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Determining the Maximal Recoverable Volume of Resistance Training in Tonnage during a Strength Phase

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Determining the Maximal Recoverable Volume of Resistance Training in Tonnage during a Strength Phase

By

Patrick C. Castelli

In Partial Completion
Of the Requirements of the Degree
Masters of Science

Kathleen Kitto, Dean of the Graduate School

ADVISORY COMMITTEE

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MASTER’S THESIS

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Date: July 21, 2017
Determining the Maximal Recoverable Volume of Resistance Training in Tonnage during a Strength Phase

A Thesis
Presented to
The Faculty of
Western Washington University

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Of the Requirements for the Degree
Masters of Science

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July 2017
Abstract

Maximal recoverable volume (MRV) has been described as the maximal volume load an individual can accumulate, recover from, and respond to positively. There has been little research conducted in attempts to quantify this load.

The purpose of this study was to determine the relative MRV of resistance training in total volume load, and employ a multiple regression model consisting of initial volume load (VL_initial) and maximum relative strength (RS) (1RM back squat divided by body weight) to define a method to accurately predict this upper tolerable limit.

VL_initial for each exercise was calculated as the product of the number of sets performed, the load on the bar, and three repetitions. The subjects performed sets of three repetitions at 80% 1RM until the average barbell velocity decreased by 7% compared to the fastest velocity collect during that session. While volume load was increased by 17% each week after determining the VL_initial, subjects performed weekly performance tests until overreaching was seen, marked as a 10% decrease in any two or three performance tests. These performance tests included vertical jump height, single rep peak velocity and average velocity of two sets of three repetitions of back squats at 80% of 1RM

Multiple regression analyses were conducted, with both VL_initial and RS as predictors for total volume load (VL_total), and volume load of the final week (VL_final). This model revealed that VL_initial and RS significantly predicted both VL_total ($F[2,11] = 52.88, p < 0.001, R^2$-adj. = 0.89), and VL_final ($F[2,11] = 59.54, p <0.001, R^2$-adj. = 0.90).
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Chapter I

The Problem and Its Scope

Introduction

When designing any resistance training program, general principles of progression, overload, and specificity are a crucial foundation. Any resistance training program designed for an individual should accomplish specific goals and be built with the specific purpose to achieve them with intensities that overload and provide a stimulus for the individual to cause super-compensation and adaptations. The intensities and demands placed on the individual should increase progressively as the individual becomes adapted to the stimuli (Baechle & Earle, 2015). However, progression is not always maintained in a steady fashion with constant improvements over time (Baechle & Earle, 2015). It is important that the resistance training programs take some form of periodization, and not just a random assortment of load and volume, in order to prevent stagnation. Periodization itself is the structuring and organization of planned variations in specificity, intensity, and volume over phases or “periods” of training (Baechle & Earle, 2015). The avoidance of stagnation and plateaus in positive adaptations is a primary purpose of applying periodization, and thus increases the effectiveness of the time spent training (Baechle & Earle, 2015; Fleck, 1999; Hoffman, 2002; Kraemer, 2007).

Many studies have demonstrated that implementing a program strategy, such as periodized training programs, are more effective than non-periodized training programs (Baker, 1994; Kraemer, 1997; Rhea, Ball, Phillips, & Burkett, 2002a; Stone, et al., 2000), however, there are multiple methods of implementing periodization. Two of the most
common periodization models include linear and daily undulating (non-linear) periodization (Hoffman, 2002). When comparing the effectiveness of these two popular styles of periodization, studies have shown improvements in performance, strength, endurance, and power after examination with some studies showing undulating periodization to be superior (Baker, 1994; Kraemer, 1997; Rhea, et al., 2002a) and some showing no significant difference between the two (Buford, 2007; Hoffman, 2009; Peterson, 2008; Rhea, 2003). It would appear that nonlinear periodization is just as, if not more, effective than the more traditional linear periodization models.

