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The Effect of Training Status on Adaptations to 11 Weeks of Block Periodization Resistance Training

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The Effect of Training Status on Adaptations to 11 Weeks of Block Periodization Resistance Training

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by

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ABSTRACT

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The primary purpose of this dissertation was to investigate the effect of training status on adaptations to resistance training. A secondary purpose of this dissertation was to investigate the relationship between subjective and objective forms of monitoring resistance training (RT).

The benefits of RT are well understood but training status may be a major influence on training outcomes. Fifteen males of various training status were recruited for this study. Subjects completed 11 weeks of block periodization (BP) training. Subjects were tested for absolute strength (ABS) and relative strength (REL) in the barbell back squat, 0kg and 20kg static jumps (SJ) and 0kg and 20kg countermovement jumps (CMJ). Initial levels of ABS and REL were significantly correlated with rates of improvement for ABS, REL, and SJ and CMJ values. All subjects statistically improved ABS ($p<0.001$) and REL ($p<0.001$) with large-very large effect sizes between groups. All subjects showed statistically significant improvements for all jump types. Statistically significant between group differences were noted for both 20kg SJ ($p=0.01$) and 20kg CMJ ($p=0.043$). The results of this study indicate BP training is effective in improving strength and explosive ability. Additionally, training status may substantially alter the response to a RT program.

Monitoring can be divided into two broad categories of objective and subjective monitoring. RT volume load is an objective form of monitoring and can be calculated without displacement (VL) or with displacement (VLd). Session Ratings of Perceived Exertion (SRPE) are a form of subjective monitoring in which the subjects' ratings (0-10) are multiplied by the session duration. Statistically significant correlations were found between VL and VLd for all blocks of training. However, there were statistically significant differences when examining percent change between blocks. A statistically significant, positive relationship was found between SRPE and VLd ($p<0.001$) but no statistically significant effect of strength or the interaction between strength and VLd was found. The results of this study suggest that VLd may improve understanding of the training process over VL alone and a significant, positive relationship exists between subjective and objective methods of monitoring RT load.

DEDICATION

This dissertation is dedicated to my wife, Courtney. Your support throughout my graduate education has been unmeasurable. I love you.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1. Introduction

Statement of the Problem

The benefits of resistance training have previously been investigated. However, there is a need for further investigation into the effect of training status on adaptations to training. Although, previous investigation has been carried out on forms of monitoring training loads, very little literature exists comparing the use of subjective and objective monitoring tools in resistance training. The purpose of this dissertation was to investigate the effect of training status on adaptations to resistance training. A secondary purpose was to compare subjective and objective forms of monitoring resistance training.

Introduction

Periodization is a logical phasic method of manipulating training variables in order to increase the potential for achieving specific performance goals and is often thought of as a blueprint for the training program (Cunanan et al., 2018; DeWeese et al., 2015a, 2015b; Stone et al., 1996, 1999a, 1999b). In modern years, the use of periodization with athletes has been widely accepted based on the work of authors such as Bompa (Bompa & Haff, 2009), Issurin (2008), Matveyev (1966), and Stone et al. (1982, 1983). Some controversy exists as to the most efficacious method of training to achieve enhanced levels of sport performance characteristics, especially as it pertains to strength and power (Buckner et al., 2016; Kiely 2018; Mattox et al., 2016). However, the vast majority of scientific literature including the majority of reviews of the literature (Cunanan et al., 2018; DeWeese et al., 2015a, 2015b; Fleck et al., 1999; Rhea et al., 2003; Issurin, V, 2008; Issurin, V. 2014 Williams et al., 2017) including several meta-analyses (Peterson et al., 2004; Williams et al., 2017) have consistently concluded that a “periodized” training concept offers advantages over non-periodized processes.

While the benefits of resistance training are well understood, training level may be a major influence on training outcomes as 1) untrained subjects using the same stimulus tend to gain strength at a faster rate than trained (Ahtiainen et al., 2003; Rhea et al., 2003); 2) however, previous training producing increased maximum strength may potentiate further gains in power when power training is emphasized (James et al., 2018; Suchomel et al., 2016a, 2016b); 3) training combinations using heavy loading (strength emphasis) plus a lighter load (power emphasis) can potentiate both strength and power gains (Carroll et al., 2018; Toji et al., 1997) and 4) initial gains in hypertrophy may be largely non-contractile protein, especially among previously untrained subjects (Damas et al., 2018). The discrepancy between strength gain in untrained subjects and trained subjects is often attributed to neural factors including increased recruitment, myelination, motor unit synchronization, rate coding, inter and intra muscular coordination and decreased inhibition (Jeffreys et al., 2016; Moritani & Devries, 1979; Phillips et al., 2000; Staron et al., 1994; Stone et al., 2007). This hypothesis stemmed from early observations of increased strength levels in novice weight-trainers without significant increases in muscle hypertrophy (Kamen & Knight 2004; Moritani & Devies 1979; Sale, 1988).

Specifically examining the differences in strength gain among subjects with a different initial training status, Mangine et al. (2018) investigated the effect of baseline strength levels on adaptations to 8 weeks of resistance training. The investigators compared the responses of a stronger group and a weaker group, both of which had previous training experience. The results showed a significant effect of baseline strength on further adaptation to training with the weaker group improving 12.5% while the stronger group improved only 1.3%. Additionally, Ahtiainen et al. (2003) found similar results when comparing hypertrophy and strength development between trained and untrained men. The untrained subjects increased strength levels by 20.9% compared to 3.9% in the trained subjects.

As training status is enhanced, further gain in strength and associated characteristics can be realized, however, the rate of increase is limited. In their review, Suchomel et al. (2016b) summarize the relationships between various maximal strength and power qualities. Rate of force development, mechanical power, jump ability, sprint ability, change of direction ability and potentiation qualities all showed moderate to large correlations with maximum strength. Additionally, a number of studies indicated that stronger individuals are able to potentiate earlier (shorter rest intervals) and to a greater extent than weaker individuals (Ruben et al., 2010; Sietz et al., 2014; Suchomel et al., 2016a). Lastly, some authors have suggested a minimal strength threshold to be considered strong enough to achieve optimum gains in power and potentiation. This threshold likely varies somewhat depending upon individual characteristic and the type of exercise, but it has been suggested for the squat to be at least 1.7-2.0x your body mass (Berning et al., 2010; Ruben et al., 2010; Seitz et al., 2014; Suchomel et al., 2016a, 2016b).

Load monitoring is a common form of fatigue management. There are two broad classifications of load monitoring in use today: subjective (internal) and objective (external) means of monitoring. Subjective load monitoring is a form of monitoring which is reliant on one's personal analysis of training. Whereas, objective load monitoring does not rely on a personal analysis of training but rather employs reliable, valid means of tracking training.

Possibly the most commonly used form of subjective load monitoring is the use of session ratings of perceived exertion (SRPE). SRPEs involve an athlete giving a subjective rating of a training session difficulty based upon a pre-defined scale. There are multiple scales which are commonly used but all are based on correlations with other physiological measures of training load, such as heart rate (Borg et al., 1970; Chen et al., 2002; Foster et al., 2001; Robertson et al., 1997).

The most common form of objective load monitoring within resistance training is tracking of volume loads (VL). The simplest form of monitoring resistance training is simply tracking total repetitions; this method does not reasonably estimate the volume of work as no load is incorporated. However, it is common to account for the total repetitions as well as the load used for each (VL). Additionally, many advocate for the use of displacement in the calculation of VL, termed volume load displacement (VLd). The benefit of VLd is that it allows for a more accurate estimation of external work (Stone et al., 1984; Haff, 2010, Hornsby et al., 2018).

The purpose of this dissertation was to first examine the effect of training status on adaptations to resistance training. A secondary purpose of this dissertation was to examine the relationship between subjective and objective forms of monitoring resistance training.

Chapter 2. Comprehensive Review of the Literature

Periodization

Periodization is a method of dividing timelines into meaningful phases with an end goal in mind. When applied to sport, a logical phasic method of manipulating training variables in order to increase the potential for achieving specific performance goals and is often thought of as a blueprint for the training program (Cunanan et al., 2018, DeWeese et al., 2015a, Stone et al., 1996, 1999a, 1999b).

Periodization is not a new concept within sport and can be traced back to the ancient Greeks (Cunanan et al., 2018). Philostratus used a form of periodization to organize training phases for Greek Olympians. In modern years, the use of periodization with athletes has been widely accepted based on the work of authors such as Bompa (Bompa & Haff, 2009), Issurin (2008), Matveyev (1966), and Stone et al. (1982, 1983). Periodization and programming depend upon four primary training principles which underlie the associated adaptations to training: Overload, specificity, variation, and reversibility. The overload principle indicates that in order to promote adaptation, a stimulus must sufficiently disrupt homeostasis above levels that one is accustomed to and the overload must be consistently applied (Stone et al., 2007). Simply put, as one adapts to a training stimulus, the stimulus must be increased, or no further adaptation will be made. Specificity describes the degree to which a training stimulus reflects the demands of the desired adaptation (Stone et al., 2007). Specificity is commonly referred to as the Specific Adaptations to Imposed Demands (SAID) principle but has also been given other names. For example, Bondarchuk refers to this principle as “transfer of training effect” (Bondarchuk, 2007). Additionally, Verkhoshanksy and Siff refer to specificity as dynamic correspondence (Suarez et al., 2019; Verkhoshansky & Siff, 1999). Regardless of the name, they all refer to the same general principle.   There may be further classifications of specificity based on both mechanical specificity which refers to kinetic and kinematic similarity as well as bioenergetic specificity, which refers to energy system use (Stone et al., 2007). Variation is concerned with appropriate manipulation of training variables such as volume, intensity, exercise selection and frequency with the goal of ensuring continual adaptation. In the absence of appropriate variation, involution may occur in as little as 6 weeks which is characterized by diminishing returns from training (Stone et al., 2007; Thompson et al., 2019). Lastly, reversibility (commonly referred to as 'use it or lose it principle') states that in the absence of a training stimulus, previous adaptations may be lost (Stone et al., 2007; Thompson et al., 2019).

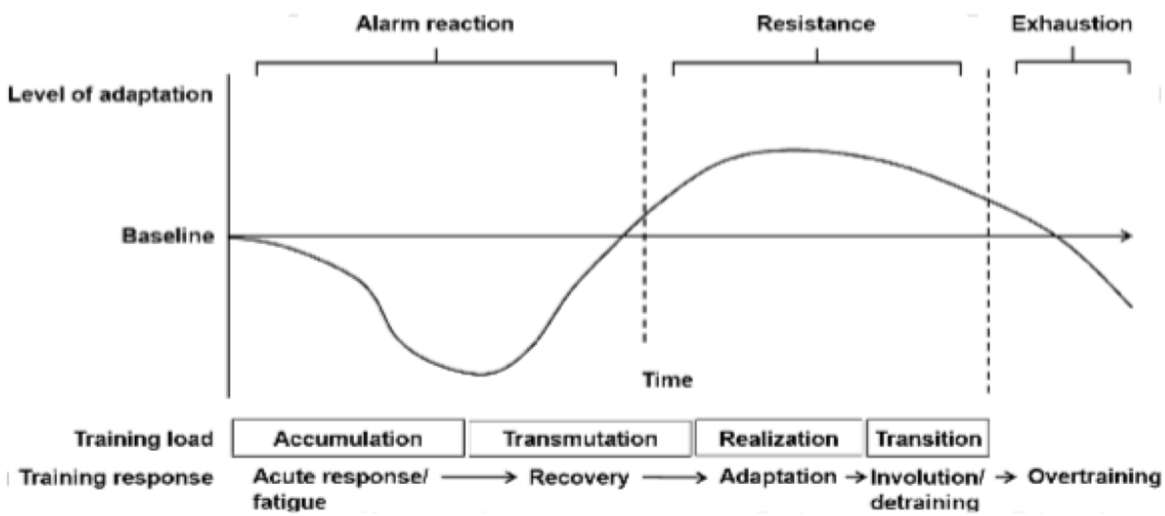
While the basic concept of periodization is generally understood, the physiological underpinnings are not commonly recognized. The mechanistic basis of periodization in sport can be traced back to the general adaptation syndrome (GAS). GAS was first described by Hans Selye in 1936 when he noticed a pattern of responses to stress (Selye, 1936). This pattern included three distinct phases: 1) alarm reaction 2) resistance and 3) exhaustion. The first phase, alarm-reaction, is characterized by an initial response to a stressor in which an organism's 'adaptation energy' is reduced (Selye, 1936, 1938, 1950, 1951, 1965, 1976). The second phase, resistance, describes a period during which an organism is able to adapt to the stressor or stimulus and adaptation energy supercompensates above initial baseline levels. Lastly, the exhaustion phase describes the decline in adaptation energy either as a result of long-term stress or age. When combined with previous findings by Bernard (Holmes, 1986) and Cannon (Cannon, 1929), this pattern can be described as representing the general response of an organism to any number of stressors, including resistance training.

