifically bind the molecules involved in the inflammatory process. When activated, the cell experiences an influx of additional cellular products which further increase the amount of inflammation. The signaling of the injured tissue acts to confine the extent of damage, kill microorganisms, and remove the cellular debris in preparation for tissue regeneration (Huether & McCance, 2008). Many of the initial events are directed toward local recruitment of specific white blood cells.

Neutrophils predominate the initial phase of acute inflammation but are no longer active following 24-hours (Smith, 1991). After the initial recruitment of neutrophils, monocytes found in the blood differentiate into macrophages once the monocyte reaches the muscle tissue.

Movement of fluid, plasma proteins, and leukocytes from the circulation into the injured tissue all make up the synchronized response (Smith, 2000). For the inflammatory response to be effective, multiple sets of different cells must collaborate. This collaboration is accomplished via the secretion of cytokines.

Cytokines are synthesized by a variety of cells ranging from immune cells, muscle cells, endothelial cells, to fat-storing cells. Stimulation of cytokines can be a result of a multitude of activities including free radicals, tissue injury, and infectious agents (Biffl, Moore, Moore, & Peterson, 1996; Cavaillon, 1994). Based on their primary role, cytokines are classified as being either pro- or anti-inflammatory, however, some cytokines can hold both pro- and anti-inflammatory properties that are dependent on their mode of activation. Cytokines affect other cells through specific cell-surface receptors and activation of intracellular signaling pathways. The newly-stimulated cell can then become activated and produce other cytokines to further enhance the response (Huether & McCance, 2008). While there are over a hundred known cytokines that have been identified, three primary cytokines appear to be involved with the response to exercise include tumor necrosis factor alpha (TNF-α), interleukin-1 (IL-1β), and interleukin-6 (IL-6) (Smith, 2000).

Macrophages secrete TNF-α which leads to a multitude of proinflammatory effects including stimulating aspects of the acute phase of the immune response. The acute phase causes vasodilation and loss of vascular permeability, which is propitious for lymphocyte, neutrophil, and monocyte infiltration into the tissues (Arango Duque & Descoteaux, 2014). TNF-α can also help recruit cells to the inflammation site by regulating chemokines and triggering the expression of neutrophil-attracting chemokines (Griffin et al., 2012).

IL-1β is one of three subsets that make up the IL-1 family and is an essential mediator of the inflammatory response. Like TNF-α, macrophages produced and release IL-1β during the early stages of the immune response to infections, lesions, and stress (Arango Duque & Descoteaux, 2014). During inflammation, IL-1β stimulates the production of acute phase proteins and the release of histamine, causing vasodilation and localized inflammation. Additionally, IL-1β increases the expression of cell adhesion molecules on leukocytes and endothelial cells (Carmi et al., 2009).

IL-6 is a unique cytokine that produces both pro- and anti-inflammatory responses during tissue repair. This cytokine affects processes ranging from immunity, tissue repair, and metabolism, promotes differentiation of B cells into plasma cells, and activates cytotoxic T cells (Arango Duque & Descoteaux, 2014). Because the IL-6 receptor is only present on a select number of cells, a soluble form of the IL-6 receptor, comprised of the extracellular portion of the receptor, can bind to IL-6 with a similar affinity as the membrane-bound IL-6 receptor (Rose-John, 2012). The IL-6 and soluble form of the IL-6 receptor can then bind to glycoprotein 130 (gp130), which is expressed on all cells, activating pro-inflammatory properties. This process is known as trans-signaling (Rose-John, 2012).

The process of trans-signaling can also lead to recruitment of monocytes to the inflammation site (Hurst et al., 2001). Moreover, the release of IL-6 can signal the liver to secrete inflammatory markers such as c-reactive protein (cRP), which is responsible for the recognition and clearance of damaged cells (Plaisance & Grandjean, 2006; Taskinen, Kovanen, Jarva, Meri, & Pentikainen, 2002). Outside of IL-6's pro-inflammatory functions, IL-6 also produces anti-inflammatory properties. This is accomplished when IL-6 signals are sent through its "classical pathway" and signal via the membrane-bound IL-6 receiver that is included on a limited number of cells (Arango Duque & Descoteaux, 2014; Rose-John, 2012). IL-6 canonical signaling has been shown to mediate apoptosis inhibition and the regeneration of intestinal epithelial cells and is likely active in a variety of epithelial cells (Rose-John, 2012; Scheller, Chalaris, Schmidt-Arras, & Rose-John, 2011).

The acute systematic response that is produced following tissue damage can be beneficial for the host when the cytokines are produced in appropriate amounts, but toxic when manufactured in a deregulated fashion (Arango Duque & Descoteaux, 2014). When acute local micro-trauma evolves into chronic inflammation, resulting from excessive high-volume/intensity training with insufficient rest/recovery, excessive production of circulating cytokines IL-1β, TNF-α, and IL-6 can occur as an attempt to reduce inflammation (Smith, 2004). This altered response is thought to become toxic because of elevated levels of cytokines creating widespread signals that can result in systemic inflammation.

Because increased systemic inflammation is strongly linked with poor fatigue management and overtraining syndrome (OTS), the uncontrolled release of cytokines is believed to be an underlying cause of overtraining syndrome (OTS) (Smith, 2000). As training is viewed on a continuum, disturbances, adaptations, and maladaptation of the immune response to resistance training can help quantify the levels of fatigue individuals experience throughout a training program (Meeusen et al., 2013). Thus, many of the above biomarkers can be used to provide insight into the degree of homeostatic disturbance induced by a training program. Once the synchronized response of the immune system is altered, it is likely that there is an imbalance between the training stimulus and recovery provided by the training process (Smith, 2000).

Hormonal Alterations to High-Intensity Training

Hormonal responses to high-intensity training can play a vital role in tissue regeneration and regulation of energy substrate metabolism (Kraemer, 2000). Hormones hold a multitude of biological actions specific to muscle physiology and tissue repair during recovery, potentially enhancing competitive readiness. While there are many hormonal effects and essential hormonal responses that stem from resistance training, the two most researched are testosterone and cortisol, because of their influence on anabolic and catabolic aspects of metabolism.

Testosterone is an androgen, most of which, in males, is produced and secreted in the testes and functions to inhibit the catabolic effects of cortisol, enhance the anabolic effect, and promote glycogen synthesis (Lamb, 1975). Following gonadotropin-releasing hormone (GnRH) synthesis within the hypothalamus, luteinizing hormone (LH) and follicle-stimulating hormone (FSH) enter the blood circulation stimulating testosterone secretion. While FSH may not directly stimulate testosterone production, it is thought to promote the release of sex hormone binding globulin (SHBG) in the liver, which aids in testosterone transport (Vingren et al., 2010). Sex hormone binding globulin circulates in the blood and can readily enter a cell due to its lipophilic nature, permitting it to diffuse across the cell membrane (Tiidus, Tupling, & Houston, 2012). The primary effects of testosterone are completed predominantly through a nuclear receptor that alters transcription of target genes and G-protein-coupled receptors located within the plasma membrane (Kovacs & Ojeda, 2012). The primary mechanism of action of testosterone is through gene depression (Florini, 1985).

Functions of testosterone include profound protein anabolic properties, inhibiting the catabolic effects of cortisol and thus enhancing anabolic effects, and promoting glycogen synthesis (Kramer, 1994; Mayer & Rosen, 1975). Furthermore, serum testosterone has been shown to be associated with enhanced muscle cross-sectional area, the magnitude and rate of force production, and power production (Fry, Kraemer, et al., 2000; Hakkinen & Pakarinen, 1993; Stone, Moir, Glaister, & Sanders, 2002). Research investigating the response of testosterone to resistance training show that long-term training can alter the concentrations, consequently affecting the previously mentioned variables and performance (Fry, Kraemer, et al., 2000; Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988; Smilios et al., 2003).

Cortisol is the predominate stress hormone that is involved in fuel substrate mobilization, gluconeogenesis, immune system suppression, and can affect catabolic alterations (Munck, Guyre, & Holbrook, 1984). The glucocorticoid is necessary to maintain critical processes at times of prolonged stress and aids to contain the reaction to inflammation (Kovacs & Ojeda, 2012). Because of either physical or emotional stress, the hypothalamus can be stimulated to secrete corticotropin-releasing factor (CRF) (Kovacs & Ojeda, 2012). The stimulation of CRF can then stimulate the anterior pituitary to release ACTH, which leads to the adrenal cortex releasing cortisol into circulation (Brooks, Fahey, & White, 1996). Completed through a negative feedback loop, stimulation of adrenal cortisol secretion, by the adenohypophyseal hormone adrenocorticotropin (ACTH), results in an increase in plasma cortisol, which in turn, inhibits hypothalamic-pituitary ACTH release (Jones & Gillham, 1988). Once in circulation, cortisol affects glucose and glycogen replenishment in recovery through its catabolic effects on peripheral tissues. Additionally, cortisol suppresses the immune system’s response to prevent an “overshoot phenomenon” and the potential damage in response to stress (Brooks et al., 1996; Munck et al., 1984).

During prolonged, hard bouts of exercise, ACTH is secreted in proportion to the level of stress that is placed on the individual. ACTH then stimulates cortisol release, which can lead to proteolysis in muscle (Brandenberger & Follenius, 1975). Following a time lag, cortisol concentrations increase at a rate proportional to the exercise intensity, while final levels of cortisol are mainly dependent on the duration of exercise (Brandenberger & Follenius, 1975). Following a high-intensity exhaustive workout, a primary physiological concern is returning to a typical blood glucose level. Cortisol, through the mobilization of muscle proteins and subsequent gluconeogenesis processes, aids in glucose and glycogen replenishment during recovery (Brooks et al., 1996). Prolonged high cortisol concentrations are associated with progressive loss of protein, atrophy, and weakness of muscles (Kovacs & Ojeda, 2012).

Cortisol and testosterone alterations from exercise and training, both acute and chronic, appear to result from changes in the loading of the work being accomplished, particualrly the volume (Fry & Kraemer, 1997). Chronic adaptations resulting from long-term resistance training have led to increased resting testosterone concentrations as well as an increased testosterone response to exercise (Fry et al., 1994; Fry & Kraemer, 1997). However, prolonged high-volume resistance training can lead to severe increases in cortisol while also potentially decreasing resting testosterone concentrations (Linnamo, Pakarinen, Komi, Kraemer, & Hakkinen, 2005). Busso (2003) studied the hormonal response of elite weightlifters over the course of a year and showed that a reduction in training volume resulted in favorable increases in resting testosterone concentrations. Furthermore, chronic alterations for cortisol ensuing from long-term resistance training has shown a return to normal resting, or sometimes even below average, indicating an adaptive response to the stress. However, this adaptation requires the volume and intensity of the training to be managed and not overly stressful (Shepard, 1982; Stone & Fry, 1997). If training volume and intensity exceed adaptive capabilities, beneficial alterations may not occur due to excessive levels of fatigue. For example, severe training with extended periods of high volume and high intensities, without sufficient rest intervals, could lead to adrenal exhaustion and most likely some degree of a nonfunctional overreach or overtraining (Fry, Schilling, Weiss, & Chiu, 2006; Smith, 2000).