When evaluating the effectiveness of training programs, a focus on avoiding stagnation and plateaus is often as important as avoiding overtraining. On one side of the spectrum, a lack of novel stimuli will not yield any progress in the adaptations derived from training, while an over application of training stress, such as too many novel stimuli or too much volume and/or intensity, may lead to negative effects, such as overtraining. One method of monitoring the amount of stimulus from resistance training is to track the total volume load, expressed as tonnage defined as summation of sets times repetitions multiplied by the load for that set. When programmed with proper application, overreaching protocols can have positive effects to break performance plateaus, however it could also be detrimental to the individual’s performance if used incorrectly, which outlines the difference between functional and non-functional overreaching. Overreaching itself is often described as a physiological state in which an individual ceases to make performance increases, or even experiences a temporary performance decrease when training stimuli is too high for a prolonged period of time with volumes and intensities that are unmanageable at that given time (Armstrong, 2002; Baechle & Earle, 2015; Borselen, 1992; Bushie, 2007).
When non-functional overreaching is left unmanaged for some time without a decrease in training intensity, training volume, or both, subjects may transition into a state of chronic fatigue known as overtraining syndrome (Hoffman, 2002). Overtraining syndrome is a severe state that typically follows prolonged non-functional overreaching, in which, some cases have taken several weeks or months of recovery before the individual returns to his/her previous state (Armstrong, 2002; Borselen, 1992; Bushie, 2007; Fry, 1997; Lemyre, 2007; Stone, 1991; Urhausen, 2002). Symptoms of overtraining include increases in resting heart rate, muscle soreness and pain, with decreases in sport performance, maximal power output, muscular strength, appetite, as well as other symptoms such as weight loss, irregular sleep patterns, decreased willingness to train, irritability, and frequent illness (Armstrong, 2002; Borselen, 1992; Fry, 1997; Stone, 1991; Urhausen, 2002).

The interest in resistance training among the recreational fitness enthusiast such as amateur bodybuilding, strongman, powerlifting and weightlifting, and the use of resistance training by a majority of athletes around the world, is growing. It would be useful to develop methods of managing the training programs to avoid non-functional overreaching and effectively administer planned methods of functional overreaching when appropriate, such as in the case of a higher-level athlete who is in need of specialized stimuli for adaptation. How to go about applying a functional overreaching dose is an on-going discussion among strength coaches, personal trainers, and those in charge of program design. It has been suggested that the use of monitoring the total volume load in tonnage of a program may decrease the risk of overtraining, so long as an upper tolerable limit has been identified, and increase the effectiveness and performance of the training cycle (Peterson, 2008).
While many strength coaches utilize methods of monitoring training programming details as well as the total volume load their athletes experience, respond positively to, and recover from, there is currently no way of determining exactly how much volume is normally beneficial. This study considered the idea of defining an athlete’s relative maximum recoverable volume of resistance training in tonnage per week, as well as the cumulative tonnage over the course of the training program until subjects began to demonstrate symptoms of functional overreaching. This was done with the use of weekly readiness monitoring via performance measures to determine the total volume load achievable before non-functional overreaching was demonstrated. Then a multiple regression model was used in order to predict this volume beforehand to yield more effective training programs and effective applications of functional overreaching.

**Purpose of the Study**

The purpose of this study was to determine the relative maximum recoverable volume of resistance training in total volume load. This study sought to employ a multiple regression model consisting of beginning work capacity and relative strength (1RM back squat divided by body weight) to define a method to accurately estimate this upper tolerable limit through regression equations to develop a novel approach to designing resistance training programs. More specifically, to develop a system of easily collected outcome measures to determine the appropriate maximal level of volume for a particular training block. These measures included body weight, RPE, vertical jump height, and bar velocity during a back squat. These measures have been used to determine athlete’s readiness to train and respond positively to the training stimulus, or if adjustments need to be made to decrease the stimulus of the upcoming training session. The effectiveness of the training
program was expressed via comparison of the pre- and post-training program strength measurements and work capacity prior to non-functional overreaching.

**Statement of the Hypothesis**

A correlation that which will be tested across the subjects between their maximal recoverable volume in training, and at least one other dependent variable, such as an athlete’s one relative strength (RS), and starting work capacity (VL_initial). These two variables, RS and VL_initial, will significantly predict total volume load, and final week volume load.

**Significance**

This study is important to any athlete or any fitness enthusiast who partakes in resistance training. It may reveal a method of easily determining the amount of volume an individual can respond positively to, in their training program, without causing non-functional overreaching or overtraining. The findings of this study could produce a viable and easy to use method of incorporating more individualization to any training program, by simply adjusting the maximum value of volume the athlete can work up to in any given training phase. The possibility of going into a state of non-functional overreaching or overtraining syndrome could also be reduced, saving weeks or even months of recovery and increasing the overall effectiveness of any training program (Fry, 1997).

**Limitations of the Study**
1. The subjects in this study included Western Washington University students and only represent a portion of the population between the ages of 18 and 25 years old. The results of this study do not hold the same validity in other populations outside of this age group.