Since his original findings, Selye has published a number of extensions regarding the application of GAS which can apply to resistance training (Selye, 1937, 1938, 1976). For example, Selye noted the specificity of adaptation to a stimulus in both type and magnitude (Selye, 1937, 1938) which serves as a basis of support for the principle of specificity. Additionally, Selye noted the cumulative effects of stress, adaptation, rest and loss of adaptation. Collectively, these findings support the need for planned variation and rest within a training program as well as the potential for overtraining.

Two logical extensions of GAS include Yakovlev's stimulus-fatigue-recovery-adaptation paradigm as well as Banister's fitness-fatigue paradigm (Yakovlev, 1967; Banister, 1975). Both Yakovlev and Banister cite an interplay between the fatigue induced by a stimulus (or stressor) and the resulting performance adaptation. Banister refers to fitness as the sum of all resulting adaptations from training and notes that these adaptations may not present themselves until fatigue from training has subsided. The performance potential as a result of both fitness and fatigue has been termed preparedness (Stone et al., 2007). When plotting preparedness, the curve closely mirrors that of the GAS curve and further lends support to the use of GAS as a conceptual model for periodization (Cunanan et al., 2018).

Figure 1

General Adaptation Syndrome. Adapted from Cunanan et al., 2018.



Some controversy exists as to the most efficacious method of training to achieve enhanced levels of sport performance characteristics, especially as it pertains to strength and power (Buckner et al., 2016; Kiely, 2018; Mattox et al., 2016). However, the vast majority of scientific literature including the majority of reviews of the literature (Cunanan et al., 2018; DeWeese et al., 2015a, 2015b; Fleck et al., 1999; Rhea et al., 2003; Issurin, V, 2008; Issurin, V. 2014; Williams et al., 2017) including several meta-analyses (Peterson et al., 2004; Rhea et al., 2003; Williams et al., 2017) have consistently concluded that a “periodized” training concept offers advantages over non-periodized processes.

Currently, there are two basic conceptual models of periodization. These two models are traditional (classic) periodization (TP) and Block Periodization (BP) (Cunanan et al., 2018; Suchomel et al., 2018). Traditional periodization allows for simultaneous alterations in a variety of fitness characteristics whereas single factor block periodization takes a more consecutive approach in which one or a few compatible characteristics are developed before emphasizing a different set of characteristics (DeWeese et al., 2015a, 2015b; Suchomel et al., 2018).

Programming which drives the consecutive approach of development has also been termed phase potentiation (Cunanan et al., 2019; DeWeese et al., 2015a, 2015b; Stone et al., 2007). Phase potentiation programming is a process by which alterations to a concentrated load in one block may further potentiate the adaptations in the subsequent blocks due to accumulated residual training effects (DeWeese et al., 2015a, 2015b). However, there appears to be some level of confusion concerning differences in periodization and programming (Cunanan et al., 2018). In recent years, there have been some challenges as to the efficacy of periodization (Abe et al., 2018; Buckner et al., 2018; Kieley et al., 2017; Mattocks et al., 2016, 2017). However, it is apparent that these challenges stem from strategies dealing with programming, not periodization (Cunanan et al., 2018). Periodization, as mentioned earlier, deals with segmenting the training program into meaningful fitness phases and timelines to ensure optimal development during key performance periods. Programming, meanwhile, deals with manipulation of training variables in order to develop the periodization "blueprint" and for block periodization to develop the concentrated load of the individual blocks. Such variables include intensity, sets and repetitions, density of training, frequency of training, exercise selection, and order of exercises (Cunanan et al., 2018; Stone et al., 2007). For example, Buckner et al. (2018) have criticized the use of GAS as a fundamental construct of periodization on the basis that resistance training is not a 'toxic' stressor as in Selye's earliest studies. However, this view of GAS fails to account for Selye's later works on GAS including its potential application to resistance training. Additionally, Mattocks et al. (2016) have concluded there is little evidence that periodized programs (particularly the accumulation phase) augment muscle size or strength compared to non-periodized programs and that gains in strength are related to the load lifted and the type of exercise. In essence these authors suggest that while the periodization programming can produce an increase in performance the periodization paradigm does not work and is unnecessary. However, this conclusion demonstrates misunderstandings by confusing periodization and programming, and misconceptions concerning underlying physiological mechanisms as well as disregarding the findings of the several reviews and meta-analyses supporting the benefit of periodized programs compared to non-periodized programs (Peterson et al., 2004; Rhea et al., 2003; Williams et al., 2017).

Training Status

While the benefits of resistance training are well understood, training level may be a major influence on training outcomes as 1) untrained subjects using the same stimulus tend to gain strength at a faster rate than trained (Ahtiainen et al., 2003; Rhea et al., 2003); 2) however, previous training producing increased maximum strength may potentiate further gains in power when power training is emphasized (James et al., 2018; Suchomel et al., 2016a, 2016b); 3) training combinations using a strength plus power emphasis can potentiate both strength and power gains (Toji et al., 1997; Carroll et al., 2018) and 4) initial gains in hypertrophy may be largely non-contractile protein, especially among previously untrained subjects (Damas et al., 2018).

One possible explanation for the difference in adaptations to resistance training between different levels of training status may be neural adaptations. It has been widely accepted that early gains in strength may be primarily due to neural mechanisms (Jeffreys et al., 2016; Mortiani et al., 1979; Phillips et al., 2000; Staron et al., 1994; Stone et al., 2007). These adaptations can include neural recruitment, myelination, motor unit synchronization, increased rate coding, increased intra and inter muscular coordination, and decreased neural inhibition. Recruitment describes the selective targeting of motor units for a designated task. With training, one can selectively recruit more pooled motor units and higher threshold motor units in order to increase force production (Stone et al., 2007) Myelin is a fatty insulation sheath which wraps around the axons of nerve cells to increase nerve conduction velocity (Jeffreys, 2016; Kandel, 2013). Motor unit synchronization occurs when multiple motor units are recruited and fire together. The synchronous firing of motor units causes a large net increase in instantaneous force output. Rate coding is defined as the rate of motor unit discharge. Increases in rate coding can also cause an increase in net force production as each discharge may become additive before previous force has fallen off. Intramuscular coordination describes the specificity of activation of motor units within a muscle while intermuscular coordination describes the interplay of the pattern of activation between muscles within a movement (Stone et al., 2007). Lastly, neural inhibition is a protective mechanism which reduces muscle tension in order to reduce injury potential at near maximal contraction. Resistance training has the potential to reduce joint and muscle receptor sensitivity which may allow for greater force production without protective inhibition. Taken together, these adaptations to training have the potential to substantially affect force production.

The neural hypothesis is partially based on observations of increased strength levels without significant increases in muscle hypertrophy or lean tissue development in novice lifters (Kamen & Knight 2004; Moritani & Devries 1979; Sale, 1988). Therefore, if the muscle has not fully adapted to training, then the increase in force must largely be due to neural factors. For example, based on muscle activation (EMG) Moritani & DeVries (1979) suggests that neural factors account for larger a proportion of strength gains for the first 3-5 weeks of training in untrained subjects with hypertrophy contributing to a greater extent in later periods. Moritani & DeVries (1979) also supported the notion of neural adaptation to resistance training by noting the increase in strength in untrained limbs with no coinciding increase in hypertrophy. Narici et al.

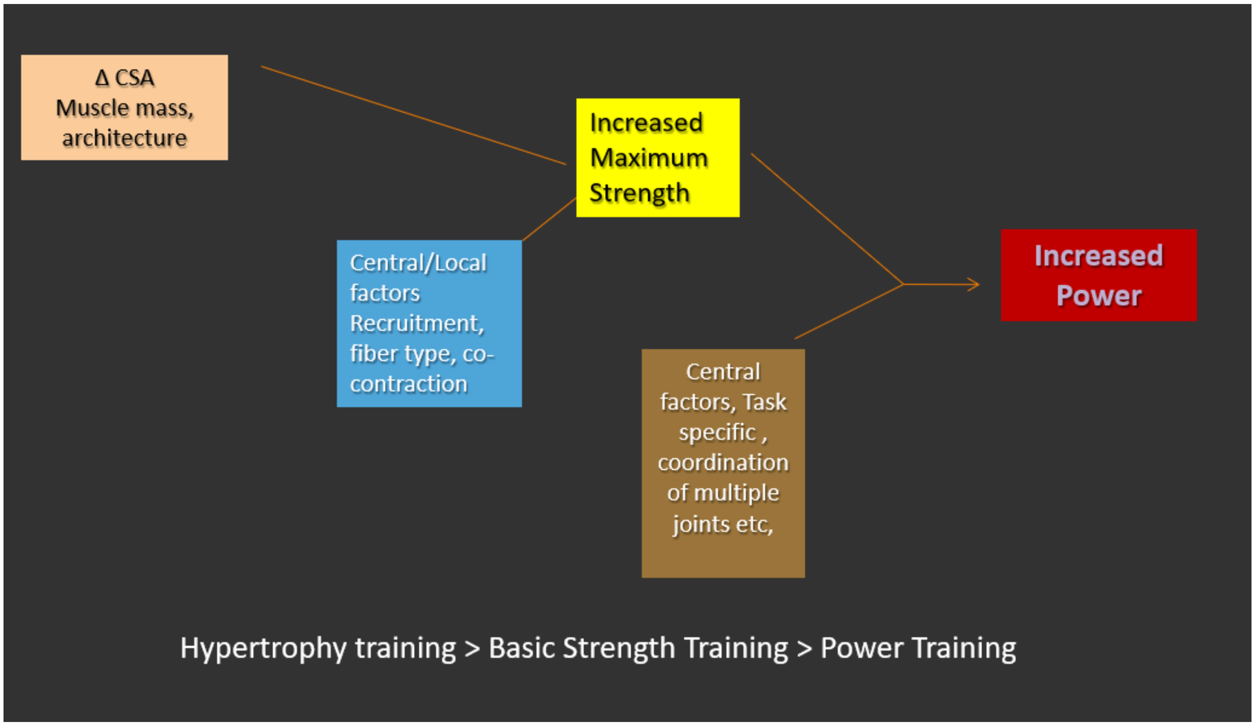
(1989) also support the notion of neural contributions to strength development. After examining changes in neural drive via electromyography and maximal voluntary contraction torque, the authors noted changes in strength gain with no changes in hypertrophy for untrained limbs. However, in the trained limbs, the authors suggest that hypertrophy accounts for ≈ 40% of the increase in strength while neural adaptations account for ≈ 60% of the strength changes. These earlier studies have been supported by two lines of research. Firstly, the findings are supported by those of Damas et al. (2018) who noted that meaningful hypertrophy above 3-4% may not take place for up to 18 resistance training sessions and early measured changes in cross-sectional area may be due to muscle damage and edema. If early gains in hypertrophy may not be contractile (myofibrillar), then the change in strength must be due to some other mechanism, likely neural adaptation. Secondly, the earlier research is also supported by investigation of the quadriceps size and maximum strength capabilities of long-term weight-trained (LTT) subjects. If alterations in muscle CSA are not primarily myofibrillar until several weeks into the training program, then long term training should reveal a stronger association between CSA and strength characteristics. Indeed, Maden-Wilkinson et al. (2019) using knee extension dynamometry demonstrated that the greater quadriceps maximum strength demonstrated by LTT subjects (n = 68) compared to untrained subjects (n = 52) was primarily due to greater muscle CSA with smaller differences in specific tension and moment arm, and thus muscle CSA was a primary explanation for the greater strength of LTT. The greater muscle volume (+56%) of LTT was due primarily to enhanced Physiological CSA (41%), indicating more sarcomeres in parallel.