Combined, the testosterone:cortisol ratio (T:C) can denote an athlete's anabolic-catabolic status and be indicative of the program's training stress and the athlete's level of preparedness at a given time point (Kraemer & Rogol, 2005). For example, Fry et al. (2000) determined the relationship the of T:C on weightlifting performance in elite junior weightlifters to be highly correlated ($r = 0.92$). Free T:C concentration may also be a useful indicator of incomplete recovery from training and a potential hormonal biomarker in monitoring overtraining (Adlercreutz et al., 1986; Banfi, Marinelli, Roi, & Agape, 1993).

Given the physiological response to training and fatigue and the theoretical misapplication of RM loading in the periodization literature, the purpose this dissertation is to compare and contrast the physiological effects pertaining to fatigue and stress of RM vs. RI loading strategies within a block periodized training model. The attempt is to determine which loading strategy should be adopted in future periodization research and practice.

Summary

Resistance training with the goal of maximizing athletic success is dependent on maintaining a symbiotic relationship between obtaining the most potent stimulus to cause optimal adaptations while managing fatigue. While it is crucial to increase the training volume an athlete experiences, it is imperative that the training volume and intensity vary according to the sport, training objectives, athlete's needs and phase of the annual training plan (Bompa & Haff, 2009). As such, a great deal of thought must go into constructing a training program to ensure the stimulus overloads the system while keeping fatigue managed. Underlying theories such as the Selye's GAS theory, the SFRA model, and the fitness-fatigue model can help guide training decisions when attempting to induce a strong stimulus and manage fatigue simultaneously.

In the continuous effort to determine the best practice and achieve an optimum relationship between stimulus and recovery, various programming strategies have been developed. Two of the more common approaches include the use of RM zones, subsequently training to momentary failure, and the inclusion of heavy and light training days. The use of RM zones ensures the stimulus the athlete is receiving overloads the system, however, its method of accounting for fatigue by merely reducing the total volume over the course of training program remains in question. On the other hand, block periodization, using phase potentiation programming, creates concentrated blocks to overload a targeted fitness characteristic while incorporating heavy and light days throughout the training plan. In phase potentiation, fatigue management is more of a priority and, therefore, often results in a lower total volume in a training program and, in turn, could potentially decrease the stimulus.

To ensure the athlete is responding appropriately to the training program, various monitoring strategies can be utilized. Monitoring tools can range from physiological measurements that help show how the body is dealing with inflammation (cytokines, cRP, NLR), the anabolic/catabolic state the athlete is in (T:C), or through performance testing to monitor fatigue through variables such as RFD and jump height. The use of monitoring tools can help guide programming decisions during the training process as opposed to competition when it is often too late.

CHAPTER 3

NEUTROPHIL:LYMPHOCYTE RATIO AS A POTENTIAL BIOMARKER FOR FATIGUE AND RECOVERY STATE

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Keywords: NLR, resistance training, recovery, stress

Abstract

Purpose: The primary purpose of this investigation was to determine the response of the neutrophil:lymphocyte (NLR) to an extended resistance-training program and its effectiveness as a long-term monitoring tool that may help provide insight to fatigue management. **Methods**: Fifteen well-trained males (age 26.95 ± 3.96 years, weight 86.26 ± 12.07 kg, height 1.78 ± 6.54 m) participated in identical ten-week periodized resistance training program and only differed regarding the method of loading (repetition maximum (RM) or relative intensity (RI_{SR})). Testing occurred pre, post, and between each training phase (five in total) and included a complete blood cell count and static jump height testing. **Results**: There was a significant main effect of time for NLR, x^2 (4) = 11.35, $p \leq 0.03$ and static jump height (SJH), x^2 (4) = 11.83, $p \leq 0.02$. The change in the NLR was inversely correlated with the changes in the dynamic performance variable, unweighted static jump height, during all five training phases in the RI_{SR} group and following the strength endurance phase in the RM group. **Conclusions**: Following the response of the NLR and its relationship with SJH throughout a ten-week resistance training program, further examination detailing the time course and chronic changes of the biomarker is warranted.

Introduction

Athletic improvements often hinge on the effectiveness of a sound strength and conditioning program that stresses the fitness characteristics related to force adaptations, while controlling for the accumulative fatigue that the individual experiences (Banister et al., 1975). The symbiotic relationship between fitness and fatigue is the foundation of a resistance training program being successful in improving performance or putting the athlete at risk of overtraining. Given that the athlete is stressed throughout the program, it is often the state of fatigue the athlete experiences during a competition that determines if the developed fitness characteristics can be expressed (Banister et al., 1975). Furthermore, there is a multitude of loading strategies that can be used during the training program which will influence the degree of stress the individual experiences. Two of the more popular loading strategies include repetition maximum (RM) loading and relative intensity (RI_{SR}).

RM loading provides a training zone dependent on the day's goal. For example, if an athlete is in a strength-endurance phase and is prescribed an 8-12 RM for the back squat, they must choose a load that can be lifted a minimum of eight times but no more than twelve. In RI_{SR}, a percent of the maximum weight (RM) for sets and repetitions is used to prescribe training loads (Stone et al. 2007; Painter et al. 2012; DeWeese et al. 2015a). Each set x repetition combination has a specific 100% value that can be referenced to determine the days training intensity. Dependent on the loading scheme applied, the same training model may yield varying amounts of stress onto the individual. One way of determining the stress placed on the athlete is through biochemical and immunological markers.

Biomarkers indicative of muscle damage and inflammation are commonly used as measures of exertion because of their ability to present an indication of exercise stress independent of factors that may confound the results of strictly functional or subjective measures (Bessa et al., 2016). Although there is not a single marker that can be used to identify a state of overreaching or overtraining, key biomarkers can help provide insight into an athlete at risk (Gleeson, 2002). One of the less common investigated biomarkers is the neutrophil:lymphocyte ratio (NLR).

It has been proposed that the NLR can be used to monitor the exercise recovery status of an individual following a bout of exercise (Bessa et al., 2016; Gleeson, 2002). Because inflammation appears to be a fundamental part of muscle repair, the appearance of leukocyte subpopulations in the bloodstream may serve as a biomarker of an individual's recovery state (Tidball, 1995). Due to the sequential response of the immune system following exercise, dominance of neutrophils in the early stages and lymphocytes in the later stages, the NLR may serve as an additional biomarker to monitor the athlete's fatigue and recovery state. The mobilization of neutrophils and lymphocytes can be used to help indicate the degree of systemic inflammation following a resistance training bout and help indicate the stage of muscle repair the individual is in (Bessa et al., 2016; Tidball, 1995; Zahorec, 2001). However, to accurately determine the usefulness of NLR as a longer-term monitoring tool, the acute phase response of each leukocyte must be considered.

The NLR response to exercise is known to elevate following prolonged exercise and peak three hours following a single bout of high-intensity resistance and endurance training before returning to baseline twelve hours following the completion of training (Bessa et al., 2016). Additionally, the NLR may act to provide the magnitude of systemic inflammation and the severity of muscle damage incurred by a given bout of exercise (Venkatraghavan et al., 2015;

Zahorec, 2001). In an athletic setting, previous research showed NLR values returning to baseline within 48-hours following a single training bout (Bessa et al., 2016).

Although examination of NLR as a biomarker for inflammation has been conventional in the clinical/hospital setting, it is limited in a sport setting. To the authors' knowledge, studies investigating NLR's responses have used endurance exercise protocols (Nieman, 2010; Nieman et al., 2001; Pedersen & Toft, 2000; Robson, Blannin, Walsh, Castell, & Gleeson, 1999) or examined the acute response following a single training session (Bessa et al., 2016). Thus, the sustained resting response of NLR following a resistance training program and its training phases has yet to be investigated. Therefore, the purpose of the present investigation is to monitor the response of NLR to an extended resistance training program to determine the effectiveness of NLR as a long-term monitoring tool and provide insight to the levels of fatigue experienced during RI_{SR} and RM loading paradigms.

Methods

Experimental Approach to the Problem

The present study was a quasi-experimental design investigating the utilization of NLR during two rivaling loading methods RI_{SR} and RM under an identical periodized training model. Training consisted of a 3-week strength endurance phase, and 4-week basic strength phase, a 1-week overreach phase, and a 2-week speed-strength phase. Thursday to mimic a typical college athletic training program and increase ecological validity, subjects performed additional sport related training (warm-up and sprint training) similar to that of throwers in a preparation phase. Both programs were identical in exercise selection and only varied by the loading technique utilized. Resistance and sprint training phases, exercise selection, and testing schedules can be found in Table 1.1. All weight-training sessions were preceded by a warm-up including light calisthenics. Major exercises (i.e., squats, pulls, bench press, overhead press) were preceded by light and moderate warm-up sets (usually 3) before the target load was reached. Maximal effort sprints were preceded by a warm-up including calisthenics, karaokes and build up sprints at approximately 50% and 75% of maximum effort.

Subjects

Eighteen well-trained individuals volunteered to participate in the present study. Following baseline testing, one subject withdrew due to scheduling conflicts, and one additional subject from each training group withdrew due to the training regime reactivating previous injuries. Therefore, fifteen trained individuals (age 26.95 ± 3.96 years, weight 86.26 ± 12.07 kg, height 1.78 ± 6.54 m) were included in the analysis. Exclusion criteria included resistance training less than a year or the presence of any injury that would limit completion of the training program. The trained status of the participants was confirmed following an activity log questionnaire. Subjects were previously classified as well-trained based on their baseline testing results (Carroll et al. 2018). Baseline isometric mid-thigh pull peak force and allometrically scaled isometric peaks force were comparable or exceeded previously reported values for collegiate athletes (4403.6 ± 664.7 N and 226.0 ± 25.8 $N/kg^{0.67}$ respectively) (Kawamori, Rossi, Justice, & Haff, 2006; McGuigan & Winchester, 2008; Thomas, Comfort, Chiang, & Jones, 2015). During the screening, subjects were informed about the study, potential risks, and experimental procedures that were required throughout the studies entirety. The study was approved by the Institutional Review Board of East Tennessee State before its initiation.

Procedures

Following baseline testing, subjects undertook a ten-week training program composed of resistance training every Monday, Wednesday, and Friday. In conjunction with resistance training, subjects also participated in sprint training every Tuesday and Thursday to increase the ecological validity. By combining resistance and sprint training, we attempted to more closely mimic the nature and schedule of collegiate level athletes, who typically combine modes and methods of training and train most days during the week. Testing occurred before the first training session and 72-hours following the completion of each block of training (weeks four, seven, eight, and eleven).