2. All subjects were required to have a minimum of one year of experience with resistance training, and familiarity with the back squat, bench press, and deadlift, with proper form being assessed during the first week of testing. However, subjects who were more experienced with strength training may have a reduced training affect from the intervention, where the less experienced subjects may show greater increases in test results simply from technical improvements in the tested movements. It is also likely that subjects with a longer training history will have developed a higher relative maximal recoverable volume and higher maximum strength levels than those subjects with just one year of resistance training experience.

3. Lack of adherence to the program could potentially impact the results. Subjects need to complete all of the training set forth in the program provided by the researcher. For those subjects who missed more than three training sessions, they were allowed to continue with the training program, however, their data was omitted from the study.

4. Lack of honest self-reported evaluations on the RPE scale after each training session could affect the data analyzed from these additional readiness indicators. This was addressed by explaining to the subjects that there is no wrong answer or penalty regardless of their answers, and that their RPE should be reported as honestly as possible.

5. Motivation within subjects could differ greatly in their intentions to train with serious intensity and focus, especially during the pre- and post-intervention testing, or in their
efforts with regards to jump performance testing and sleep duration. This could not only effect the testing measurements, but also the adaptations made throughout the training intervention. A strategy implemented by the researcher included notifying the subjects of their progress made from week to week.

6. Strength training was restricted in the training groups to only the training program provided for this experiment, although other physical activities including cardiovascular exercise were not restricted. This may impact the results if some subjects were performing a greater volume of physical activity than others.

Definition of Terms

*Basic Strength Training Phase:* A resistance training period consisting of high loads and low volume. This phase is done with the purpose of increasing strength (Baechle & Earle, 2015).

*Central Fatigue:* The fatigue hypothesis stating that muscles are believed to be capable of greater output, but the central nervous system blocks continued extraordinary effort, whether chronically or acutely. This may be done to prevent injury (Taylor, Allen, Butler, & Gandevia, 2000).

*Daily Undulating Periodization:* The strategy of training periodization that involves large daily fluctuations in the load, volume assignment, and set by rep organization, of exercises from one training session to the next (Baechle & Earle, 2015).

*Hypertrophy/Endurance Training Phase:* A resistance training period consisting of very low to moderate loads and moderately high to very high volume. The goals of this phase include
increasing lean body mass, increasing muscular and metabolic endurance, and developing a training base for more intense training in later training phases (Baechle & Earle, 2015).

_Hypertrophy:_ An increase in the size of cells or organs, especially muscle fibers (Kraemer, 2007).

*Linear Periodization:* The strategy of purposely varying specificity, intensity, and volume of a training program in a linear fashion with intensity increasing over time (Baechle & Earle, 2015).

*Macrocycle:* Training period that typically constitutes an entire training year or complete training program (Baechle & Earle, 2015).

*Microcycle:* Training period that typically lasts between one and two weeks, depending on the program (Baechle & Earle, 2015).

*Mesocycle:* Training period that typically lasts several weeks to several months depending on the specific training focus of each mesocycle (Baechle & Earle, 2015).

_Peripheral Fatigue:* When a muscle’s homeostasis has been disturbed, through tissue damage, decreased pH, or some other factor, to the point that the muscle is incapable of responding to loading stimuli effectively as it does when rested (MacIntosh & Rassier, 2002).

_Strength/Power Training Phase:* A resistance training period consisting of high loads, or low to moderate loads and high velocities, paired with low volume, usually utilizing some combination of strength exercises and power/explosive exercises. This phase is utilized to increase an athlete’s expression of power (Baechle & Earle, 2015).
Standing Vertical Jump: A test used to measure lower body power output. This test is performed beginning with an individual standing on a force plate holding a PVC pipe on their back to control for arm-swing. The participant is allowed to perform a countermovement composed of bending the lower extremities before jumping in an attempt to jump as high as possible. Data ground reaction forces from the force plate will be used to determine jump height. (Kraemer, 2007).

Tonnage: The total mass lifted in a given training session, week, or block of training defined by the summation of the number of sets multiplied by the number of repetitions multiplied by the load of the bar in pounds, in each respective set, to calculate the total mass lifted.