Specifically examining the differences in maximum strength gain between training status, Mangine et al. (2018) investigated the effect of baseline strength levels on adaptations to 8 weeks of resistance training. The study compared the responses of a stronger group and a weaker group, both of which had previous training experience. The results showed a significant effect of baseline strength on further adaptation to training with the weaker group improving 12.5% while the stronger group improved only 1.3%. Additionally, Ahtiainen et al. (2003) found similar results when comparing hypertrophy and strength development between trained and untrained men. The untrained subjects increased strength levels by 20.9% compared to 3.9% in the trained subjects.

As mentioned previously, prior gains in maximal strength can lead to further potentiation of gains in power. Modes of phase-potentiation periodization strategies have been proposed to maximally develop strength and power capabilities. In one example, using literature review and mathematical modeling, Zamparo, Minetti and di Prampero (2002) and Minetti (2002) further expanded upon phase potentiation in their proposed model for power development. In this model, the authors suggest a sequential order of development to best enhance power development progressing emphasis from cross-sectional area development, to maximum strength, to power output. Figure 2 summarizes this model.

Figure 2

A Hypothetical Model for Strength Development. Modified from DeWeese et al., 2015a, 2015b.



In their review, Suchomel et al. (2016b) discussed the importance of maximum strength levels on other capabilities related to power and athletic performance. In this review, the authors summarize the current literature correlating maximum strength with rate of force development, external mechanical power, jumping ability, sprinting ability, change of direction ability, sport specific skill tasks, and lastly, potentiation potential. When considering all of the included studies, all of the examined qualities showed moderate to large correlations with maximum strength. However, one of the most interesting findings was the relationship between maximum strength and the ability to realize potentiation. It was noted that stronger athletes may develop higher levels of fatigue resistance to high loads which may allow for greater potentiation following resistance training. Additionally, a number of studies indicated that stronger individuals are able to potentiate earlier (shorter rest intervals) and to a greater extent than weaker individuals (Ruben et al., 2010; Sietz et al., 2014; Suchomel et al., 2016a). Taken together, 58% of the included studies showed a moderate or greater relationship between maximal strength and potentiation potentials while 49% found a large or greater relationship. Full results are displayed in Table 1.

Table 1.1

Summary of Current Literature Findings on the Relationships Between Maximum Strength and Various Performance Qualities. Modified from Suchomel et al., 2016a

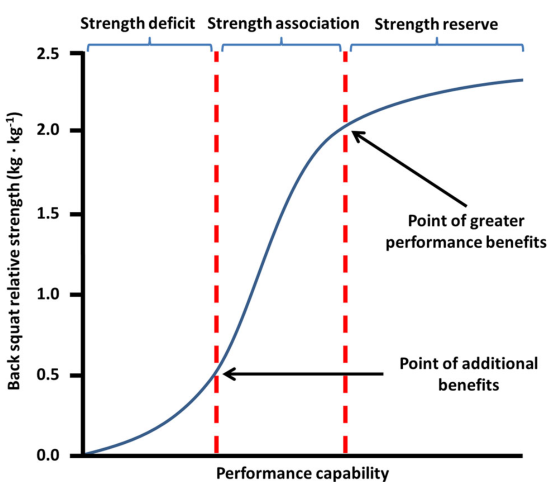
	Number of studies finding moderate relationships or greater ($r \geq 0.3$)	Number of studies finding Large relationships or greater ($r \geq 0.5$)
Max Strength – RFD	57/59 (97%)	44/59 (75%)
Max Strength – External Mechanical Power	134/177 (76%)	116/177 (65%)
Max Strength - Jumping	91/116 (78%)	69/116 (59%)
Max Strength - Sprinting	57/67 (85%)	44/67 (66%)
Max Strength – Change of direction	35/45 (78%)	27/45 (60%)
Max Strength – Sport Specific Skill	101/107 (94%)	89/107 (83%)
Max Strength - Potentiation	39/67 (58%)	33/67 (49%)

Further support for the relationship between maximum strength and power is provided by James et al. (2018). In their study, the authors compared power adaptations of a weak group (relative strength = 1.2x body weight) and a strong group (relative strength = 2.01x body weight) after 10 weeks of resistance training. The results clearly favored the strong group, showing greater improvement in all velocity metrics (peak velocity, average velocity, velocity at peak power, and jump height) as well as a greater improvement in peak power earlier in the training program. When examining the force-time characteristics the vertical jump testing, it was noted that the strong group improved their ability to use the stretch-shortening cycle to a greater extent during earlier phases of training when compared to the weak group. Although these findings may seem contradictory to the principle of diminishing returns, these findings are supported by the theoretical models proposed in phase potentiation. However, it is worth noting that the strong group showed a decrease in force at peak power during the later phase of training. The programmed training had a clear shift towards velocity-oriented training, and this may indicate a need for a partial emphasis of maximal strength qualities throughout a training cycle, regardless of strength levels.

Lastly, some authors have suggested a minimal strength threshold to be considered strong enough to achieve optimum gains in power and potentiation. This threshold varies somewhat but is generally suggested to be the ability to squat at least 1.7-2.0x your body mass (Berning et al., 2010; Ruben et al., 2010; Seitz et al., 2014; Suchomel et al., 2016a, 2016b). Further research should be performed to establish a relative strength threshold for further power adaptations. Figure 3 is adopted from Suchomel et al. (2016a) which describes this relationship.

Figure 3

Strength Threshold for Optimal Gains in Power and Potentiation



Load Monitoring

Monitoring has been described as "A spectrum of activities leading to an understanding of the training and performance process" (Stone et al., 2007). Although there is some overlap, athlete monitoring can be conceptually divided into fatigue management and program efficacy measurements. Both fatigue management and program efficacy can be used to guide future training decisions. This collective definition of monitoring encompasses a wide variety of techniques as well as activities which form a part of the training process (i.e. conditioning, resistance training, competition, recovery etc.). However, the ultimate goal of monitoring is to track progress (or lack thereof) to better inform decisions which guide future steps of the process. For example: One of the most common applications of the program efficacy monitoring process (and subsequent decisions) is the use of maximum strength testing in order to determine if the program has caused a positive adaptation. This information can subsequently be used to plan future stages and select appropriate loads.

Load monitoring is a common form of fatigue management. There are two broad classifications of load monitoring in use today: subjective (internal) and objective (external) means of monitoring. Subjective load monitoring is a form of monitoring which is reliant on one's personal analysis of training. Whereas, objective load monitoring does not rely on a personal analysis of training but rather employs reliable, valid means of tracking training.

Subjective Load monitoring includes many possible methods. These methods range from daily wellness questionnaires to simple coaches' notes from a practice session. However, session ratings of perceived exertion (SRPE) is likely the most commonly used and researched method of subjective load monitoring. There are several RPE scales commonly in use today including the Borg 6-20 scale, Borg Category-ratio 10 scale and the Foster 0-10 scale (Eston et al., 2012). Though slightly different, all three use a numerical scale ranging from easy to hard and have descriptor words associated with each number. These scales were based on correlations with other physiological measures of training load, such as heart rate. Using a subjective measure of training afforded coaches and sport scientists the ability to track and monitor training while requiring relatively little equipment or financial cost. The Borg 6-20 scale was eventually modified into a more easily understandable scale grounded from 0-10 which is still commonly used today. The CR-10 scale places descriptor words of rest at 0 to Extremely strong at 10. Although based on the CR-10, the foster 0-10 scale does not have the same fractionalized scale or number descriptors. Additionally, the foster 0-10 scale also attempted to utilize some of the merits of Banister's original TRIMP scale by including the influence of session duration (Banister et al., 1975). Taken together, the Foster scale has come to be known as the session RPE scale and is calculated by multiplying the session rating (0-10) by the total session duration. The complete session RPE scale is shown in Table 2 below.

Table 2

Three Methods of RPE Reporting

Borg 6-20		Borg CR-10		Foster Session RPE	
6	No Exertion at all	0	Nothing At all	0	Rest
7		0.5	Extremely Weak (just noticeable)	1	Very Easy
	Extremely light	1	Very Light	2	Easy
8		2	Weak (light)	3	Moderate
9	Very Light	3	Moderate	4	Sort of hard
10		4	Somewhat hard	5	Hard
11	Light	5	Strong (heavy)	6	
12		6		7	Very hard
13	Somewhat Hard	7	Very Strong	8	Very, very hard
14		8		9	Near maximal
15	Hard (Heavy)	9		10	Maximal
16		10	Extremely Strong (almost maximum)		
17	Very Hard	*	Maximal		

18						
19	Extremely Hard					
20	Maximal Exertion					

Researchers have validated each of the three scales with criterion methods of training load monitoring. For example, Pfeiffer et al. (2002) investigated the validity and reliability of the Borg 6-20 scale. The results of this study showed the Borg 6-20 scale was reliable (rxx = 0.78) as well as valid when compared to %HRmax (rxy = 0.66) and % VO_{2max} (rxy = 0.70). The results of this study are consistent with previous findings using the Borg 6-20 scale (Bar-Or, 1989; Lamb, 1995; Mahon & Marsh, 1992). Additionally, Foster et al. (2001) examined the validity of the Borg CR-10 scale in two forms of exercise compared with HR. In this study, subjects completed steady state and interval cycle exercise as well as basketball practice. The results of this study indicate a strong correlation between RPE and summated HR zone methods of deriving a training impulse score (TRIMP). However, in all modes of training, the RPE method created significantly higher TRIMP. This suggests that these methods are not interchangeable because of the difference in scale but that either method may be used consistently to monitor training given their strong correlations with each other. Lastly, Borreson et al. (2008) validated the use of the session RPE scale against two forms of HR based training scores. The results of this study showed strong RPE indicated a strong relationship between SRPE and TRIMP (r=0.76) as well as a strong relationship (r=0.84) between SRPE and the Summated Heart Rate Zones method for calculating TRIMP as described by Edwards (1993). Taken together, these studies clearly describe the reliability and validity of RPE methods for monitoring training loads.

Further methods employing the use of RPEs have called for differential RPEs (Pandolf et al., 1982) whereby athletes would give RPEs for both local stress (exercising muscles and joints) as well as central stress (primarily cardiovascular stress) to better understand the root of training stress. Additionally, some have advocated for the use of RPE at multiple time points throughout a training session, such as after every set of a resistance training exercise, to further understand an individual's progress within a session and possibly predict time to volitional fatigue (Eston et al., 2012; Silva et al., 2014). However, the use of one combined rating is far more commonly used in applied settings.

The nuances between the scales mainly deal with the differences in number format as well as specific anchor words employed by each. The Borg CR-10 as well as SRPE methods are further simplifications of the original Borg 6-20 scale which may make this scale more easily used in a multitude of settings outside the laboratory. One further difference between the Borg CR-10 and SRPE is described by Herman et al. (2006). The SRPE asks for a global rating (ex: how was your workout?) compared to the CR-10 which assesses momentary exhaustion. It is also recommended that coaches and sport scientists wait 30 minutes post-session to collect SRPEs to ensure it is truly a global rating and not disproportionately affected by the end of the session (Herman et al., 2006).

Objective load monitoring includes many commonly used methods for tracking training such as HR measures, GPS metrics, and effort counts (ex: pitches thrown, number of jumps etc.). Possibly the most commonly used form of objective load monitoring is volume load (VL) tracking. Perhaps the most basic form of tracking resistance training workloads is executed through total repetition monitoring (Haff, 2010). This method has merit in that it helps to understand the total resistance training volume for a session and is easily understood to compare between phases. However, this method provides no method of accounting for differences in load used or set/repetition schemes. For example, three sets of 10 repetitions would produce the same repetition load as 10 sets of three repetitions even though the load used would logically be very different. For further understanding of resistance training workloads, the load used in training must be considered. VL is calculated by multiplying the number of sets by the number of repetitions by the weight lifted (Haff, 2010; Hornsby et al., 2018). VL monitoring provides a means by which coaches and sport scientists are able to better understand training strain resulting from resistance training and the expected outcomes of training. As mentioned previously, a periodized approach to training employs various training volumes, intensities and exercise selections to best match the desired goals of each training phase (Stone et al., 2007).