All testing sessions included a blood draw performed by certified personnel from an antecubital vein into 4-mL Ethylenediaminetetraacetic acid (EDTA) vacutainer. Following blood collection, samples collected in EDTA vacutainers were analyzed for routine complete blood counts and provided leukocyte subset counts. Following blood collections, the participants completed performance testing which included unweighted static jumps. Jumps were performed on force plates (1000 Hz) and the jump height calculated from flight time (Markovic, Dizdar, Jukic, & Cardinale, 2004).

Statistical Analysis

A 2 (program) x 5 (time) Mixed Design ANOVA was performed to determine any statistical differences for NLR or performance variables among training blocks using the statistical software R (R version 3.4.0, Vienna, Austria). Upon a significant effect, simple contrasts with a Benjamini-Hochberg correction were conducted to determine where the changes occurred. Hedge's *g* effect size was also calculated to determine the magnitude of each effect for subsequent training phases to determine the degree of change folloiwng the previous training block. Determination of the magnitude of the effect was based on the strength of magnitude scale put forth by Hopkins (Hopkins, 2002).

Table 1.1. Training phases, exercise selection and testing schedule for all subjects

Training Block	Sets x Reps (Day 1%, Day 2%, Day 3%)		Monday/Friday (Weights)	Tuesday/Thursday (Sprints)	Wednesday (Weights)
Testing - A					
Strength-Endurance:	RI_{SR}	RM	Back Squat, Overhead Press, Bench Press, DB Tricep Ext.	2x3x20m w 2/4min	CG MTP, CG SLDL, BB Bent-Row, DB Ben Lateral Raise
Week 1:	3x10 (80%, 80%, 70%)	3x8-12 (100%, 100%, 100%)			
Week 2:	3x10 (85%, 85%, 75%)	3x8-12 (100%, 100%, 100%)			
Week 3:	3x10 (90%, 90%, 80%)	3x8-12 (100%, 100%, 100%)			
Testing - B					
Max-Strength*:	RI_{SR}	RM	Back Squat, Push Press, Incline Bench Press, Wtd. Dips		CG MTP, Clean Pull, SG SLDL, Pull-Ups
Week 4:	3x5 (85%, 85%, 70%)	3x4-6 (100%, 100%, 100%)		3x3x20m w 1/2.5min	
Week 5:	3x5 (87.5%, 87.5%, 72.5%)	3x4-6 (100%, 100%, 100%)			
Week 6:	3x5 (92.5%, 92.5%, 75%)	3x4-6 (100%, 100%, 100%)			
Week 7:	3x5 (80%, 80%, 65%)	3x4-6 (100%, 100%, 100%)		2x3x20m w 2/4min	
Testing - C					
Overreach:	RI_{SR}	RM	Back Squat, Push Press, DB Step Up, Bench Press	3x3x20m w 1/3min	CG CM Shrug, Clean Pull CG SLDL, SA DB Bent-Row
Week 8:	5x5 (85%, 85%, 75%)	5x4-6 (100%, 100%, 100%)			
Testing - D					
Speed-Strength	RI_{SR}	RM	Back Squat + Rocket Jump, Push Press, Bench Press + Med Ball Chest Pass		CG MTP, CG CM Shrug, Vertical Med Ball Toss
Week 9:	3x3 (87.5%, 87.5%, 67.5%)	3x2-4 (100%, 100%, 100%)		2x3x20m w 2/4min	
Week 10:	3x2 (85%, 85%, 65%)	3x1-3 (100%, 100%, 100%)		1x3x20m w 2min	
Testing - E					

*Symbolizes down set at 60% of working weight (RISR only), RI_{SR}= relative intensity based on sets and repetitions, RM= repetition maximum. DB= dumbbell, CG= clean grip, MTP= mid-thigh pull, BB= barbell, Ext= extension, Wtd= weighted, SG= snatch grip, SLDL= stiff-legged deadlift, SA= single arm, CM= counter-movement, Sprints = setsxrepsxdistance with intra-set rest/inter-set rest

Results

NLR and static jump height (SJH) ANOVAs failed to reach statistical significant interactions. There was a significant main effect of time for NLR, x^2 (4) = 11.35, p = 0.02 and SJH, x^2 (4) = 11.83, p = 0.01. Contrasts revealed significantly higher differences for NLR when comparing testing sessions, B to A (p = 0.005) and D to B (p = 0.001). Main effect contrast for SJH revealed significant differences when comparing timepoint B to E. Absolute neutrophil, lymphocyte and NLR values for each subject and trendlines of each marker can be found in Figure 1.1 Hedge's g effect size statistics can be found in Figure 1.2.

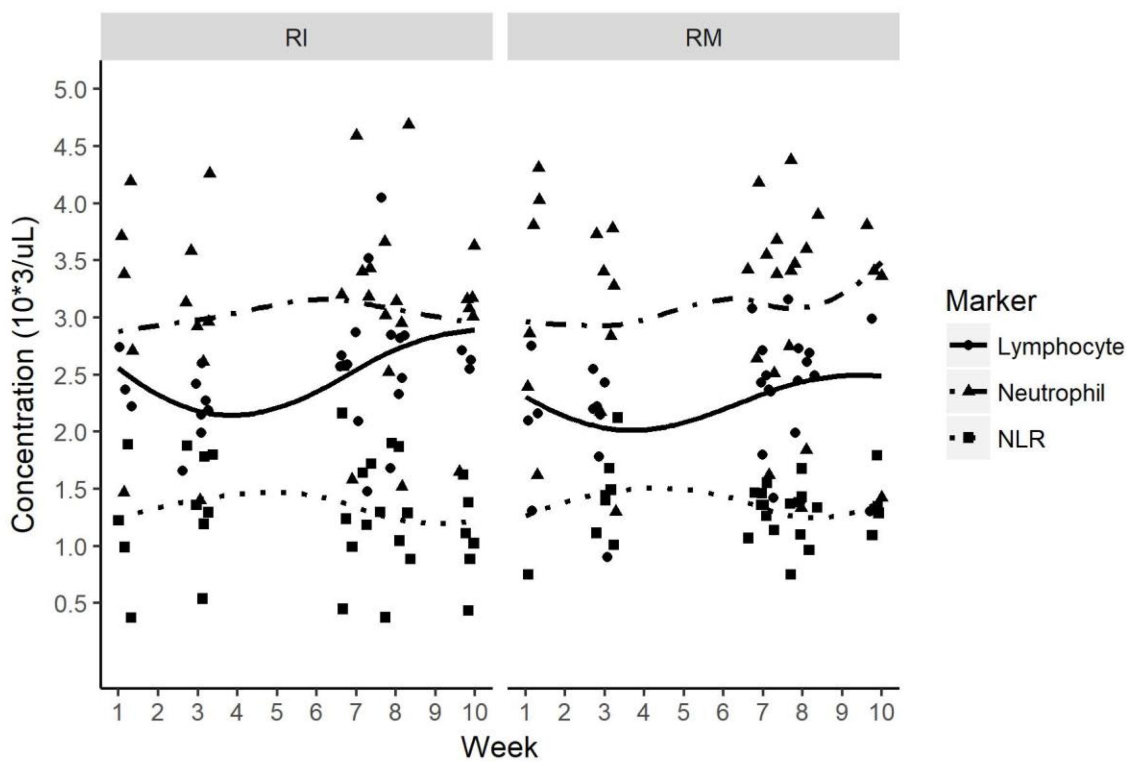

Figure 1.1. Neutrophil, Lymphocyte, and NLR Concentrations Across a Ten-Week Training Protocol.

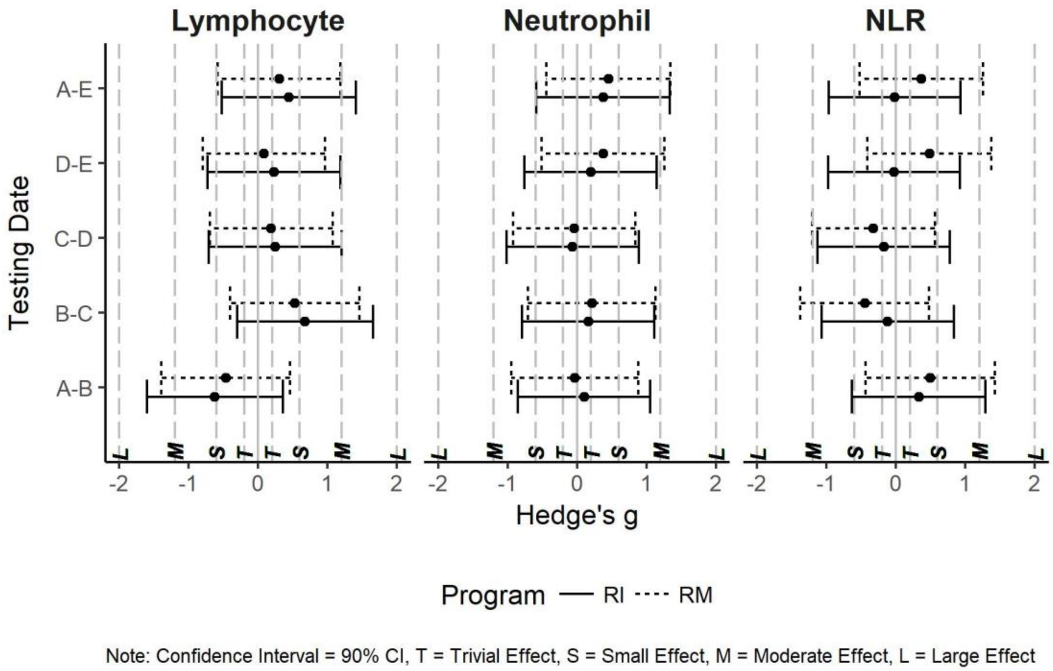

Figure 1.2. Lymphocyte, Neutrophil, and NLR Effect Size Comparison Between Each Training Block and Group