Weekly Undulating Periodization: The strategy of training periodization that involves variations in the load, volume assignment, and set by rep organization of exercises from one week to the next (Buford, 2007).
Chapter II
Review of Literature

Introduction

Block periodized training is characterized by various blocks or cycles of training known as “mesocycles.” Each mesocycle focuses on a specific training goal and can last anywhere from a couple weeks to months at a time. By manipulating the volume, intensity, rest periods, and exercise selection within sessions during a mesocycle, it is possible to bring about specific performance improvements. Various types of foci during mesocycles include a hypertrophy/endurance, strength, power, and peaking (Baechle & Earle, 2015; Kraemer, 2007). Some of the most common forms of periodization used in resistance training program implementation today include linear and nonlinear (undulating) periodization (Hoffman, 2002).

Undulating periodization is the strategy of organizing training that involves large daily or weekly fluctuations in the load, volume assignment, and set by rep organization of exercises from one training session to the next. Linear periodization is the strategy of purposely varying specificity, intensity, and volume of a training program in a linear fashion with intensity increasing over time (Baechle & Earle, 2015). In determining the effectiveness of these two styles of periodization, studies have compared the two against one another to determine which yields the best results in multiple performance measures including strength, endurance, and power (Baker, 1994; Buford, 2007; Hoffman, et al., 2009; Peterson, 2008; Rhea, 2003; Rhea, et al., 2002a; Stone, et al., 2000).
The two sections of this review focus on Linear vs. Undulating (Nonlinear) Periodization, and The Effects on Daily Readiness, with the latter being organized into subsections of factors that will be considered in the monitoring of the individual’s recovery from the previous training load and readiness including Rating of Perceived Exertion, and Performance Testing, followed in closing with a Summary section.

The first section reviews the literature related to the effectiveness and performance improvements caused by the two common methods of periodization. Linear periodization is often considered to be the most “traditional” method among the studies, while undulating periodization is then compared in order to explore its relative effects (Baker, 1994; Buford, 2007; Hoffman, Wendell, Cooper, & Kang, 2003; Peterson, 2008; Rhea, 2003; Rhea, et al., 2002a).

There is an examination of various measurements that have been used in previous studies to identify readiness to train and respond positively to training while managing the fatigue caused by the training stimuli. These measurements are further discussed in subsections including RPE and Performance Testing (Alcaraz, 2008; Dressendorfer, 1985; Foster, 1998; Fry, 1994a; Fry, 1994b; Fry, 2000; Hoffman, 2000; Jeukendrup, 1998; Jeukendrup, 1992; Snyder, et al., 1993; Warren, 1992).

**Linear vs Undulating (Nonlinear) Periodization**

Arguably two of the most common forms of periodization used today in resistance training are linear periodization and non-linear or undulating periodization (Hoffman, 2002). Linear periodization is the more traditional periodization model developed by the former Soviet Union and has been used extensively by athletes and recreationally trained
individuals. This model is characterized by various blocks or cycles of training known as “mesocycles.” Each mesocycle focuses on a specific training goal and can last anywhere from a couple weeks to months at a time. By manipulating the volume, intensity, rest periods, and exercises of a mesocycle, it is possible to bring about specific performance improvements in the human body. These mesocycles typically include a hypertrophy/endurance phase, strength phase, power phase, and peaking phase (Baechle & Earle, 2015; Kraemer, 2007). A typical way in which the traditional linear periodization model is implemented is to perform the hypertrophy/endurance phase for a number of weeks, followed by the strength phase, then the power phase, and so on. The thinking behind this progression was that the athlete aimed to increase muscle mass (hypertrophy), increase strength, convert the expression of that strength into powerful movements, then to achieve peak condition for competition. A commonly cited downside for this type of periodization is that it is not practical for people who either compete often, or who are in a competitive season (Baechle & Earle, 2015; Kraemer, 2007; Peterson, 2008).

Rhea et al. (2002) compared linear and daily undulating periodization effects on strength gains using 20 male subjects recruited from college weight training classes. All subjects had a minimum of 2 years of weight training experience. Subjects were required to resistance train three times a week for 12 weeks using the leg press and bench press. Abdominal crunches, bicep curls, and lat pull-downs were also performed, but any other resistance training was prohibited. The daily undulating periodization group cycled from set schemes of 3 sets of 8 repetitions to 3 sets of 6 repetitions to 3 sets of 4 repetitions on each consecutive workout. The linear periodization model used these same set and repetition schemes, but stayed consistent with one scheme for 4 weeks at a time. This allowed the two
training groups to have equated intensity and volume over the 12-week study. Testing of the two groups was performed pre-training, 6 weeks into the intervention, and at week 12. Testing consisted of 1-repetition max on the bench press and a Cybex incline leg press machine, body composition assessment by way of air plythesmyography (Bod Pod), and chest and thigh circumference measurements. Both the LP and DUP groups increased their strength significantly in the bench press by 14.4% and 28.8%, respectively; as well as by 25.7% and 55.8% in the leg press, respectively. The DUP group experienced significantly greater strength gains in terms of percentage than the LP group from weeks 1 to 6 and weeks 6 to 12. No significant differences were observed with body composition. The subjects in the DUP group did begin to report extended muscle soreness and fatigue in weeks 10-12. This may have been an indication of overreaching, even though strength tests did not appear to be considerably affected. This study showed that a 12-week DUP program was more effective at increasing strength than a LP program using a college-aged male population. However, the DUP program may have begun to show signs of overtraining late in the study.