However, work is defined as force x displacement. If a better estimate of mechanical work is desired, then attention should be given to the displacement of an exercise (Stone et al., 1987a, 1987b). Exercise displacements may differ for each phase of a training cycle. As a result, the load lifted may also vary greatly based on the displacement. For example, early in a training cycle, full displacement back squats may be employed to develop work capacity and basic strength. During a realization phase, partial displacement ¼ squats may be employed as a means of developing specific strength. A much heavier load may be possible for a ¼ squat as one does not need to pass the sticking point where the body has the least mechanical advantage in the range of motion. Therefore, the work accomplished can vary greatly between the two exercises.

Hornsby et al. (2018) investigated the effect of calculating VL with or without displacement. Training workloads were analyzed from 8 highly trained weightlifters over the course of five months. The program followed a block periodization design with four distinct training blocks. When investigating the relationships between VL and VLd, strong, significant correlations were found for all training blocks, days, and weeks of the program. However, when analyzing the percent changes in workload between periods, VL and VLd were significantly different for four of the seven periods analyzed. These findings support the use displacement as it gives practitioners additional insight when analyzing mechanical work and may better help explain the stress induced from training. Previous studies have also employed the use of VLd as a means of monitoring resistance training workloads as they relate to performance outcomes (Bazyler et al., 2017; Bazyler et al., 2018; Carroll et al., 2018; Hornsby et al., 2017).

Table 3

Calculations for Workload in Resistance Training

Total Repetitions	TR = sets x reps
Volume Load	VL = sets x reps x load (kg)
Volume Load Displacement	Work = sets x reps x load (kg) x vertical displacement (m)

Both subjective and objective forms of monitoring have their own merits. For example, subjective measures (such as RPE) are often free or inexpensive, easy to implement and simple to understand. Possibly the biggest benefit of subjective monitoring is the fact that it may provide unique insight into an individual's response to a stimulus. It is well known that individual responses to a stimulus may vary greatly based on training history, age, and genetic factors (Ahtiainen et al., 2003; Rhea et al., 2003). Meanwhile, objective monitoring such as VL has merit in that it is has strong validity and reliability and can be used when making training decisions with high precision. Another classification of the two previous examples of RPE and VL could be measures of internal training load and external training loads, respectively. However, in order to have a wholistic approach to monitoring, it may be advisable to combine subjective and objective, internal and external load measures. For example, Aoki et al. (2017) recommend the use of both internal (RPE) and external load (accelerometry) monitoring when implementing a tactical periodization plan for team sports and noted that internal load was more sensitive to intensity changes whereas external load was more sensitive to volume changes. Similarly, Schneider et al. (2018) term this a multivariate approach. The authors recommend the combination of objective HR measures with subjective RPE to better discern changes in fitness over time. For example, if over time, exercise HR is constant for a given loading, but RPE decreases over time, a reasonable deduction would be that fitness has improved. Conversely, If HR during rest and RPE are both elevated, then the athlete is likely fatigued. Lastly, Lambert et al. (2010) advocate for the creation of sport specific consensus positions on best practice monitoring. This is because sports differ in their needs and ease of implementing each monitoring tool. For example, cycling is best suited for precise external training measurements as well as internal physiological loads. In this context, one may apply the use of a mobile ergometer, HR monitor and RPE to gain a wholistic understanding of the training loads of cyclists. Regardless of the methods chosen, coaches and sport scientists should carefully and consistently monitor progress over time to better understand the adaptations imposed by training.

Chapter 3.

THE EFFECT OF TRAINING STATUS ON ADAPTATIONS TO 11 WEEKS OF BLOCK PERIODIZATION TRAINING

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The Effect of Training Status on Adaptations to 11 Weeks of Block Periodization Training

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Abstract: Some controversy exists as to the most efficacious method of training to achieve enhanced levels of sport performance. Controversy concerning the efficacy of periodization and especially block periodization (BP) likely stems from the use of poorly or untrained subjects versus trained who may differ in their responses to a stimulus. The purpose of this study was to investigate the effect of training status on performance outcomes resulting from 11 weeks of BP training. Fifteen males were recruited for this study and placed into strong (age=24.3±1.9 yrs., Body Mass=87.7±8.7 kg, squat:body mass=1.96±0.16), moderate (age=25.3±2.7 yrs., Body Mass=100.2±15.5 kg, squat:body mass=1.46±0.14) or weak (age=23.2±3.9 yrs., Body Mass=83.5±17.1 kg, squat:body mass=1.17±0.07) groups based on relative strength. Testing was completed at baseline, and after each block which consisted of 1RM squat, 0kg static jump (SJ), 0kg countermovement jump (CMJ), 20kg SJ and 20kg CMJ. Absolute and relative strength were strongly correlated with rates of improvement for absolute strength, relative strength, 0kg and 20kg vertical jumps. All subjects substantially improved back squat ($p<0.001$), relative back squat ($p<0.001$) with large-very large effect sizes between groups for percent change favoring the weak group over the moderate and strong group for all performance variables. All subjects showed statistically significant improvements in 0kg SJ ($p<0.001$), 0kg CMJ ($p<0.001$), 20kg SJ ($p=0.002$) and 20kg CMJ ($p<0.001$). Statistically significant between group differences were noted for both 20kg SJ ($p=0.01$) and 20kg CMJ ($p=0.043$) with the strong group statistically greater jump heights than the weak group. The results of this study indicate BP training is effective in improving strength and explosive ability. Additionally, training status may substantially alter the response to a resistance training program.

Keywords: Strength; Relative Strength; Resistance Training

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1. Introduction

Controversy exists as to the most efficacious method of training to achieve enhanced levels of sport performance characteristics, especially as it pertains to strength and power [1,2,3]. The majority of reviews of the literature [4,5,6,7,8,9,10,11] including several meta-analyses [10,11] have consistently concluded that a "periodized" training concept offers advantages over non-periodized processes.

However, some controversy concerning the periodization models exists [11]. There are only two models of periodization, Traditional (Classic) and Block [4,12]. Traditional periodization allows for simultaneous alterations in a variety of fitness characteristics whereas single factor block periodization takes a more consecutive approach in which one or a few compatible characteristics are developed before emphasizing a different set of characteristics [5,6,12].

Much of this controversy stems from confusion of periodization with programming [4]. It should be noted that periodization is a conceptual paradigm that deals with: 1) Fitness phases and 2) Time lines for implementation of the fitness phases. There are two basic (general) premises of the periodization concept: 1) less specific to more specific and 2) higher volume to lower volume [5,6,13]. Based on past [14,15], and particularly recent evidence [13,16,17], it is becoming increasingly clear that Block Periodization provides superior results when properly programmed.

Briefly Simple Block periodization consist of three primary phases, Accumulation (General Preparation), Transmutation (Special Preparation) and Realization (Competition and Taper). Periodization is supported mechanistically by several basic hypotheses/theories of describing an organism's reaction to a specific stimulus [4,12]. These conceptual mechanisms include stimulus-fatigue-recovery adaptation, the General Adaptation Syndrome (GAS) and specifically for strength power training development of hypertrophy, then basic strength then power [4,12,18,19].

Much of the controversy concerning the efficacy of periodization and especially block periodization likely stems from the use of trained versus poorly or untrained subjects and the use of programming techniques used to drive the periodization model [4]. For example: Recently Painter et al. [16,17] and particularly Carroll et al. [13] have provided evidence that training to failure using RM zones may inhibit gains in maximum strength, rate of force development (RFD) and power. Compared to non-failure, training to failure can produce a relatively high degree of training monotony and strain that is reflected to greater extent in negative physiological/metabolic responses (e.g. testosterone, cortisol, neutrophil: leucocyte ratios etc.). This negative aspect of adaptation noted with training to failure is also in agreement with recent studies indicating an extended recovery necessary for training to failure [20,21,22]. Extended recovery may inhibit adaptation or potentiate non-functional overreaching or overtraining [13,17], particularly when applied to a sport environment with other training in addition to the resistance program.

Training level may be a major influence on training outcomes as 1) untrained subjects using the same stimulus tend to gain strength at a faster rate than trained [10,23]; 2) previous training producing increased maximum strength may potentiate further gains in power when power training is emphasized [24,25,26]; 3) training combinations using a strength plus power emphasis can potentiate both strength and power gains [4,12] and 4) initial gains in hypertrophy may be due to changes in edema and swelling [27]. Thus, the purpose of this study is to study the effect of training status on adaptation to block periodization resistance training.

2. Materials and Methods

2.1. Subjects

Based on the results of previous investigations [13], power analysis for repeated measures ANOVA with a moderate effect size was calculated ($\alpha = 0.05$, f = 0.9, number of groups = 3, number of measurements = 5). It was determined that a sample size of 12 was needed (Gpower vers. 3.0.10). Fifteen healthy males of various training experience volunteered for this study. Correlations indicate a strong and consistent negative relationship between the initial 1 RM and gains in performance (Table 6). This would indicate that weaker subject's progress at a greater rate than stronger subjects. Considering these correlations subjects were divided into three groups based on their initial 1RM squat. Based on the criteria outlined by Suchomel et al. 2018, subjects were grouped according to their relative (1RM/ Body mass) squat [12]. Subjects (n = 7) unable to back squat at least 1.25 kg/kg were considered weak (age=23.2±3.9 yrs., BM=83.5±17.1 kg, squat:BM=1.17±0.07). A 1RM back squat between 1.25 – 1.75kg/kg were considered moderate (n = 4) (age=25.3±2.7 yrs., BM=100.2±15.5 kg, squat:BM=1.46±0.14). A 1 RM back squat greater than 1.75 kg/kg were considered strong (n = 4) (age=24.3±1.9 yrs., BM=87.7±8.7 kg, squat:BM=1.96±0.16). This study was approved by the university Institutional Review Board (IRB) and all subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

2.2. Procedures

A block periodization design was used for the resistance training program as it has been previously shown to be effective in developing maximum strength and power [16,17,14,15]. All subjects completed one baseline testing session, and a testing session following each of the four training blocks. Subjects with no prior training history underwent a two-week familiarization period in which they learned each of the exercise techniques prior to beginning training to account for learning effects. Pre-testing took place one week before the beginning of the training intervention. Each post-block testing session was completed on the last training session of the block with two days separating post-block testing and the beginning of the next block of training. All testing sessions were completed at the same time of day and in the same order of tests. Training loads were consistently tracked. A mixed within and between subject design was selected to examine the effect of the training program on performance characteristics both within subjects and between groups.

All groups completed the same non-failure strength training program and testing scheme. The training program followed a single factor block periodization model and was programmed with an emphasis on strength and power development.

The subjects completed three resistance sessions per week (Monday, Wednesday and Friday) and two sprint sessions per week (Tuesday and Thursday). The sprint warm-up and program was designed to simulate a sport practice environment.

The training program contained three sequential summated microcycles or blocks (strength-endurance, maximal strength, and power) including a functional overreach and taper. Additionally, each summated microcycle contained heavy and light days to both manage fatigue and ensure a spectrum of power outputs. Lastly, all training loads were selected using relative intensities (% set-rep best). The training program is shown in Table 1.

Table 1. Resistance training program, * signifies down set at 50% of target weight after major exercise (squats, bench, mid-thigh pull).

Training Block	Week	Sets x Reps	Day 1 and 2	Day 3
Strength-Endurance	1	3x10	80%	70%
	2	3x10	85%	75%
	3	3x10	90%	80%
Maximum Strength	4	3x5 (1x5)*	85%	70%
	5	3x5 (1x5)*	87.5%	72.5%
	6	3x5 (1x5)*	92.5%	75%
	7	3x5 (1x5)*	80%	65%
Overreach	8	5x5	85%	75%
Speed-Strength	9	3x3 (1x5)*	87.5%	67.5%

	10	3x2 (1x5)*	85%	65%
	11	2x2 (1x5)*	65% & 60%	---------

The exercise selection for both groups is shown in Table 2.