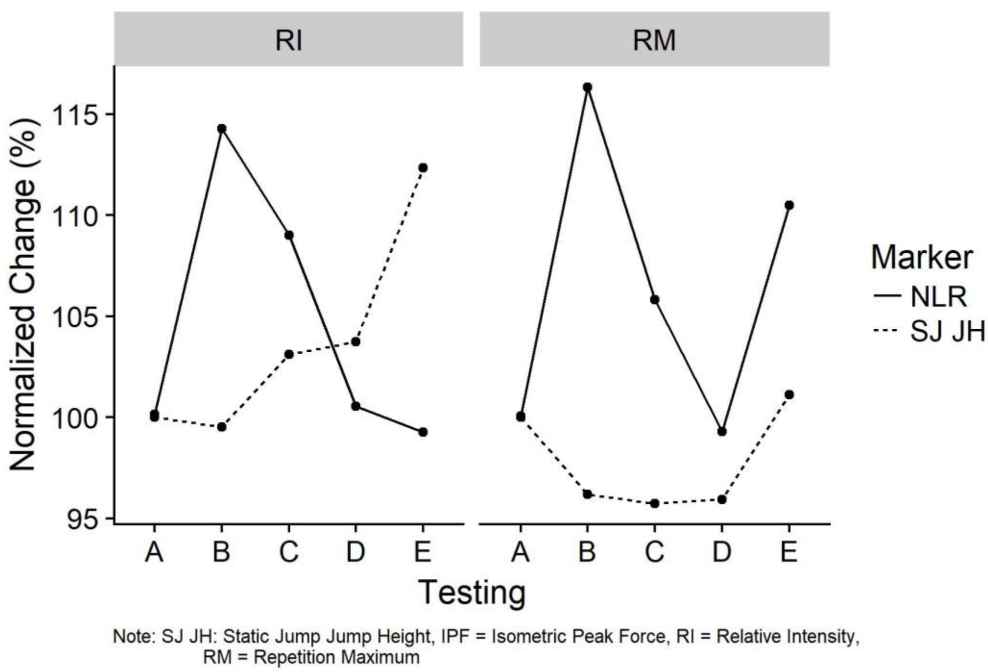

Figure 1.3. NLR and Static Jump Height

Discussion

The purpose of the present investigation was to determine the response of NLR during an extended resistance training program to determine the effectiveness of NLR as a long-term monitoring tool and help provide insight to the levels of fatigue an athlete experiences. When investigating the NLR response over the course of a ten-week training program, trends of NLR and each leukocyte help to give insight into the potential inflammatory/fatigue response during each training block. As expected, following the strength endurance block (weeks 1-3), the NLR showed a statistically significant increase in both groups. It appears that the lymphocyte count is mainly responsible for the change in the NLR throughout the first half of training where the neutrophil count appears responsible for the increase in the RM group following the taper (Figure 1.1 and 1.2). The elevated lymphocyte response help to show that the strength endurance phase was relatively intense (McCarthy & Dale, 1988). Furthermore, the neutrophil response through the early training phases is likely a result of the blood cells rapid response following tissue damage to clear the affected site of cellular debris. Neutrophil's typical disappearance 24-hours post-exercise can explain why levels were not increased following the 72-hour interval between the last training session and blood draw (Bessa et al., 2016; Fielding et al., 1993; Grounds, 1987; Tidball, 1995).

Based on effect statistics comparing the degree of change expressed between blocks, the most substantial change for each group appeared between the baseline and strength endurance high volume training phase. Interestingly, the magnitude of responses exhibited by NLR was higher for the RM loading group throughout the training programs.

One unexpected occurrence was the decrease the NLR exhibited following the planned overreach for both groups (Time Point D). Our expectation entering the study was that the NLR would follow a similar trend to the volume performed, as volume has been shown to be a central cause of resistance training fatigue (Baker et al., 1994). Because the samples were obtained 72-hours following the last training session, the sustained response of the NLR may have remained unaffected by a one-week training phase. Alternatively, the lack of response may be due to the subjects' being accustomed to the stressful training (Fry et al., 1994).

Although the NLR response followed a similar trend throughout the first four phases of training, the response diverged following the taper. The different response could be a result of a delayed response following the overreach block without adequate time to recover through the taper due to the maximal loading scheme in the RM group. A contributing factor may also be the influence of additional outside stressors placed on the students as the semester began prepping for finals (Bartholomew, Stults-Kolehmainen, Elrod, & Todd, 2008; Stone et al., 2007). The outside stressors may be affecting the RI_{SR} and RM groups differently due to varying levels of fatigue occurred from training. As a result, the additional outside stressors likely affected RM subjects to a noticeable extent because of their increased susceptibility stemming from their increased levels of fatigue from training. Without equal degrees of fatigue, the RI_{SR} group likely handled the additional stressors better.

During the present investigation, the change in the NLR was inversely correlated with the changes in our dynamic performance variable, unweighted static jump height, during all five training phases in the RI_{SR} group and following the strength endurance phase in the RM group. Interestingly, this trend is consistent with the NLR's relationship to the maximum upper body strength performance following a single training bout. In a previous study conducted by Bessa et al. (2016), NLR was inversely correlated with 1RM bench press performance during the acute phase response of a single training session. The exercise protocol consisted of a strength workout of six sets of maximum repetitions of deep squats performed with 85% of their 1RM alternating with six sets of maximum repetitions of bench presses performed with 85% of their 1RM. This strength workout was immediately followed by 1 hour of cycling at 85% of their VO2peak.

Inflammation is a crucial component of the recovery and repair process following resistance training. However, if the stimulus continues without adequate time for recovery, the athlete may progress from local acute inflammation to local chronic inflammation (Smith, 2000). Once this transition occurs, the athlete may be at an increased risk of experiencing a state of systemic inflammation causing suppression of performance for weeks, or even months (Stone et al., 2007). The relationship between inflammation and performance is highlighted by the RI_{SR} subjects' NLR response and SJH performance and the RM subjects' response during the first phase of training.

As expected, the RM group experienced a higher increase in NLR and decreased SJH following the strength endurance phase. Between-group Hedge's *g* following the initial training phase was $g = 0.42$ (90% CI = -0.2 to 1.1). Interestingly, following the initial training phase, the NLR response gradually returned to baseline values. However, SJH remained diminished. The occurrence may be a result of the subjects experiencing a repeated bout effect because of the monotonous training program through the basic strength and overreach phases limiting the inflammatory response (Ebbeling & Clarkson, 1989).

A possible explanation of why the relationship between NLR and SJH diverted during the taper for the RM training group may have been a residual response of the increased volume during the overreach block coupled with inadequate recovery during the taper (Banister, Carter, & Zarkadas, 1999; DeWeese et al., 2015a, 2015b; Morán-Navarro et al., 2017). The reduction in volume during the taper allowed the subjects in both groups to experience a rebound in performance as expected (Inigo Mujika & Padilla, 2003). However, because of the diminished performance experienced by the RM group throughout the first four training phases and continuing to train to failure on most exercises through the taper, subject's performing RM loading simply rebounded back to baseline. Conversely, subjects in the RI_{SR} group were able to recover and adapt to a higher degree through the taper, shown through the NLR response, and experience a supercompensation effect resulting in improved performance.

Conclusion

To the authors' knowledge, this is the first investigation examining the NLR beyond the acute phase response in resistance training. Previous research has pointed to the NLR as a means to indicate the relative post-exercise recovery status of an individual following a single bout of resistance training (Bessa et al., 2016). Following the response of the NLR and its relationship with SJH throughout a ten-week resistance training program, further examination detailing the time course and chronic changes of the biomarker is warranted. Furthermore, based on the NLR and SJH response of the two training programs, it appears that utilizing an RM loading scheme under the present training model is inferior when compared to RI_{SR} loading scheme. Alterations to the NLR indicate that RM's diminished ability to manage fatigue may be responsible for the inferior performance adaptations, expressed as SJH, experienced in the RM group.

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CHAPTER 4

AN INVESTIGATION INTO THE EFFICACY OF REPETITION MAXIMUM AND RELATIVE INTENSITY LOADING SCHEMES FOR MANAGING FATIGUE UNDER A PERIODIZED TRAINING MODEL

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Keywords: Fatigue management, stress, periodization

Abstract

Purpose: The purpose of this investigation is to compare repetition maximum (RM) and relative intensity (RI_{SR}) loading styles using an identical periodized training model to determine which scheme is superior at managing physiological fatigue and its effect on performance. **Methods**: Fifteen well-trained males (age 26.95 ± 3.96 years, weight 86.26 ± 12.07 kg, height 1.78 ± 6.54 m) participated in identical ten-week periodized training program and only differed regarding the method of loading. Testing occurred pre, post, and intermediate between each training phase (five in total) and included a complete blood cell count, and isometric mid-thigh pulls (IMTP). Measurements in the investigation included; IL-6, IL-1β, TNFα, cRP, testosterone, cortisol, testosterone:cortisol (T:C), neutrophil:lymphocyte (NLR), training strain, isometric peak force (IPF), and allometrically scaled isometric peak force (IPFa). **Results**: The 2 (program) x 5 (time) Mixed Design ANOVA revealed significant interactions for training strain, x^2 (9) = 41.6, $p \leq$ 0.0001, IL-1β, x^2 (4) = 16.80, p = 0.001, and T:C, x^2 (4) = 11.96, p = 0.01. There was a significant main effect of time for NLR, x^2 (4) = 11.35, p = 0.02, IL-6, x^2 (4) = 13.53, p = 0.008, IPF, x^2 (4) = 14.14, p = 0.006, and IPFa, x^2(4) = 14.86, p = 0.004. Adjusted contrast revealed significantly higher training strain for the RM group when comparing microcycles four (p = .018), five (p =.018), six (p =.04), seven (p =.018), eight (p = 0.0009), nine (p =.018), and ten (p = .018). Contrasts revealed significant higher concentrations of NLR when comparing testing sessions, B to A (p = 0.005) and D to B (p = 0.001). Lastly, Contrasts for IPFa revealed significantly higher strength values when comparing testing sessions, E to A (p = 0.007), E to B (p = 0.04), and E to D (p = 0.004). **Conclusions**: Results from the present study suggest that using an RM loading scheme under a periodized model may not allow for an adequate amount of recovery, especially during phases where recovery is of utmost importance. Lastly, the strongest

subject in the study, assigned to the RM group, entered a state of a nonfunctional overreach, based on his increase in NLR and cortisol concentrations, along with decreases in testosterone concentrations, T:C levels and maximal strength. This occurrence suggests that there may be a threshold where RM loading may become detrimental to the individual's well-being.

Introduction

Resistance training with the goal of maximizing athletic success is dependent on maintaining a symbiotic relationship between obtaining the highest stimulus to cause optimal adaptations. However, this can only occur if fatigue is adequately managed. For strength and conditioning programs to be successful, the programming (sets x reps) must align with the theory of the chosen training model. Programming can be further be broken down into the method of loading individuals elect to use. Common loading strategies used in the field and research include sets and repetitions based on repetition maximum (RM) zones or a percent of a maximum value, either 1RM or sets and repetitions maximums (Painter et al., 2012; Stone et al., 2007).

Within the training literature, one of the most widely used loading schemes is RM loading (Davies et al., 2016; Drinkwater et al., 2005; Martorelli et al., 2017). In this loading strategy, individuals are provided a training zone dependent on the day's goal. For example, if an athlete is in a hypertrophy phase and is prescribed an 8-12 RM for the back squat, they must choose a load that can be lifted a minimum of eight times but no more than twelve. As a result, RM training results in momentary failure on some or all sets of the exercise. Furthermore, RM loading and training to failure have been suggested to provide an increased stimulus to the athlete apart from lifting a relative percentage of their 1RM (Davies et al., 2016; Rooney et al., 1994).

A second loading scheme found in periodization models is the use of heavy and light days utilizing a relative intensity (RI_{SR}) loading scheme. In RI_{SR}, a percent of the maximum weight (RM) for sets and repetitions is used to prescribe training loads. Each set x repetition combination has a specific 100% value that can be referenced to determine the days training intensity. RI_{SR} is believed to allow for enhanced consistency in prescribing relative loads, regardless of the set and repetition combination and the daily level of fatigue the athlete may be experiencing (Painter et al., 2012; Stone et al., 2007). Proponents of RI_{SR} suggest that utilizing heavy-and-light training days result in enhanced fatigue management and, therefore, superior adaptations (DeWeese et al., 2015a, 2015b; Harris et al., 2000; Stone et al., 2000).

When investigating the effectiveness of each programs management of fatigue, various blood markers can be utilized to help give insight into the training stress response. Common biomarkers found in the literature that relate to physiological strain resultant of training include IL-6, IL1β, TNFα, neutrophil:lymphocyte (NLR), testosterone, and cortisol (Bessa et al., 2016; Myrick, 2015; Smith, 2000). Additionally, subjective measurements such as session RPE can help give insight into the state of the individual and allow for the calculation of training strain (Foster, 1998b). When combined, insight into physiological strain can be accomplished.

Both, RM and RI_{SR} loading strategies have been explored in various periodized models regarding performance and physiological adaptations separately. However, RM and RI_{SR} loading techniques under an identical periodized model have yet to be investigated to determine which method is superior in managing fatigue.

Therefore, the purpose of this investigation is to compare RM and RI_{SR} loading styles using an identical periodized training model to determine which scheme is superior at managing physiological fatigue and its effect on performance.

Methods

Subjects

Well-trained individuals were recruited through flyers and requests from various undergraduate and graduate classes at East Tennessee State University. After screening for training experience and previous injuries that would affect participation, 18 healthy young men volunteered to participate in the study. Exclusion criteria included resistance training less than one year or the presence of any injury that would limit completion of the training program. Subjects were classified as well-trained based on their baseline testing results. Baseline isometric mid-thigh pull peak force and allometrically scaled isometric peak force were comparable or exceeded previously reported values for collegiate athletes (4403.61 ± 664.69 N and 226.04 ± 25.81 $N/kg^{0.67}$ respectively) (Kawamori et al., 2006; McGuigan & Winchester, 2008; Thomas et al., 2015). Following baseline testing, one subject withdrew due to scheduling conflicts. Additionally, two subjects (one from each training group) dropped out of the study due to agitation of old injuries. Following dropouts, 15 individuals (age: 26.9 ± 3.9 years, weight: 86.2 ± 12.1 kg, height: 1.8 ± 6.5 m, resistance training experience: 7.8 ± 4.1 years) were included in the present investigation (Table 2.1). During the screening, subjects were informed about the study's potential risks, and experimental procedures. The study was approved by the university's Institutional Review Board before its initiation.

Table 2.1. Descriptive and starting strength statistics

Program	RI			RM		
	Mean		SE	Mean		SE
Age (years)	27.4	±	1.3	26.5	±	1.6
Height (m)	1.8	±	2.8	1.8	±	1.9
Weight (kg)	89.1	±	4.4	83.7	±	4.4
RT Exp (years)	10.1	±	1.7	5.6	±	1
PF (N)	4383	±	245	4500	±	219
IPFa ($N \cdot kg^{-0.67}$)	220	±	9.9	235	±	6.2

Note: RT Exp = Resistance Training Experience, PF = Peak Force, IPFa = Allometrically Scaled Peak Force, RI = Relative Intensity, RM = Repetition Maximum, se = Standard Error

Experimental Design

The current investigation was a quasi-experimental design examining the effect of two separate loading schemes within an identical ten-week periodized training model. Following baseline testing, subjects were ranked from strongest to weakest and matched pairs were randomly assigned into respective groups to ensure groups were equalized and a strength component would not skew the results. Maximum strength was determined from peak force measured through an isometric mid-thigh pull (IMTP) (Kawamori et al., 2006; Thomas et al., 2015). Following baseline testing, subjects undertook a ten-week training program including resistance training every Monday, Wednesday, and Friday. In conjunction with resistance training, subjects also participated in sprint training every Tuesday and Thursday to increase the ecological validity. Testing occurred before the study's first training session (A) and the Monday morning following the completion of each training phase (weeks four (B), seven (C), eight (D), and eleven (E)). This schedule allowed for testing to occur 72-hours following the previous week's last training session.

Training Programs

The training program consisted of resistance training every Monday, Wednesday, and Friday in combination with sprint training every Tuesday and Thursday. Saturday and Sunday were rest days. Identical training programs were prescribed regarding exercise selection and order (Table 2.2). The only difference between groups included the loading scheme that was utilized; relative intensity (RI_{SR}) or repetition maximum (RM). All weight-training sessions were preceded by a warm-up including light calisthenics. Major exercises (i.e., squats, pulls, bench press, overhead press) were preceded by light and moderate warm-up sets (usually 3) before the target load was reached. Maximal effort sprints were preceded by a warm-up including calisthenics, karaokes and build up sprints at approximately 50% and 75% of maximum effort.

Volume load displacement (VL_d) was calculated for each exercise as (repetitions x load x sets x displacement) to ensure the total work accomplished did not confound results (Hornsby, 2013). Following data collection, the VL_d was summed for each microcycle.

Subjects supplied a rating of perceived exertion (RPE) ranging from 1 to 10 following each training session to gauge the training strain of the respective loading schemes. Session RPE (sRPE) was calculated by multiplying each individuals RPE by the duration of the workout (Casamichana, Castellano, Calleja-Gonzalez, San Román, & Castagna, 2013). Once the sRPE was determined, the training monotony for each microcycle was calculated as (Foster, 1998b):

$$monotony\ (a.u.) = \frac{mean\ sRPE}{standard\ deviation}$$

Once monotony was determined, the amount of training strain resultant from each training microcycle was then calculated for each loading scheme as (Foster, 1998b):

$$strain\ (a.u.) = monotony\ x\ sRPE$$

Table 2.2. Training phases, exercise selection and testing schedule for all subjects

Training Block	Sets x Reps (Day 1%, Day 2%, Day 3%)		Monday/Friday (Weights)	Tuesday/Thursday (Sprints)	Wednesday (Weights)
			Testing - A		
Strength-Endurance:	RI_{SR}	RM	Back Squat, Overhead Press, Bench Press, DB Tricep Ext.	2x3x20m w 2/4min	CG MTP, CG SLDL, BB Bent-Row, DB Bent Lateral Raise
Week 1:	3x10 (80%, 80%, 70%)	3x8-12 (100%, 100%, 100%)			
Week 2:	3x10 (85%, 85%, 75%)	3x8-12 (100%, 100%, 100%)			
Week 3:	3x10 (90%, 90%, 80%)	3x8-12 (100%, 100%, 100%)			
			Testing - B		
Max-Strength*:	RI_{SR}	RM	Back Squat, Push Press, Incline Bench Press, Wtd. Dips	3x3x20m w 1/2.5min	CG MTP, Clean Pull, SG SLDL, Pull-Ups
Week 4:	3x5 (85%, 85%, 70%)	3x4-6 (100%, 100%, 100%)			
Week 5:	3x5 (87.5%, 87.5%, 72.5%)	3x4-6 (100%, 100%, 100%)			
Week 6:	3x5 (92.5%, 92.5%, 75%)	3x4-6 (100%, 100%, 100%)			
Week 7:	3x5 (80%, 80%, 65%)	3x4-6 (100%, 100%, 100%)		2x3x20m w 2/4min	
			Testing - C		
Overreach:	RI_{SR}	RM	Back Squat, Push Press, DB Step Up, Bench Press	3x3x20m w 1/3min	CG CM Shrug, Clean Pull, CG SLDL, SA DB Bent-Row
Week 8:	5x5 (85%, 85%, 75%)	5x4-6 (100%, 100%, 100%)			
			Testing - D		
Speed-Strength	RI_{SR}	RM	Back Squat + Rocket Jump, Push Press, Bench Press + Med Ball Chest Pass		CG MTP, CG CM Shrug, Vertical Med Ball Toss
Week 9:	3x3 (87.5%, 87.5%, 67.5%)	3x2-4 (100%, 100%, 100%)		2x3x20m w 2/4min	
Week 10:	3x2 (85%, 85%, 65%)	3x1-3 (100%, 100%, 100%)		1x3x20m w 2min	
			Testing - E		

*Symbolizes down set at 60% of working weight (RISR only), RI_{SR}= relative intensity based on sets and repetitions, RM= repetition maximum. DB= dumbbell, CG= clean grip, MTP= mid-thigh pull, BB= barbell, Ext= extension, Wtd= weighted, SG= snatch grip, SLDL= stiff-legged deadlift, SA= single arm, CM= counter-movement, Sprints = setsxrepsxdistance with intra-set rest/inter-set rest

Testing Measurements

All testing sessions included a blood draw and isometric mid-thigh pull (IMTP). Blood draws were performed 72-hours following the last training session of the previous training phase, fasted, and at the same time of day to prevent any alterations being dinural variation. All blood draws were performed by certified personnel from an antecubital vein into a 9-mL serum separator tube (SST) and 4-mL Ethylenediaminetetraacetic acid (EDTA) vacutainer. Following blood collection, samples collected in EDTA vacutainers were analyzed for routine complete blood counts and provided leukocyte subset counts. Samples collected in an SST vacutainer were allowed to clot for a minimum of 30-minutes before being centrifuged for 15-minutes. Serum was divided into 2-mL aliquots and stored at -80 ◦C. Following the completion of the study, all serum samples were analyzed together for each kit. Samples undertook no more than three freeze-thaw cycles to ensure the stability of the measurements. Serum cortisol and testosterone were analyzed using a solid-phase, two-site competitive chemiluminescent immunoassay using the IMMULITE® 2000 immunoassay system (Siemens, Malvern, PA). Total serum concentrations of interleukin-6 (IL-6), interleukin-1β, tumor necrosis factor alpha (TNFα) and high sensitivity c-reactive protein (hsCRP) were determined using high sensitivity quantikne solid-phase ELISA kits provided by R & D Systems (Minneapolis, MN). All ELISAs were completed using a DSX 4 Plate automated ELISA system, product version 6.26, and Revelation DXS Data Reduction Software, file version 6.0.183.427 (Dynex Technologies, Inc, Chantilly, VA, USA).

Performance assessment was completed via an isometric mid-thigh pull (IMTP) in a custom-built power rack (Beckham et al., 2018). Subject knee and hip angles were measured using a hand-held goniometer where subjects were required to obtain a 125 ± 5° knee angle and a

145 ± 5° hip angle. The custom power rack contained dual force plates with a 1000 Hz sampling rate (Rice Lake Weighing Systems, Rice Lake, WI). Subjects were secured to the bar using lifting straps and athletic tape to ensure grip strength did not affect results. Following a warm-up that included isometric pulls at 50% and 75% (Beckham et al., 2012), each subject performed multiple maximum effort trials until their peak force values were within 250N without the occurrence of a countermovement exceeding 200N. Three minutes of rest was provided between all maximal effort trials. The two closest IMTP trials were averaged together for statistical analysis on isometric peak force (IPF) and allometrically scaled isometric peak force (IPFa) (Schmidt-Nielsen, 1984).