*DB= dumbbell, CG= clean grip, MT*P*= mid-thigh pull, BB= barbell, Ext= extension, Wtd= weighted, SG= snatch grip, SLDL= stiff-legged deadlift, SA= single arm, CM= counter-movement.

Table 2. Resistance Training Exercise Selection.

Training Block	Day 1	Day 2	Day 3
Strength-Endurance	Back Squat, Overhead Press, Bench Press, DB Tricep Ext.	CG MTP (3x5), CG SLDL, BB Bent Over Row, DB Bent Lateral Raise	Back Squat, Overhead Press, Bench Press, DB Tricep Ext.
Maximum Strength	Back Squat, Push Press, Incline Bench Press, Wtd. Dips	CG MTP, Clean Pull, SG SLDL, Pull Ups	Back Squat, Push Press, Incline Bench Press, Wtd. Dips
Overreach	Back Squat, Push Press, DB Step Ups, Bench Press	CG CM Shrug, Clean Pull, CG SLDL, SA DB Bent Over Row	Back Squat, Push Press, DB Step Ups, Bench Press
Speed-Strength	Back Squat + Rocket Jumps, Push Press, Bench press + Medicine Ball Chest Pass (4.5kg)	CG MTP, CG CM Shrug, Medicine Ball Countermovement Toss for height (4.5kg)	Back Squat + Rocket Jumps, Push Press, Bench press + Medicine Ball Chest Pass (4.5kg)

Pre-intervention testing was conducted one week prior to the start of the intervention and concluded 48 hours prior to the start of the intervention for the participant. Pre-testing included hydration status, jump height and dynamic strength. Hydration was tested using a refractometer (Atago, Tokyo, Japan). Dehydration has been shown to have a negative effect on performance, cognitive abilities and ultimately testing results [28]. Subjects were required to have a USG >1.20 to begin testing.

Static jumps (SJ) and counter movement jumps (CMJ) were assessed using dual force plates (2 x 91cm x 45.5cm) sampling at 1000Hz (Rice Lake Weighing Systems, Rice Lake, WI). Both unweighted (PVC pipe) and weighted (20kg barbell) jumps were collected for both SJ and CMJ. The PVC pipe and barbell were used to eliminate arm swing and to standardize testing conditions between subjects [13]. Subjects performed a SJ from an internal knee angle of approximately 90^{o} [13]. SJ testing followed a standardized warm-up [29] and subjects performed two warm-up jumps for the unweighted SJ at 50% and 75% effort. Subjects then performed at least two SJ at 100% effort. If jump heights differed by greater than 2cm, then additional trials were performed until two unweighted jumps within 2cm of each other. Once complete, subjects began testing weighted jumps using the same procedure as unweighted jumps. Unweighted and weighted CMJ were performed using the same procedure as SJ.

Dynamic strength was assessed via 1 repetition maximum back squat. Prior to the first attempt, a standardized warm-up was performed [30]. This standardized warm up is shown in Table 3 below.

Table 3. Warm-Up protocol prior to all 1RM lift attempts and rest time after all warm-up sets.

* 1 RM weight for untrained subjects will be based on the participant's estimated 1 RM.

5x30% of 1RM*	3x50% of 1RM*	2x70% of 1RM*	1x80% of 1RM*	1x90% of 1RM*
1 minute	1 minute	2 minutes	3 minutes	3 minutes

The testing percentages were based on self-estimated 1RM and the trial and error method for 1RM [31]. After a successful attempt, subjects continued to attempt progressively heavier loads until a true 1RM was reached. Attempts were deemed successful if the line from the top of the knee to the hip crease was parallel (or below) with the floor. Squat depth was determined by two experienced certified strength and conditioning specialists.

Post block testing consisted of hydration, performance testing and dynamic strength measures. Post block testing was completed after the 3-week strength endurance (SE) block, 4-week maximum strength (MS) block, the 1-week functional overreach (FOR) and the 3-week taper. Post block testing was completed on the last scheduled training session of every block (Friday). Testing consisted of performance (jumps), and dynamic strength (1 RM squat). After testing, subjects completed the remainder of their scheduled day 3 training session (with the exception of back squat).

2.3. Statistics

A series of 3x5 two-way mixed design ANOVAs (group x time) was used for this study with an alpha level of $p<0.05$. In addition to null hypothesis testing, magnitudes of effect were calculated using Cohen's *d* effect sizes. Additionally, correlational statistics were calculated using Pearson's *r* to assess the relationships between training status and performance. All statistics were calculated using JASP (JASP vers. 0.11.1.0). Cohen's *d* magnitude thresholds and correlation thresholds are shown in table 4.1 [32].

Table 4. 1 Magnitude thresholds for Cohen's *d* and Pearson's *r*.

Cohen's *d*		**Pearson's *r***	
0-0.2	Trivial	0.0-0.1	Trivial
0.2-0.6	Small	0.1-0.3	Small
0.6-1.2	Moderate	0.3-0.5	Moderate
1.2-2.0	Large	0.5-0.7	Large
>2.0	Very Large	0.7-0.9	Very Large
		1.0	Perfect

Intraclass correlations for all force plate measures were considered excellent (0.986-0.994) [32]. Reliability statistics for our lab are shown in table 4.2

Table 4. 2 Reliability Statistics.

	ICC
0kg SJ JH	0.986
20kg SJ JH	0.994
0kg CMJ JH	0.991
20kg CMJ JH	0.992
0kg SJ PP	0.982
20kg SJ PP	0.984
0kg CMJ PP	0.991
20kg CMJ PP	0.994

3. Results

3.1. Correlation between strength levels and adaptations to training

All dependent variables met the assumptions of normality and sphericity at the level of significance. When investigating the relative rates of change in performance between groups, several distinctions can be made. In dynamic strength, for example, both the moderate and weak groups showed their greatest change from baseline to the end of the SE phase. However, the strong group showed its greatest improvement from the end of SE to the end of the MS phase. Similar trends were found for relative dynamic strength but with the strong group's greatest improvement from the end of the FOR to the taper phase. Taken together with all performance variables, there is a clear difference in rates and timing of adaptation to a stimulus between strength groups.

Table 5. Blocks with greatest percent changes.

	0kg SJ	20kg SJ	0kg CMJ	20kg CMJ	Abs Back Squat	Relative Back Squat
Weak	Taper	SE	Taper	Taper	SE	SE
Moderate	SE	Taper	Taper	FOR	SE	SE
Strong	Taper	Taper	Taper	SE	MS	Taper

Statistically significant correlations were found between both absolute and relative strength levels and various rates of physical improvements. For example, initial absolute squat strength was strongly correlated with absolute squat pre/post change (r=-0.738), relative squat pre/post change (r=-0.767) pre/post change for both 0kg (r=-0.555) and 20kg SJ (r=-0.608), and peak power pre/post change for both 0kg (r=-0.709) and 20kg (r=-0.709) SJ. Additionally, strong correlations were noted between absolute strength and early (first block) strength changes (r=-0.524) as well as post-taper improvements in SJ (r=-0.526) and CMJ (r=-0.517). Similar relationships exist between relative strength levels and physical adaptations to training including, pre/post change in absolute strength (r= -0.751), pre/post change in relative strength (r=-0.727), pre/post change in 20kg CMJ (r=-0.526), pre/post change in 0kg SJ peak power (r=-0.586) and 20kg SJ peak power (r=-0.589), and early (first block) changes in absolute (*r=-0.544)* and relative strength (r=-0.517). A full list of statistically significant correlations is shown in Table 6.

Table 6. Correlations between initial strength levels and training adaptations.

		Pearson's *r*	***p*-value**
Pre-Absolute 1RM	Pre-Relative Squat	-0.833	<0.001
Pre-Absolute 1RM	Absolute Squat Pre/Post % change	-0.738	0.002
Pre-Absolute 1RM	Relative Squat Pre/Post % change	-0.767	<0.001
Pre-Absolute 1RM	0kg SJ pre/post % change	-0.555	0.0032
Pre-Absolute 1RM	20kg SJ pre/post % change	-0.608	0.016
Pre-Absolute 1RM	T1-T2 Abs. Squat % change	-0.524	0.045
Pre-Absolute 1RM	0kg SJ T4-T5 % change	-0.526	0.044
Pre-Absolute 1RM	20kg CMJ T4-T5 % change	-0.517	0.049
Pre-absolute 1RM	0kg SJ Peak Power pre/post % change	-0.709	0.003
Pre-Absolute 1RM	20kg SJ Peak Power pre/post % change	-0.709	0.003
Pre- Relative 1RM	Absolute 1RM pre/post % change	-0.751	0.01
Pre-Relative 1RM	Relative 1RM pre/post % change	-0.727	0.002
Pre-Relative 1RM	20kg CMJ pre/post % change	-0.526	0.044
Pre-Relative 1RM	0kg SJ peak power pre/post % change	-0.586	0.022
Pre-Relative 1RM	20kg SJ peak power pre/post % change	-0.589	0.021
Pre-Relative 1RM	Absolute 1RM T1-T2 % change	-0.544	0.036
Pre-Relative 1RM	Relative 1RM T1-T2 % change	-0.517	0.048

3.2. Vertical Jump Testing

Both weighted and unweighted vertical jumps were measured before and after each block of training. The 0kg SJ showed a statistically significant main effect for time increase in jump height ($p<0.001$). While there were not statistically significant differences between groups for 0 kg, the strong group improving 7.6%, the moderate group improving only 0.3% and the weak group improving 25.6% over the course of the study. It is worth noting that two subjects in the moderate group improved (4.8cm and 2.3cm, respectively) while two decreased (-3.9cm and -2.9cm, respectively) likely confounded the overall group mean. Similar results were found for the 0kg CMJ with a significant effect for all subjects over the course of the study ($p<0.001$) and non-significant differences between groups. However, noticeable differences in the percent changes were noted with the strong group improving 9.9%, moderate group improving 11.0% and the weak group improving 23.8% over the course of the study.

The 20kg static jumps showed statistically significant improvements for all subjects ($p=0.002$) and statistically significant effects of strength level on jump height from baseline to post-testing ($p=0.01$). The strong group improved 4.8%, the moderate group improved 8.4% and the weak group improved 28.2%. Similarly, the 20kg CMJ showed statistically significant improvements for all subjects ($p<0.001$) and statistically significant differences between groups ($p=0.043$). The strong group improved 9.6%, the moderate group improved 9.0% and the weak group improved 27.9% over the course of the study from pretesting to post testing.

Full results for all vertical jumps are shown in the Tables 7.1 and 7.2 below.

Table 7. 1: Vertical Jump % change after 11 weeks of training.

	0kg SJ	Effect Size	0kg CMJ	Effect Size	20kg SJ	Effect Size	20kg CMJ	Effect Size
All subjects n=16	14.7%*	0.839 (moderate)	15.8%*	1.379 (Large)	18.1%*	0.834 (moderate)	16.6%*	1.102 (moderate)
Strong n=4	7.6%	0.553 (small)	9.9%	0.598 (moderate)	4.8%	0.325 (small)	9.6%	0.532 (small)
Moderate n=4	0.3%	0.013 (trivial)	11.0%	0.583 (moderate)	8.4%	0.406 (small)	9.0%	0.435 (small)
Weak n=7	25.6%*	1.403 (Large)	23.8%*	1.377(large)	28.2%*	1.305 (large)	27.9%*	1.447 (large)

*indicates significance (p<0.05).

Table 7. 2: Vertical Jump between group effect size after 11 weeks of training.

	0kg SJ	0kg CMJ	20kg SJ	20kg CMJ
Moderate-Strong	-0.360 (Small)	0.244 (Small)	-0.589 (Small)	-0.304 (Small)
Moderate-Weak	0.197 (Trivial)	0.337 (Small)	0.270 (Small)	0.387 (Small)
Strong-Weak	0.609 (Moderate)	0.612 (Moderate)	0.940 (Moderate)*	0.730 (Moderate)*

*indicates significance (p<0.05).