Statistical Analysis

A Welch's *t*-test was used to assess any differences in baseline characteristics between the two resistance training groups. The primary objective of the study was to examine any differences resulting from response to the two loading schemes.

A 2 (program) x 5 (time) Mixed Design ANOVA was used to assess any differences in training strain, IL-6, IL-1β, TNFα, cRP, testosterone, cortisol, testosterone:cortisol (T:C), neutrophil:lymphocyte (NLR), IPF, and IPFa using statistical software R (R version 3.4.0, Vienna, Austria). Upon a significant interaction effect, Welch's *t*-tests were performed for each time point separately to determine any differences between groups with a Benjamini-Hochberg correction to limit the false discovery rate. Hedge's *g* effect size was calculated to determine the magnitude of each effect. Determination of the magnitude of each effect was determined using the scale developed by Hopkins (Hopkins, 2002). Lastly, the individual responses of each marker were examined to gauge an outlying responses among the groups.

Results

For the ELISAs, the coefficient of determination (R^2) of all standard curves was $\geq .92$. The percent coefficient of variation between duplicate samples was less than 8%. Results stemming from all blood samples are presented in Table 2.3. Furthermore, effect sizes comparing subsequent training phases and pre-post values are presented in Figure 2.1. Respective training strain scores, measured in arbitrary units (a.u.) can be found in Figure 2.2 (Foster, 1998b). As planned, there was no statistical significance when comparing volumeloads of the two training programs Figure 2.3. Within-subject, between-trial reliability assessed by ICC and within-subject CV for IMTP were IPF (ICC = 0.95, CV = 2.83%) and IPFa (ICC = 0.95, CV = 2.83%).

The 2 (program) x 5 (time) Mixed Design ANOVA revealed significant interactions for training strain, x^2 (9) = 41.6, $p \leq 0.0001$, IL-1β, x^2 (4) = 16.80, $p = 0.001$, and T:C, x^2 (4) = 11.96, $p = 0.01$. Contrast revealed significantly higher training strain for the RM group when comparing microcycles for weeks four ($p = .018$), five ($p =.018$), six ($p =.04$), seven ($p =.018$), eight ($p = 0.0009$), nine ($p =.018$), and ten ($p = .018$). IL-β and T:C failed to reveal significance contrasts. There was a significant main effect of time for NLR, x^2 (4) = 11.35, $p \leq 0.03$, IL-6, x^2 (4) = 13.53, $p \leq 0.009$, IPF, x^2 (4) = 14.14, $p \leq 0.007$, and IPFa, x^2(4) = 14.86, $p \leq 0.005$. Contrasts revealed significant higher concentrations of NLR when comparing testing sessions, B to A ($p = 0.005$) and D to B ($p = 0.001$). No contrasts for IL-6 revealed statistical significance. Contrasts revealed significantly higher values for IPF when comparing testing sessions, D to A ($p = 0.01$), D to B ($p = 0.02$), and E to D ($p = 0.008$). Lastly, contrasts for IPFa revealed significantly higher strength values when comparing testing sessions, E to A ($p = 0.007$), E to B ($p = 0.04$), and E to D ($p = 0.004$). All remaining variables failed to yield significance.

Effect size statistics were calculated for all variables to compare any subsequent changes within each respective group and can be found in Figure 2.1. Hedge's *g* effect size statistics compare successive changes among testing sessions along with pre-post changes (A-E). Effect size statistic is graphed for each group individually along with its 90% confidence interval. Successive changes compare the current testing session with the most previous. Notable pre-post individual changes among physiological blood markers were found for NLR (+36%, +52%), testosterone (-39%, -38%), cortisol (+83%), T:C (-66%). When examining pre-post maximal strength values only two subjects experienced a decrease in IPF and IPFa values (-2.16% and -5.58%). All notable physiological and performance variables mentioned stemmed from the RM training group.

Table 2.3. Performance and Biomarker Descriptive Statistics

	A: *Week 1*			**B**: *Week 3*			**C**: *Week 7*			**D:** *Week 8*			**E**: *Week 11*		
	Mean	±	SE	Mean	±	SE	Mean	±	SE	Mean	±	SE	Mean	±	SE
RI_{SR}															
Neutrophil (10*3/uL)	2.88	±	0.35	2.98	±	0.33	3.14	±	0.35	3.07	±	0.37	3.29	±	0.41
Lymphocyte (10*3/uL)	2.56	±	0.28	2.18	±	0.11	2.54	±	0.24	2.72	±	0.27	2.89	±	0.24
NLR	1.23	±	0.2	1.41	±	0.18	1.34	±	0.21	1.24	±	0.2	1.22	±	0.2
Cortisol (ug/dL)	15.21	±	1.95	13.45	±	1.64	13.63	±	2.07	15.47	±	1.37	14.54	±	1.05
Testosterone (ng/dL)	460.43	±	32.08	445.29	±	47.13	445.29	±	30.63	477.43	±	30.46	469.71	±	35.62
T:C	3.32	±	0.52	3.59	±	0.51	3.58	±	0.41	3.24	±	0.36	3.36	±	0.19
IL1β (pg/mL)	0.07	±	0	0.06	±	0.01	0.05	±	0	0.04	±	0	0.04	±	0
IL6 (pg/mL)	1.04	±	0.14	1.08	±	0.21	0.97	±	0.18	1.1	±	0.2	1.52	±	0.39
TNFα (pg/mL)	0.76	±	0.06	0.76	±	0.04	0.76	±	0.08	0.71	±	0.05	0.77	±	0.07
cRP (mg/L)	0.85	±	0.27	1.01	±	0.45	0.98	±	0.59	0.53	±	0.24	0.52	±	0.31
IPF (N)	4383	±	245	4589	±	209	4945	±	158	5022	±	281	5162	±	277
IPFa (N)	220	±	9.9	228	±	10.7	244	±	5.59	247	±	10.4	254	±	9.16
RM															
Neutrophil (10*3/uL)	3.16	±	0.43	3.05	±	0.38	3.19	±	0.32	3.26	±	0.37	3.43	±	0.39
Lymphocyte (10*3/uL)	2.33	±	0.23	2.01	±	0.25	2.41	±	0.19	2.44	±	0.22	2.41	±	0.21
NLR	1.33	±	0.14	1.54	±	0.14	1.31	±	0.06	1.32	±	0.09	1.41	±	0.1
Cortisol (ug/dL)	17.25	±	2.34	14.69	±	1.45	18.86	±	1.3	16.13	±	1.43	16.87	±	1.11
Testosterone (ng/dL)	521.43	±	56.6	505	±	52.93	500.86	±	17.13	529.43	±	44.88	484.86	±	25.05
T:C	3.39	±	0.69	3.72	±	0.44	2.69	±	0.19	3.27	±	0.26	2.93	±	0.19
IL1β (pg/mL)	0.05	±	0	0.04	±	0.01	0.05	±	0.01	0.04	±	0	0.05	±	0
IL6 (pg/mL)	0.89	±	0.08	0.7	±	0.06	0.97	±	0.11	1.11	±	0.11	1.18	±	0.21
TNFα (pg/mL)	0.72	±	0.03	0.66	±	0.05	0.66	±	0.03	0.65	±	0.03	0.68	±	0.05
cRP (mg/L)	0.3	±	0.12	0.75	±	0.4	0.26	±	0.09	0.23	±	0.06	0.51	±	0.25
IPF (N)	4500	±	219	4450	±	401	4752	±	325	4712	±	315	5158	±	306
IPFa (N)	235	±	6.19	224	±	15.2	242	±	11.4	240	±	10.6	263	±	11.8

Notes:
RI_{SR} = Relative Intensity
RM = Repetition Maximum
cRP = C-reactive Protein
NLR = Neutrophil : Lymphocyte
T:C = Testosterone : Cortisol

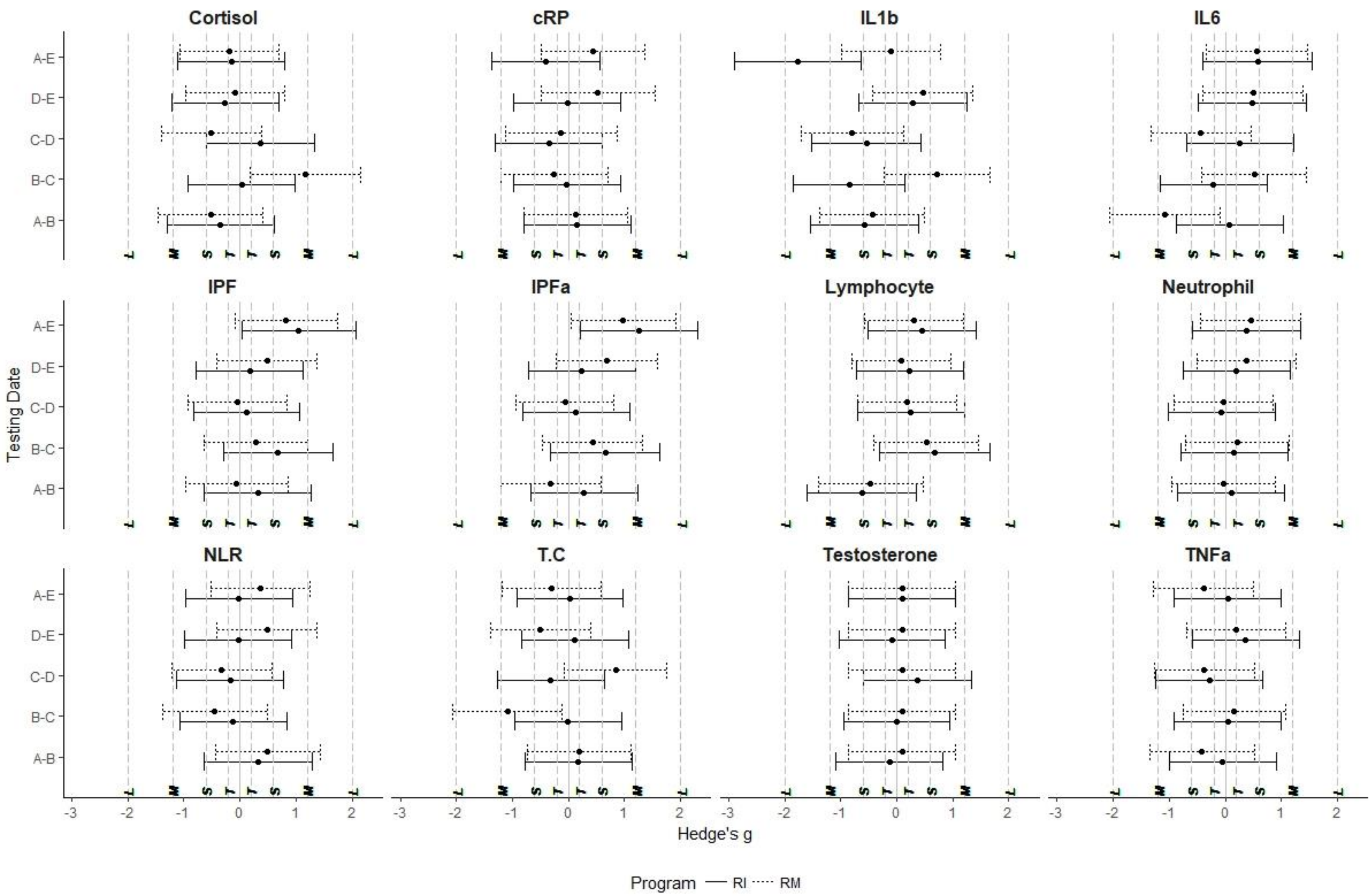

Figure 2.1. Physiological and Performance Effect Size Between Each Training Block