3.3. Peak power

Peak power (PP) was measured across all four vertical jump conditions. PP statistically improved for 0kg SJ, 20kg SJ, 0kg CMJ and 20kg CMJ (p<0.001). Percent change in PP for each jump condition is listed in the table 8 below.

Table 8. Pre-Post percent change in vertical jump peak power.

	0kg SJ	20kg SJ	0kg CMJ	20kg CMJ
Strong	4.36%	7.66%	4.51%	4.96%
Moderate	4.42%	3.29%	8.52%	4.94%
Weak	20.51%	18.72%	12.56%	11.68%

3.4. Dynamic Strength

Dynamic strength showed significant improvements for all subjects (*p*=0.002). Post-Hoc analysis showed significant differences between groups with small to large effects. The largest improvement was noted in the weak group (25.9%) with smaller improvements in the moderate (18.2%) and strong groups (11.3%). All results are shown in the Tables 9.1 and 9.2.

Table 9. 1: Dynamic strength % change after 11 weeks of training.

	Back Squat % Change	Effect Size	Relative Back Squat % Change	Effect Size
Strong	11.3%	1.385 (Large)	10.4%	1.589 (Large)
Moderate	18.2%	1.871 (Large)	14.0%	1.587 (Large)
Weak	25.9%	2.361 (Very Large)	23.1%	2.789 (Very Large)

Table 9. 2: Between group effect size for dynamic strength.

	Back Squat	Relative Back Squat
Moderate-Strong	-0.318 (Small)	-1.373 (Large)
Moderate-Weak	0.769 (Moderate)	0.783 (Moderate)
Strong-Weak	1.129 (Large)	2.322 (Very Large)

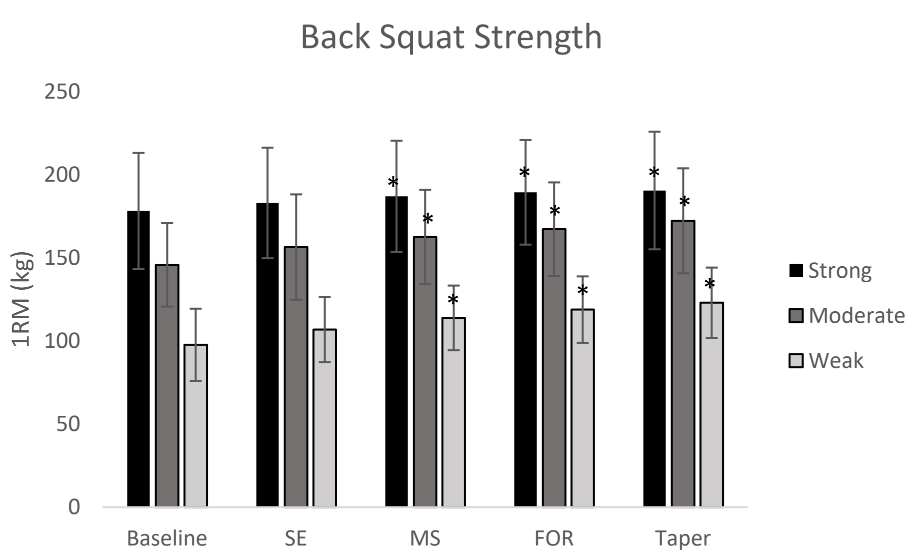

Figure 1. Block to Block changes in absolute back squat.

*indicates a statistically significant change from baseline strength (*p*<0.05).

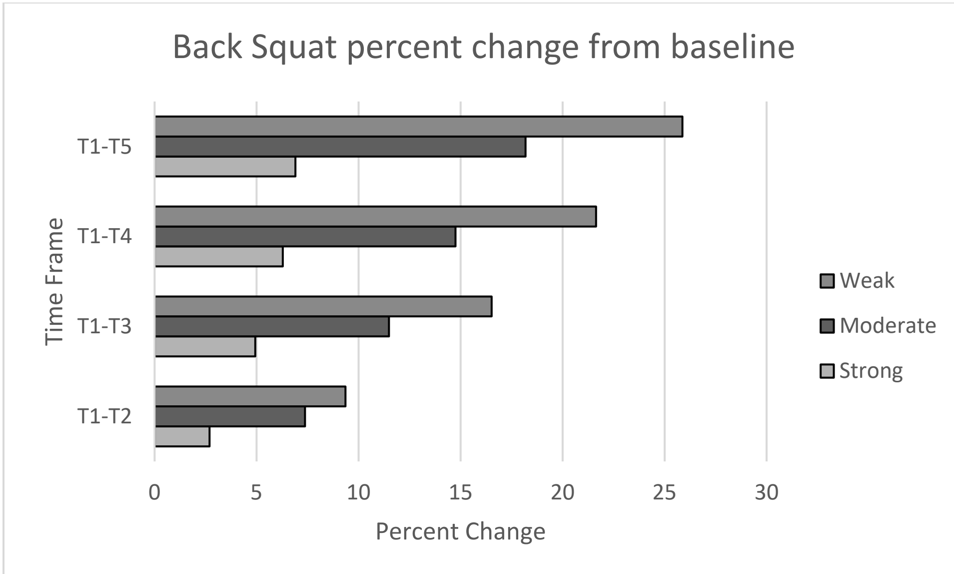

Figure 2. Block to block percent change in absolute back squat.

(1)

4. Discussion

The vast majority of existing reviews of the literature [5,6,7,8,9,10,11] and several meta-analyses [10,11,33] ,have consistently concluded that a "periodized" training concept offers advantages over non-periodized processes. The results of our current study support the previous literature in the effectiveness of a periodized program in enhancing maximum strength and power. The sequential programming approach used within BP has also been termed phase-potentiation [15]. Phase potentiation programming is a process by which programming alterations in a concentrated load in one block may further potentiate the adaptations in the subsequent blocks due to accumulated residual training effects [5,6] Power, along with impulse, has previously been defined as a most important attribute for athletic performance [15]. As noted in the introduction, development of maximal strength may potentiate further gains in power. Our results support this theory as subjects realized early gains in strength after the SE and MS blocks which led to large improvements in jump height and PP during the taper. It should be noted however, the strong group generally realized the greatest gains as a result of the taper (Table 5). These results, particularly for the strong group, are indicative of the shift in emphasis over a BP program from general strength endurance towards realizing maximum strength and power in the later phases of training, along with a volume reduction. Similar results have been found previously by Carroll et al., (2018) who employed a very similar BP training program. In their results, subjects substantially improved their scaled PP from pre to post ($p=0.003$) as well as during the final phase of the program (taper) ($p=0.026$) [13]. Our current findings along with previous findings support the efficacy of a BP model for maximizing strength and power, especially in the later phases of training.

The results of this study highlight the importance of training status on adaptation to a training stimulus. Statistically significant correlations were found between initial strength levels (both absolute and relative) and improvement in strength (absolute and relative) over time. Specifically, strong negative correlations were found between initial strength levels and percent change in maximum strength and vertical jump ability indicating that weaker individuals improve at a greater rate than stronger individuals. These results are supported by those of Ahtiainen et al. (2003) who compared strength athletes and non-athletes over the course of 21 weeks of training. The results noted a 20.9% increase in maximum strength for non-athletes and only 3.9% in the strength athlete group [23]. Additionally, a meta-analysis by Rhea et al. (2003) notes different responses to training based on training status [10]. Specifically, previously trained subjects require higher intensities for maximal gains compared to their untrained counterparts. However, one very interesting finding of the current study was the correlation between strength levels and both early and late phase development. Absolute strength was negatively correlated with early strength development (T1-T2) (r=-0.524) and negatively correlated with later improvements in jump height (T4-T5) (r=-0.526 for 0kg SJ and r=-0.517 for 20kg CMJ) showing greater gains for weaker subjects than stronger ones. Theoretically, these correlations support the proposed mechanisms of phase-potentiation as early gains in strength for untrained subjects manifests itself via power gains later in the program. Both the moderate and weak groups showed their greatest improvements in maximum strength after the SE block. However, the strong group showed its greatest change in maximum strength after the MS block indicating that stronger individuals may not realize substantial improvements in maximum strength until a more specific stimulus is applied. Lastly, there were marked differences in relative strength changes during the taper phase. While all groups showed improvement during the taper, only the strong group showed it's greatest improvement in relative strength during the realization phase. A major goal of a taper is the reduction in volume which may dissipate fatigue as well as improve relative strength due to residual training effects. The gain in relative strength may contribute to increased power development which is fundamental for sport success during important competition periods. Previous research has proposed several mechanisms which may contribute to this observed increase in power during a taper. There is typically a reduction in fatigue accompanying volume reductions which may lead to increased performance in keeping with the fitness fatigue paradigm [34]. One possible mechanism which may also contribute to the increase in power development during a taper is a shift in myosin heavy chain (MHC) isoform. Several studies have cited a shift from slower to faster isoforms during periods of reduced training [35,35,36,37]. Andersen et al. (2000) studied changes in MHC after 3 months of heavy resistance training and again after 3 months of detraining [35]. The results showed a significant shift of type IIx MHC to MHC IIa after resistance training with significant hypertrophy of the type II fibers. Interestingly, after 3 months of detraining, MHC isoforms had shifted back towards IIx with values statistically higher than baseline. The observed fiber type distribution mirrored the changes in MHC isoform. The results of this study lend support to the possibility of a IIx "super compensation" after a period of reduced training and may partially explain the increase in power potential during a taper as IIx MHC are more explosive than type I or IIa. Additionally, residual training effects resulting in maximum strength may last well into a period of reduced training. The maintenance of maximum strength paired with a possible shift of fiber type towards more powerful MHC isoforms, provide a sound basis for including a taper during periods of time in which power is the goal, such as important competitions. However, given the results of our study, it is possible that in developing athletes, taper responses may differ, as we observed different changes in relative strength levels and PP between the strong and the moderate/weak groups.

Lastly, previous authors have proposed that greater levels of variation or advanced training tactics may be beneficial for more advanced athletes. For example, in their review, Kraemer and Ratamess (2004) state that advanced lifters progress at much slower rates compared to lesser trained individuals as they begin to approach their genetic ceiling [38]. The authors also note that small changes in strength may require large amounts of training time, but the time can be worth the effort because small changes may be the difference between winning and losing. Therefore, the authors state that advance training is more complex and requires greater variation specific to training goals.

One possible limitation of the current study is the limited sample size. To better understand the effect of training status on adaptations to training, further research with greater sample sizes is warranted. One additional limitation of the current study is the relatively short duration of 11 weeks (one stage). While the current study is one of the longest-term studies currently available, it would be very informative to continue to follow adaptations to a program multiple stages in length.

5. Conclusions

The findings of the current study demonstrate the effectiveness of a BP training program in improving both strength and power capabilities across different training levels. An important concept in power development is that increases in maximum strength before a realization phase emphasizing power will potentiate power adaptations [15,24,39]. Our results indicate a marked difference in rates of improvement between different training level groups agreeing with this concept. Specifically, initial strength levels were negatively correlated with rates of improvement in strength and power. Therefore, it is recommended that coaches and sport scientists use a periodized training program with their athletes. Additionally, we recommend practitioners implement a regular monitoring program to better understand potential adaptations to a resistance training program based on training status. Lastly, as athletes improve their training status and begin to approach their genetic potential, more advanced training tactics may be warranted to continue to promote adaptation to a specific stimulus.

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Chapter 4

COMPARISON OF SUBJECTIVE AND OBJECTIVE MEASURES OF RESISTANCE TRAINING LOAD

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Abstract

Many forms of monitoring resistance training (RT) loads exist including simple repetition counts, volume load tracking (VL), volume load tracking with displacement measures (VLd), session ratings of perceived exertion (RPE), and heart rate measures. Further, these methods can be divided into two classifications: subjective and objective measures. Both forms can be effectively used to inform the training process, however, current recommendations may differ as to the most advantageous methods to monitor RT. The purpose of this study was to first, determine the effect of considering displacement within measures of VL and secondly to determine what relationship exists between objective measures (VLd) and subjective measures (SRPE) of RT load. Fifteen males were recruited for this study (Age=24+±3.3yrs, BM=89.1±16.4kg). Subjects completed 11 weeks of block periodized RT. SRPE were collected after each training session and VL were tracked for each exercise. Displacements were measured for all exercises employed within the program. When examining the relationship between subjective and objective methods, a statistically significant, positive relationship was found between SRPE and VLd ($p<0.001$) but no significant effect of strength or the interaction between strength and VLd was found. Statistically significant correlations were found between VL and VLd for all blocks of training. However, there were statistically significant differences between methods when examining percent change between blocks.

Key Words: Monitoring, Volume Load

INTRODUCTION

Monitoring has been described as "A spectrum of activities leading to an understanding of the training and performance process" (29). Although there is some overlap, athlete monitoring can be conceptually divided into fatigue management and program efficacy measurements. Both fatigue management and program efficacy can be used to guide future training decisions. This collective definition of monitoring encompasses a wide variety of techniques as well as activities which form a part of the training process (i.e. conditioning, resistance training, competition, recovery etc.). However, the ultimate goal of monitoring is to track progress (or lack thereof) to better inform decisions which guide future steps of the process. For example: One of the most common applications of the program efficacy monitoring process (and subsequent decisions) is the use of maximum strength testing in order to determine if the program has caused a positive adaptation. This information can subsequently be used to plan future stages and select appropriate loads. While program efficacy monitoring provides valuable information about adaptations to training, it is unable to address the second purpose of athlete monitoring, fatigue management. Fatigue management is a process by which an athlete or subject's responses to a stimulus are monitored to ensure sufficient recovery is provided and adaptation continues. For example, the use of wellness questionnaires can provide valuable insight into an athlete or subject's status such as fatigue, soreness and desire to train which can be used to help avoid non-functional over-reaching or possibly, overtraining.

In resistance training, there are two broad forms of load monitoring as a form of fatigue management: subjective and objective means of monitoring. Subjective load monitoring is a form of monitoring which is reliant on the experience of a subject and their response to training demands. Whereas, objective load monitoring does not rely on a personal analysis of training but rather employs reliable, valid means of tracking training. Both forms are commonly used in practice and warrant further discussion.

Subjective load monitoring includes many possible methods. These methods range from daily wellness questionnaires to simple coaches' notes from a practice session. However, session ratings of perceived exertion (SRPE) is likely the most commonly used and researched method of subjective load monitoring. There are several RPE scales commonly in use today including the Borg 6-20 scale, Borg Category-ratio 10 scale and the Foster 0-10 scale (14). Though slightly different, all three use a numerical scale ranging from easy to hard and have descriptor words associated with each number. The basis for these scales was their association correlations with physiological measures of training load, such as heart rate (7,10,15,26). Using a subjective measure of training offers coaches and sport scientists the ability to track and monitor training while requiring no equipment or financial cost. The Borg 6-20 scale was eventually modified into a more easily understandable scale grounded from 0-10 which is still commonly used today. Although based on the CR-10, the Foster 0-10 scale does not have the same fractionalized scale or number descriptors. Additionally, the Foster 0-10 scale also attempted to utilize some of the merits of Banister's original TRIMP scale by including the influence of session duration (3). Taken together, the Foster scale has come to be known as the session RPE scale and is calculated by multiplying the session rating (0-10) by the total session duration. The complete session RPE scale is shown in table 1 below.

Table 1: Foster's Session RPE

Borg 6-20		Borg CR-10		Foster Session RPE	
6	No Exertion at all	0	Nothing At all	0	Rest
7		0.5	Extremely Weak (just noticeable)	1	Very Easy
	Extremely light	1	Very Light	2	Easy
8		2	Weak (light)	3	Moderate
9	Very Light	3	Moderate	4	Sort of hard
10		4	Somewhat hard	5	Hard
11	Light	5	Strong (heavy)	6	
12		6		7	Very hard
13	Somewhat Hard	7	Very Strong	8	Very, very hard
14		8		9	Near maximal
15	Hard (Heavy)	9		10	Maximal
16		10	Extremely Strong (almost maximum)		
17	Very Hard	*	Maximal		
18					
19	Extremely Hard				
20	Maximal Exertion				

Researchers have validated each of the three scales with criterion methods of training load monitoring. For example, Pfeiffer et al., (2002) investigated the validity and reliability of the Borg 6-20 scale (24). The results of this study showed the Borg 6-20 scale was reliable (r_{xx} = 0.78) as well as valid when compared to %HRmax (r_{xy} = 0.66) and % VO_{2max} (r_{xy} = 0.70). The results of this study are consistent with previous findings using the Borg 6-20 scale (4,19,21). Additionally, Foster et al. (2001) examined the validity of the Borg CR-10 scale in two forms of exercise compared with HR (15). In this study, subjects completed steady state and interval cycle exercise as well as basketball practice. The results of this study indicate a strong correlation between RPE and summated HR zone methods of deriving a training impulse score (TRIMP). However, in all modes of training, the RPE method created substantially higher TRIMP. This suggests that these methods are not interchangeable because of the difference in scale; however either method can be used consistently to monitor training given their strong correlations with each other. Lastly, Borreson et al. (2008) validated the use of the session RPE scale against two forms of HR based training scores (8). The results of that study indicated a strong relationship between SRPE and TRIMP (r=0.76) as well as a strong relationship (r=0.84) between SRPE and the Summated Heart Rate Zones method for calculating TRIMP as described by Edwards (1993). Taken together, these studies clearly describe the reliability and validity of RPE methods for monitoring training loads (13).

Objective load monitoring includes many commonly used methods for tracking training such as HR measures, GPS metrics, and effort counts (ex: pitches thrown, number of jumps etc.). Resistance training volume is an estimate of work accomplished (16,17,28). Although simple methods for tracking volume resulting from resistance training have been used in the past, such as counting total repetitions, these methods do not provide accurate estimates of work (16,17,28). Currently, the most commonly used form of objective load monitoring for resistance training is volume load (VL) tracking (17). For further understanding of resistance training workloads, the load used in training must be considered. VL is calculated by multiplying the number of sets by the number of repetitions by the weight lifted (16,17). VL monitoring provides a means by which coaches and sport scientists can better understand stressors resulting from resistance training and the expected outcomes of training.

Mechanical work is defined as force x displacement. If a better estimate of mechanical work is desired, then attention should be given to the displacement of an exercise (28). Exercise displacements may differ for each phase of a training cycle. As a result, the load lifted may also vary greatly based on the displacement. For example, early in a training cycle, full displacement back squats may be employed to develop work capacity and basic strength. During a realization phase, partial displacement ¼ squats may be employed as a means of developing specific strength. Therefore, the work accomplished can vary greatly between the two exercises.

Hornsby et al. (2018) investigated the effect of calculating VL with or without displacement (17). Training workloads were analyzed from 8 highly trained weightlifters over the course of five months. The program followed a block periodization design with four distinct training blocks. When investigating the relationships between VL and VLd, strong, statistically significant correlations were found for all training blocks, days, and weeks of the program. However, when analyzing the percent changes in workload between periods, VL and VLd were statistically different for four of the seven periods analyzed. These findings support the use displacement as it gives practitioners additional insight when analyzing mechanical work and may better help explain the stress induced from training. Previous studies have also employed the use of VLd as a means of monitoring resistance training workloads as they relate to performance outcomes (5,6,9,18,28).

Both subjective and objective forms of monitoring have their own merits. For example, subjective measures (such as RPE) are often free or inexpensive, easy to implement and simple to understand. Possibly the biggest benefit of subjective monitoring is the fact that it may provide unique insight into an individual's response to a stimulus (2,30). It is well known that individual responses to a stimulus may vary greatly based on training history, age, and genetic factors (1,25)**.** Meanwhile, objective monitoring such as VL has merit in that it is has strong validity and reliability and can be used when making training decisions with high precision (16). Another classification of the two previous examples of RPE and VL could be measures of internal training load and external training loads, respectively. However, in order to have a holistic approach to monitoring, it may be advisable to combine subjective and objective, internal and external load measures. Verkhoshansky (2000) advocates for the combination of subjective and objective monitoring of RT stating, “numerical computations as the sole descriptor of loading often overlooks the fact that apparently objective measures do not take into account athlete’s subjective perception of the intensity and overall effects of the loading.” (30). Verkhoshansky (2000) terms this approach ‘cybernetic periodization’ (30). However, similar recommendations exist outside of RT. For example, Aoki et al. (2017) recommend the use of both internal (RPE) and external load (accelerometry) monitoring when implementing a tactical periodization plan for team sports and noted that internal load was more sensitive to intensity changes whereas external load was more sensitive to volume changes (2). Lastly, Lambert et al. (2010) advocate for the creation of sport specific consensus positions on best practice monitoring (20). This is because sports differ in their needs and ease of implementing each monitoring tool. For example, cycling is best suited for precise external training measurements as well as internal physiological loads. In this context, one may apply the use of a mobile ergometer, HR monitor and RPE to gain a holistic understanding of the training loads of cyclists. Regardless of the methods chosen, coaches and sport scientists should carefully and consistently monitor progress over time to best understand the adaptations imposed by training. The purpose of this study is to investigate the relationship between subjective and objective measures of resistance training load as well as the effect strength may have on those relationships. A secondary purpose is to compare calculations of VL with and without displacement.

METHODS

Experimental Approach to the Problem

A block periodization design was used for the resistance training program as it has been commonly used in research (22,23,28,29). All subjects completed 11 weeks of RT. All training loads were tracked throughout the entirety of the training program and exercise displacements were measured for all subjects with every exercise used. Lastly, subjects rated each training session after its completion according to the Foster session RPE scale.

Subjects

Based on power analysis for a moderate effect size, it was determined that a sample size of 12 was needed (Gpower vers. 3.0.10). Fifteen healthy males of various training status volunteered for this study (Age=24+±3.3yrs, BM=89.1±16.4kg, Strength to BM ratio=1.46±0.35). Subjects of various training status were included to provide a wholistic understanding of the relationships between monitoring as well as provide insight as to the influence of strength levels on these relationships. The study was approved by the university Institutional Review Board (IRB) and all subjects were informed of the potential benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

PROCEDURES

Training Program

All subjects completed the same non-failure strength training program and testing scheme. The training program followed a single factor/target block periodization model and was programmed with an emphasis on strength and power development.

The subjects completed three resistance sessions per week (Monday, Wednesday and Friday) and two sprint sessions per week (Tuesday and Thursday). The sprint warm-up and program was designed to simulate a sport practice environment.

The training program contained three sequential blocks (strength-endurance, maximal strength, and power) including a functional overreach and taper. Additionally, each microcycle contained heavy and light days to both manage fatigue and ensure a spectrum of power outputs. Lastly, all training loads were selected using relative intensities (% set-rep best). The training program and exercise selections are shown in table 3.1 and 3.2, respectively.