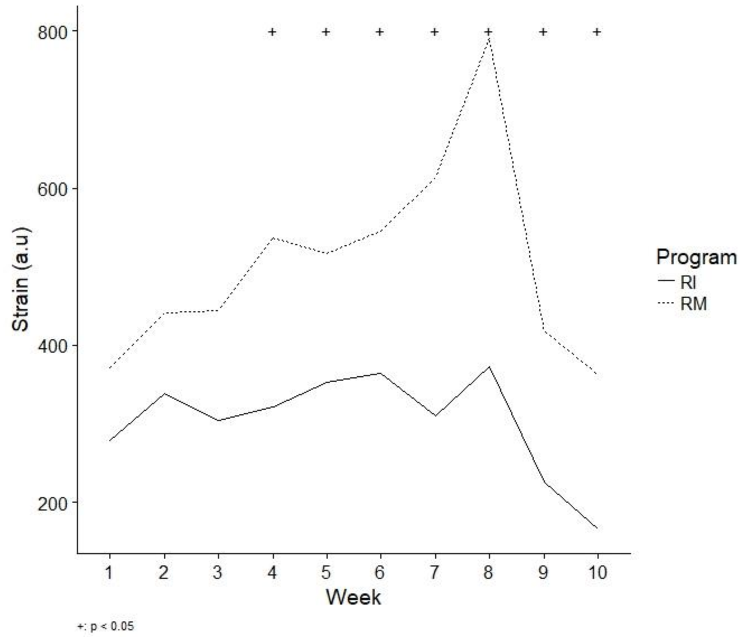

Figure 2.2. Repetition Maximum and Relative Intensity Program Strain Score

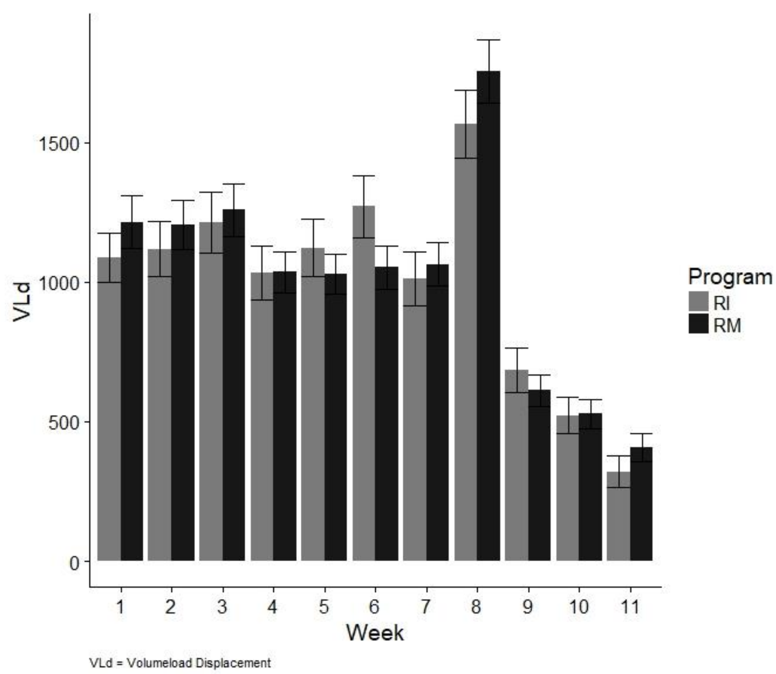

Figure 2.3. Volumeload Displacement Across the 10-Week Training Program

Discussion

The main findings stemming from this investigation include 1) under an identical model, the calculated training strain was 48% higher for the RM loading group, 2) endocrine response favored the RI_{SR} group, 3) RI_{SR} allows for enhanced fatigue management. Overall, current findings argue that the utilization of an RM loading scheme under a periodized training model should be avoided.

This study was an investigation into the efficacy of two different loading techniques using an identical periodized model. Low volume sprint/agility training was also performed to increase the ecological validity of the study (Table 2.2). Both training protocols were designed to simulate a typical training stage that a competitive field athlete might perform. VLd of the two programs were not statistically different indicating that the results were dependent on the training methodology and not the total work accomplished (Figure 2.3). This study aimed to investigate the cumulative response of the two programs as opposed to the short-term changes that occurred (Meckel et al., 2011; Pareja-Blanco et al., 2017; Storey, Birch, Fan, & Smith, 2016).

Training monotony and strain where significantly higher ($p \leq 0.4$) in the RM group for all training weeks outside of the initial high-volume training phase (Figure 2.2). Previous research suggests that increased levels of training monotony and strain lead to an increased risk for injury and illness (Foster, 1998b; McGuigan & Foster, 2004). Due to the loading schematics of each program, the RI_{SR} group experienced nearly half the training strain (47.8%) over the course of the identical ten-week training program. Of interest, while the pattern of monotony scores was similar, the RI_{SR} experienced an average score that was 51% lower. Although injury rates were equal among groups through ten weeks, it is likely participants in the RM group were at a significantly higher risk if the training program continued.

Of all the biomarkers analyzed, RI_{SR} yielded moderate effects for changes in lymphocytes and IL-1β. However, changes in IL-1β were statistically insignificant as the highest absolute value of change was 0.01 pg/mL. Furthermore, the limited response in the remaining cytokines remains suggest that the subjects did not enter a state of chronic systemic inflammation throughout the 10-week training program. As 72-hours is beyond the acute response of the measured cytokines, it is not likely that any subjects entered a state of overtraining (Louis, Raue, Yang, Jemiolo, Trappe, 2007; Smith, 2000)

Physiological biomarkers indicative of the inflammatory and endocrine response of training showed little difference or primarily favored the RI_{SR} group when compared to the RM training group. When combined, results indicate that a RI_{SR} loading scheme may be a preferred loading methodology when compared to RM loading under a periodized training model and is likely due to its ability to manage fatigue. The inability for RM loading to adequately manage fatigue is possibly a result of the increase training strain that accompanies an RM loading scheme.

For example, although both groups experienced increased levels of NLR following the strength endurance phase, the RM group showed a rise to a higher degree (Figure 2.1). The heightened increase of NLR may indicate the RM group experienced additional muscle damage/inflammation through the first phase of training. Therefore, the RI_{SR} group was likely less fatigued at the start of the basic strength phase (week 4) of the program (Bessa et al., 2016).

Interestingly, NLR increased for the RM group following the reduced volume taper (Table 2.2). The increase in the NLR appears to be due to the sustained increase in neutrophil count 72-hours following the final training session. Increases in cortisol concentrations following the taper in four out of the seven RM subjects help to explain why the NLR increased following the reduced volume training phase. Cortisol exerts its effects on neutrophil leukocytosis with a time lag of at least two hours following intense long-term exercise (Izquierdo et al., 2009; Pedersen et al., 1997; Pedersen & Toft, 2000). As the response remains visible past its acute response phase of 48-hours (Bessa et al., 2016) following the taper, the sustained stress of RM loading is likely the result of the inability of the final training phase to managing fatigue. Because the RM loading strategy does not entirely fit the methodology of a taper, it likely overstressed the athletes during a scheduled time for recovery to occur. The NLR response for RI_{SR} continued to remain at the baseline values throughout the taper.

The divergent changes between groups for the NLR can be likely attributed to the neutrophil changes amid the training programs. The decreased NLR through the taper indicates that the RI_{SR} group may have been further into their recovery during the final testing session when compared to the RM group (Bessa et al., 2016). However, because of the magnitude of change, differences between groups may just be due to typical day to day variation (Winkel, Statland, Saunders, Osborn, & Kupperman, 1981).

When examining the pre-post individual responses of NLR, most individuals realized no change or a slight decrease. However, two subjects exhibited notable increases in their NLR levels, both of which participated in the RM loading scheme. Increases in the NLR for the two subjects were 36% and 52% respectively. Perhaps the alterations in these two subjects could be accounted for by idiosyncratic responses or outside stressors.

Following the strength endurance phase, IL-6 was one of two biomarkers to show a medium magnitude of effect in the RM group while it remained mostly unchanged for the RI_{SR}

group. One possible connection between the varying responses of IL-6 can be explained by the more significant decrease in TNFα for the RM group (Table 2.3). As the inflammatory process is initiated, TNFα induces production of IL-6 (Smith, 2000). With a decreased production of TNFα, a decreased production of IL-6 is expected (Smith, 2000).

Through the study's entirety, both groups followed a similar trend for the biomarker testosterone (Table 2.3). Following the strength endurance phase, both groups experienced an expected decrease in resting testosterone levels. Among well-trained strength-power athletes, testosterone has been shown to decrease in concentration following a high-volume training phase and increased levels of training (Gotshalk et al., 1997; McCaulley et al., 2009; Painter et al., 2018; Vingren et al., 2010).

The most prominent alterations in testosterone occurred following the overreaching phase (OR) where the RI_{SR} and RM groups showed a 7.2% and 5.7% increase in resting testosterone concentrations, both of which surpassed resting baseline values. Unlike the response following the strength endurance phase, this increase is consistent with previous studies showing an increase following an upsurge in training volume (Gotshalk et al., 1997; McCaulley et al., 2009; Vingren et al., 2010). However, the difference, between the fall (testosterone) after the strength-endurance phase and the increase after the OR, in this study compared to previous studies (Gotshalk et al., 1997; McCaulley et al., 2009; Painter et al., 2018; Vingren et al., 2010), may be due to the length of the increased volume phase and perhaps intensity differences. Moreover, we have also noted that testosterone may increase following very short periods of increased volume (≤ 1 wk) such as an overreaching phase (unpublished data).

During the final testing session, resting testosterone concentrations displayed a moderate decrease in the RM group and trivial change in the RI_{SR} training group. As shown in Table 2.3, a pre-post comparison of the resting concentrations yielded a 7% decrease for the RM group and a 2% increase for RI_{SR}. Furthermore, when examining the pre-post individual responses of testosterone, two subjects stand out, both of which participated in the RM loading group. While most subjects experienced little change in their A-E testosterone levels, two subjects in the RM group exhibited substantial decreases of 39% and 38% from baseline to final concentrations. One of the subjects who experienced a notable 52% increase in NLR also experienced the noteworthy 38% decrease in testosterone highlighting the potential need to note individual alterations.

Much like testosterone, cortisol displayed a similar response following the strength endurance phase in both groups (Table 2.3). Again, cortisol's decrease following the strength endurance phase does not align with occurrences from previous studies (Ahtiainen, Pakarinen, Alen, Kraemer, & Häkkinen, 2005; Kraemer & Ratamess, 2005; Smilios et al., 2003). Cortisol's change through the basic strength and overreach block remained consistent with previous research for the RI_{SR} group but continued to be sporadic for the RM group (Ahtiainen et al., 2005; Kraemer & Ratamess, 2005; Smilios et al., 2003). As the taper concluded, cortisol began to decrease in concentration for the RI_{SR} training group while showing an increase in the RM group. Again, when considering individual responses of pre-post cortisol levels, one subject stood out as he experienced an 83.0% increase over the course of the study. The same subject also experienced the 52% increase in NLR and 38% decrease in testosterone also experienced the noteworthy increase in cortisol when comparing pre (A) and post (E) concentration values.

The group's expected decrease in cortisol concentrations following the taper in the RI_{SR} training group may be indicative of enhanced recovery and elimination of accumulative fatigue established through previous phases of training (Mujika, Chatard, Padilla, Guezennec, & Geyssant, 1996; Mujika & Padilla, 2003). However, the increased response of cortisol concentration in the RM group may be a result of increased levels of accumulated stress stemming from the program's increased training strain throughout the program (Figure 2.2). A secondary explanation may be the increased intensity of the taper and consistent training to failure may not have allowed for adequate recovery to take place for the RM group.

While testosterone and cortisol both play vital roles in the adaptation processes following resistance training, the T:C ratio is often used to evaluate the level of athlete preparedness (Adlercreutz et al., 1986; Vervoorn et al., 1992; Viru & Viru, 2005). The most important distinction between the two training programs is the change T:C exhibited following the taper and the mean percent change throughout the program's entirety (Figure 2.1). Following the taper, the RI_{SR} group showed an increased response and remains consistent with previous research (Haff et al., 2008). RM, however, exhibited a decrease in the T:C following the taper. When coupled with the increased training strain, the decrease in T:C suggests a diminished level of preparedness when competition matters most. This occurrence is consistent with increased recovery time associated with training to failure (Izquierdo et al., 2006). When comparing post-training values with baseline levels of T:C, RI_{SR} yielded an increase of 0.9% change while the RM group experienced a 16.3% decrease in their T:C. The decrease exhibited by the RM group is mainly due to a single subject's pre-post T:C change of -66.0%. Interestingly, the subject who experienced the 66% decrease in pre-post T:C also experienced the increase in NLR, cortisol, and decrease in testosterone.

Previous research has suggested the correlation between testosterone, cortisol, the T:C and maximum strength and explosiveness may offer insight into the relative degree of fatigue management (Maresh et al., 1994; Painter et al., 2018). While many of the RM subjects may not have entered a state of overtraining in the ten-weeks of the study, the trends of testosterone, cortisol, and T:C suggest that fatigue management was impaired and, therefore, put the athlete at risk if RM training continued.

Beyond the physiological response of each loading program, maximum strength variables also showed similar upward trend through the programs entirety (Figure 2.3). Although both groups completed the study at nearly the same IPF values, the RI_{SR} group began at a somewhat lower strength level as shown in Table 2.1. Although not statistically significant, the RM group improved their maximum strength to a lesser magnitude when compared to the RI_{SR} group. Furthermore, both IPFa and IPF exhibited a crossover among the two groups following the strength endurance training phase. Throughout the three testing sessions, the RM group's maximum strength remained below the RI_{SR} group.

When dissecting the individual pre-post response of each subject, only two subjects experienced a decrease in performance, both of which participated in RM loading. While the pre-post changes ranged from -2.16% to -5.58% for PF and IPFa, additional decreases were apparent following the overreach (-8.3%). Again, the subject who experienced changes in NLR (+52%), testosterone (-38%), cortisol (+83%), and T:C (-66%) was also one of the two subjects in the RM group to experience a decrease in pre (A)-post (E) maximal strength values for PF (-3.0%) and IPFa (-5.6%) and a decrease in PF (-8.3%) and IPFa (-8.3%) following the overreach phase. It is likely that the increased degree of inflammation along with the diminished level of preparedness stemming from the mismanagement of fatigue resulted in the diminished performance. This occurrence is essential to keep in mind when working with the density of modern-day sporting schedules.

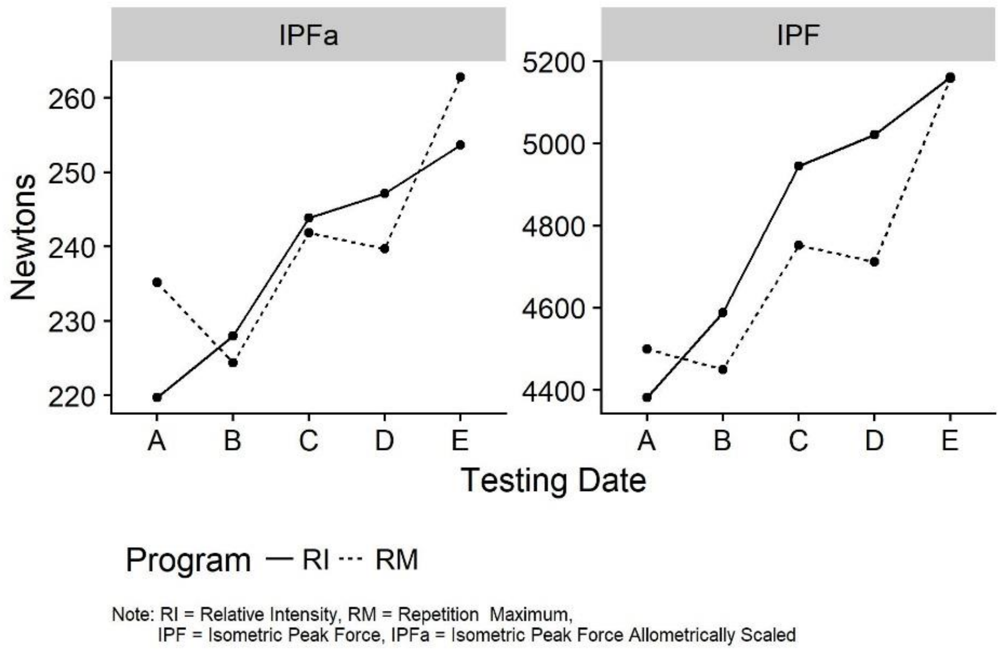

Figure 2.4. Maximal Strength Trends Across a 10-week Training Program

Lastly, it is likely that at least one subject from the RM group was at an elevated risk of entering a state overtraining. At a minimum, the subject entered a state of a nonfunctional overreach, based on his increase in NLR and cortisol, along with decreases in testosterone, T:C levels and maximal strength (Fry & Kraemer, 1997; Halson & Jeukendrup, 2004; Myrick, 2015). From baseline IPF and IPFa values, the subject who entered a state of a nonfunctional overreach was also the strongest participant in the study. Beyond the efficacy of utilizing an RM loading in a periodized model, this may suggest that there is a threshold as to where RM loading can be detrimental to the wellbeing of the athlete. When combining the physiological and maximal strength data, the individual trends of each biomarker, and additional performance results from (Carroll et al. 2018), evidence suggests that using an RM loading scheme within a periodized model may be not be warranted due to its potential for poor fatigue management.

Conclusion

Resistance training with the goal of maximizing athletic success is dependent on maintaining a symbiotic relationship between obtaining the most potent stimulus to cause optimal adaptations while managing fatigue. While, at times, it is essential to maximize the training volume an athlete experiences, it is imperative that the training volume and intensity vary according to the phase of the annual training plan (Bompa & Haff, 2009). Results from the present study suggest that using an RM loading scheme under a periodized model may not allow for an adequate amount of recovery, especially during phases where recovery is of utmost importance. Therefore, strength coaches and researchers should reconsider the use an RM loading scheme when selecting a periodized resistance training plan.

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CHAPTER 5

SUMMARY AND FUTURE INVESTIGATIONS

The purpose of this dissertation was to determine if NLR was a suitable biomarker beyond its acute phase response determine if repetition maximum or relative intensity loading scheme is superior in managing fatigue through the hormonal, inflammatory, and performances response.

The symbiotic nature of fitness and fatigue as it relates to performance is of utmost importance when developing and implementing a training program with the goal of maximizing performance. When training variables are appropriately manipulated the athlete can experience an increase in preparedness increasing the potential for enhanced performance when competition matters most (Banister et al., 1999; Mujika & Padilla, 2003). As such, the NLR has been suggested as a potential biomarker to help gauge the stage of recovery an individual is at (Bessa et al., 2016). Results from Chapter 3 indicate that alterations in NLR were inversely related with SJH changes, when performing a RI_{SR} loading scheme, as well as when performing a high-volume training phase under an RM loading scheme. Furthermore, the NLR showed a statistical increase following the high-volume training phase for both groups. Following the response of the NLR and its relationship with SJH throughout a ten-week resistance training program, further examination detailing the time course and chronic changes of the biomarker is warranted.

The goal of monitoring fatigue is to increase the ability of a training program to adequality manage it. Typical strategies for managing fatigue include a reduction of volume and variation. As mentioned throughout, once a training model has been established, the strength and conditioning professional has a multitude of loading strategies to choose from. Common loading strategies used in the field and research include sets and repetitions based on repetition maximum (RM) zones or a percent of a maximum value, either 1RM or sets and repetitions maximums (Painter et al., 2012; Stone et al., 2007).

Results from Chapter 4 indicate that under an identical periodized model, a RI_{SR} loading scheme is superior at managing fatigue and thus improving performance. Physiological biomarkers indicative of the inflammatory and endocrine response of training showed little difference or primarily favored the RI_{SR} group when compared to the RM training group. Furthermore, when dissecting the individual pre-post performance results, the three largest decreases in SJH (out of four) participated in the RM loading group. Additionally, only two subjects experienced decreases in their maximal strength (based on isometric mid-thigh pull), both of which participated in the RM loading group. Physiological and performance differences among groups were likely a result of the 48.7% increase in training strain the RM group experienced over the ten-week training program.

Lastly, it is highly likely that one subject from the RM group was at risk of entering a state overtraining. At a minimum, the subject entered a state of a nonfunctional overreach, based on an increase in cortisol concentrations, NLR, T:C levels and a decrease in testosterone concentrations and maximal strength performance. Interestingly, this subject was also the strongest in the entire study based on IPF and IPFa baseline values. Thus, there may be a threshold where RM loading becomes detrimental to the athlete's well-being.

Future research should continue investigating the effectiveness, responsiveness, and individual responses of NLR as a long-term monitoring tool for resistance training. Furthermore, results of this dissertation show that future periodization research should consider the exclusion of incorporating an RM loading scheme within the experimental model.

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