Table 2.1**:** Resistance training program, * signifies down set at 50% of working weight after major exercise (squats, bench, MTP)

Training Block	Week	Sets x Reps	Day 1 and 2	Day 3
Strength-Endurance	1	3x10	80%	70%
	2	3x10	85%	75%
	3	3x10	90%	80%
Max Strength	4	3x5 (1x5)*	85%	70%
	5	3x5 (1x5)*	87.5%	72.5%

	6	3x5 (1x5)*	92.5%	75%
	7	3x5 (1x5)*	80%	65%
Overreach	8	5x5	85%	75%
Speed-Strength	9	3x3 (1x5)*	87.5%	67.5%
	10	3x2 (1x5)*	85%	65%
	11	2x2 (1x5)*	65% & 60%	---------

Table 2.2: Resistance Training Exercise Selection

*DB= dumbbell, CG= clean grip, MT*P*= mid-thigh pull, BB= barbell, Ext= extension, Wtd= weighted, SG= snatch grip, SLDL= stiff-legged deadlift, SA= single arm, CM= counter-movement

Training Block	Day 1	Day 2	Day 3
Strength-Endurance	Back Squat, Overhead Press, Bench Press, DB Tricep Ext.	CG MTP (3x5), CG SLDL, BB Bent Over Row, DB Bent Lateral Raise	Back Squat, Overhead Press, Bench Press, DB Tricep Ext.
Max Strength	Back Squat, Push Press, Incline Bench Press, Wtd. Dips	CG MTP, Clean Pull, SG SLDL, Pull Ups	Back Squat, Push Press, Incline Bench Press, Wtd. Dips
Overreach	Back Squat, Push Press, DB Step Ups, Bench Press	CG CM Shrug, Clean Pull, CG	Back Squat, Push Press, DB Step Ups, Bench Press

		SLDL, SA DB Bent Over Row	
Speed-Strength	Back Squat + Rocket Jumps, Push Press, Bench press + Med Ball Chest Pass	CG MTP, CG CM Shrug, Vertical Med Ball Toss	Back Squat + Rocket Jumps, Push Press, Bench press + Med Ball Chest Pass

Training loads were recorded for all subjects for each prescribed exercise. VL was calculated as sets x reps x load (kg). Exercise displacements were calculated for the concentric portion of each exercise throughout the training program. Displacements were measured manually to the nearest millimeter and VLd was calculated as sets x reps x load (kg) x displacement (m).

Table 3: Calculations for workload in resistance training

Volume Load	VL = sets x reps x load (kg)
Volume Load Displacement	Work = sets x reps x load (kg) x vertical displacement (m)

Session Ratings of Perceived Exertion

Subjects reported RPEs for each training session and the duration of each session (min) was recorded. RPEs were rated according to the Foster Session RPE scale and subjects were provided with a chart containing descriptor words for each numerical rating (14). All RPEs were collected 30 minutes following completion of training. SRPE was calculated as the product of the RPE (0-10) and the duration of the session (min).

Statistics

Correlational statistics were calculated using Pearson's *r* to assess the relationships between training status and performance. All statistics were calculated using JASP (JASP vers. 0.11.1.0).

Table 4. Correlation thresholds

Pearson's *r*	
0.0-0.1	Trivial
0.1-0.3	Small
0.3-0.5	Moderate
0.5-0.7	Large
0.7-0.9	Very Large
1.0	Perfect

To examine the relationship between subjective and objective measures of training load, repeated measures mixed linear modeling was employed with SRPE as the dependent variable (DV) and VLd, Strength levels and the interaction of VLd and Strength as independent variables (IV). After checking for assumptions, it was determined that our IVs violated multicollinearity meaning that two or more of our independent variables were correlated. Therefore, all IVs were centered around the mean. Because of our small sample size, bootstrapping was used (n=2000). Conditional and Marginal R^2 were calculated to determine the proportion of variance accounted for by our model. Additionally, 95% confidence intervals for each IV were presented to determine the greatest contribution to the model. To investigate whether the relationships between the DV and IVS changed over the course of the study, three individual general linear models were created. Weeks 1, 7, and 11 were selected as they represent initial, mid-study and final strength levels. Multiple R^2 was calculated for each of the three time points to determine the overall model fit. Additionally, relative importance of each IV was calculated for each time point to investigate the relative proportions of shared variance accounted for by each IV. Alpha level was set as $p \leq 0.05$. All modeling was performed in R version 3.6.1.

RESULTS

Relationship between Subjective and Objective training loads

When investigating the effect of VLd, strength and the interaction of strength and VLD on the reported SRPE, the model accounted for 63.3% of the shared variance (conditional) between subjective and objective training loads. After accounting for the random effects of subject, our model accounted for 46.0% of the shared variance (marginal). When investigating each IV separately, only VLd was significantly correlated with SRPE ($p<0.001$) with non-significant relationships between SRPE and Strength ($p=0.34$) and SRPE and the interaction of strength and VLd ($p=0.93$). Further, the coefficients show a positive relationship between VLd and SRPE and the interaction of strength and VLd, and a negative relationship between SRPE and strength. Full results including 95% confidence intervals are shown in Table 5.3

Table 5. Relationships between subjective and objective training loads

	p-value	Coefficient	95% CI Lower Limit	95% CI Upper Limit
VLd	<0.001	0.105	0.087	0.124
Strength	0.34	-0.021	-681.0	-0.026
VLd*Strength	0.93	0.002	-0.051	0.056

To investigate whether or not the effect of VLd, strength and the interaction of strength and VLd on SRPE changed over the course of the study, individual models were run for weeks 1, 7 and 11. The results show that the proportion of variance shared between each IV and SRPE did change over the course of the study. At the start of the study, VLd accounted for 8% of the variance in SPRE. At the middle time point (week 7), VLd only accounted for 0.69% of the variance in SRPE. However, during the taper (week 11), change in VLd accounted for 13.8% of the variance in SRPE. A similar trend was seen for the effect of strength on the variance in SPRE ranging from 0.817%, 0.027% and 3.6% for weeks 1, 7 and 11, respectively. Lastly, the interaction of VLD and accounted for 6%, 2.57% and 0.009% of the variance in SRPE for weeks 1, 7, and 11, respectively.

Table 6. Proportions of variance explained by each IV at three time points

	Week 1	Week 7	Week 11
VLD	0.08	.00699	0.138
Strength	0.00817	0.000268	0.03677
VLD*Strength	0.06	0.0257	0.0000899
Model multiple R2	0.015	0.03	0.175

Comparison of Volume Load and Volume load Displacement

Similar to previous findings, VL and VLd showed statistically significant correlations for all three blocks of training. However, when examining the percent change in VL and VLd, there were statistically significant differences between the two methods of measurement for blocks 1 and 2, blocks 1 and 3 but not between blocks 2 and 3. The findings are presented in Table 7.1 and 7.2 below.

Table 7.1: Relationship between VL and VLd

	Pearson's *r*	*p*-value
Block 1	0.944	<0.001
Block 2	0.917	<0.001
Block 3	0.803	<0.001

Table 7.2 Percent change in VL and VLd

	% Change VL	% Change VLd	p-value
Block 1 - 2	31.1%	48.3%	<0.001
Block 2 - 3	-41.7%	-41.3%	0.559
Block 1 - 3	-23.5%	-13.0%	0.012

DISCUSSION

The results of this study also indicate that there was a statistically significant relationship between subjective (SPRE) and objective (VLd) measures of training load. However, no substantial relationships were found between strength and SRPE or the interaction of strength/VLd and SRPE. While the proportion of SRPE variance accounted for by strength did increase from weeks 1 to 7 to 11, the final shared variance was only 3.67%.

The results of our study are supported by those of Silva et al. (2014) who found that RPE was statistically related to VL (27). In their study, subjects completed three sets to failure at either 50% or 70% 1RM and reported RPEs for each set. Their findings showed that there was no statistical difference in RPE between conditions. The authors suggested that RPE may be affected by the total amount of work accomplished rather than the intensity chosen.

Although our subjects used different absolute loads, relative intensities were the same, therefore, the primary difference between subjects was likely due to the total load lifted in a training session and its' effect on SRPE agreeing with Silva et al. (2014) (27). Because RPE is a subjective indication of internal load or stress, as workload increases so would the production of metabolic byproducts, energy depletion etc. which contributes to one's perception of stress (14).

Eston et al. (2012) reviewed the literature surrounding RPE as a psychophysiological indicator (14). Their findings suggest that RPE rises as a linear function with exercise duration until exhaustion. The authors suggest that RPE can serve as a self-regulatory mechanism which is sensitive to changes in internal physiological stress. Additionally, the authors suggest that RPE may be a useful tool to predict time to exhaustion while training. Researchers have previously supported the use of RPE in monitoring resistance training (12,27). However, a combined approach of both subjective and objective forms of monitoring such as VLd may provide additional benefit (11).

The results of our current study support those previously reported by Hornsby et al. (2018) (17). When comparing VL and VLd for each block, both methods were highly correlated. However, VLd differed statistically from VL when comparing block to block percent change. When employing programming which varies exercise selection, VLd is able to account for any change in exercise displacements and mechanical work (16, 17). If practitioners wish to adequately monitor changes in RT workloads, including displacement in their calculations warrants consideration. Several methods exist to accurately measure exercise displacement. Possibly the most simple and cost-effective method can be performed with a tape measure, as carried out in this study. Practitioners would simply measure the distance from the end of the bar to the floor at the initiation of the concentric portion as well as the end of the concentric portion. However, other methods have been proposed which may be more accurate. For example, Hornsby et al., (2018) used a v-scope optical measurement system to determine exercise displacement (17). Additionally, Wagle et al. (2018) measured exercise displacement using linear position transducers (31). While these methods may offer some advantages over manually measured methods, they also require more time, equipment, technical proficiency with the devices used and funding.

One possible limitation to the current study is our limited sample size. Additionally, the current study only investigated the relationships between subjective and objective training loads in resistance training and not other forms of sporting exercise. Future studies should investigate other forms of training.

PRACTICAL APPLICATIONS

Monitoring training load is essential to understanding and modifying training. The results of this study and others suggest that volume load with displacement may provide additional sensitivity when monitoring resistance training compared to volume load without displacement measures. Additionally, there was a meaningful relationship between subjective measures of perceived exertion and objective measures of volume load regardless of strength levels. To enhance the sensitivity of the fatigue management process, coaches and practitioners should consider designing a more robust monitoring program which contains both subjective and objective measures of training load.

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Chapter 5. Summary and Future Directions

The results of this dissertation demonstrate the effectiveness of block periodization resistance training models in improving both strength and power for all subjects. This finding is supported by the results of several reviews of the literature (Cunanan et al., 2018; DeWeese et al., 2015 a, 2015b; Fleck et al., 1999; Issurin, V., 2008; Issurin, V., 2014; Rhea et al., 2003; Peterson et al., 2004; Williams et al., 2017). Additionally, this study noted significant correlations between subjects' training status and rates of improvement for absolute strength, relative strength, unweighted and weighted vertical jumps. Specifically, a strong negative correlation was found between initial maximal strength and the percent improvement in maximal strength and vertical jump performance over 11 weeks.

One interesting finding of this dissertation was the differences in rates of improvement between groups. For example, the moderate and weak groups had their greatest improvement in both SJ and CMJ immediately following the first block of training. The strong group, however, showed their greatest improvement in the later stages of the program following the taper. This finding has been supported by those of (Ahtiainen et al., 2003; Mangine et al., 2018; Rhea et al., 2003) who noted differences in adaptations between subjects of varying training status.

Taken together, these results support the notion that training status may have an important effect on the response to a given stimulus. Although all subjects underwent identical training and testing protocols, their adaptations were measurably different and may be attributed to initial strength levels. Consistent monitoring of responses to training may prove useful in understanding individual adaptations to a given stimulus.

The second portion of this dissertation found significant correlations between VL and VLd for all blocks. However, VLd proved to be more sensitive to percent changes in training load between blocks due to changes in exercise selections and displacements. Significant correlations were only found between SRPE and VLd in this study with no significant effect of strength or the interaction of strength and VLd on SRPE. This indicates that as external work is accomplished, an individual's perception of exertion also increases. When investigating if this relationship improved over time, slight improvements in the proportion of variance in SRPE accounted for were found. However, these relationships were still poor accounting for only 17.5% of the variance after 11 weeks of training. These results support the use of displacement in calculations of workloads. Additionally, it is clear there is a relationship between SRPE and VLd which does not depend upon a subject's training level.

While the benefits of resistance training and periodized programs in particular are clear, many practitioners may work with clients and athletes of various fitness levels. Future studies should continue to expand upon these findings by working with different populations such as competitive athletes. Additionally, this dissertation was only concerned with adaptations to resistance training and not other forms of training. It is very likely that training status may also affect adaptations to other stimuli such as sprinting or sport specific training. Lastly, many new forms of objective and subjective monitoring are becoming widely available. These tools include objective forms such as wearable technology (global positioning systems, heart rate trackers, accelerometers etc.), barbell velocity devices and video analysis as well as subjective tools such as wellness questionnaires. Future studies should expand upon these findings by investigating the relationship between different objective and subjective monitoring tools. Additionally, these relationships should be investigated when used in other settings such as sport practice.

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