A study by Buford et al. (2007) compared the effects of 9 weeks of resistance training using either a linear periodization model (LP), weekly undulating periodization model (WUP), or daily undulating periodization (DUP) model. The subjects consisted of 20 men and 10 women from college weight training classes with previous weight training experience, but not within the past 2 months. All three groups trained 3 times a week using a full body free-weight routine consisting of exercises that included bench press, leg press, seated row, lat pulls, upright rows, lunges, leg extension, leg curls, standing calf raises, preacher curls, triceps extension, incline sit ups, back extension, and knee raises. Volume and intensity were equated over the 9-week period between the two conditions. Subjects
were tested pre- mid- and post-training by way of skinfold body fat measurements, thigh and chest circumference, and 1RM testing on both the bench press and leg press exercise. RPE was also recorded using the Borg CR-10 scale to monitor subjects’ perceived difficulty of each exercise set and exercise session. The LP, DUP, and WUP groups all experienced significant increases over the 9 weeks of 24.2%, 17.5%, and 24.5% in the bench press and 85.3%, 79%, and 99.7%, in the leg press, respectively (Buford et al. 2007). Additionally, thigh and chest circumferences also showed a significant time effect in the LP, DUP, and WUP groups. Chest circumferences increased from 91.94±7.28 cm to 93.78±7.61 cm in the LP group, 96.75±9.91 cm to 96.95±9.74 cm in the DUP group, and 94.89±9.49 to 95.72±8.19 cm in the WUP group. Thigh circumferences increased from 49.44±4.65 cm to 52.72±5.40 cm in the LP group, 51.90±4.45 cm to 53.80±5.37 cm in the DUP group, and 50.22±5.31 cm to 53.89±3.79 cm in the WUP group. The average RPE rating of an exercise session decreased in the linear periodization and weekly periodization groups over the 9 weeks by 5.4% and 6.1%, but increased by 3.5% in the daily undulating periodization group. This finding indicates that undulating periodization may increase individuals’ session RPE, although this was not found in another study comparing the same three periodization models (Rossi, 2007). Their study demonstrated that significant strength and size increases can be observed over the course of 9 weeks in both male and female college students using linear, daily undulating, and weekly undulating periodization programs.

Hoffman et al. (2009) compared the effectiveness of two different periodization models as well as a non-periodized model of resistance training on 51 NCAA Division III football players. The training groups consisted of a non-periodized program (NP), periodized linear program (PL), and a planned nonlinear periodized (PNL) program. All
three groups performed resistance training for 12 weeks, 4 days a week, with days one and three focusing on the chest, shoulders, and triceps, and days two and four focusing on the legs, back, and biceps. The NP group used the same training “intensity” throughout the study. The same set and rep schemes, as well as rest periods between sets, were used. The PL group performed a 4-week hypertrophy phase, 6-week strength phase, and a 4-week power phase. The PNL group changes its volume and intensity from workout to workout, alternating between a power workout and a hypertrophy workout. This is referred to in some other literature as daily undulating periodization (Baker, 1994; Rhea, 2003; Rhea, et al., 2002a).

Testing was performed pre- mid- and post testing (Hoffman, 2009). The testing consisted of 1RM bench press and back squat, vertical jump using a countermovement and a seated medicine ball throw. All three groups experienced significant improvements in 1RM in both the back squat and bench press from pre- to post-testing. The NP, PL, and PNL groups increased their 1RM bench from 125.9±12.2 kg to 136.8±9.5 kg, 118.5±18.3 kg to 127.7±20.7 kg, and 124.0±25.0 kg to 134.3±27.1 kg, respectively. The same groups increased their 1RM squat from 161.8±16.6 kg to 194.8±24.5 kg, 149.5±25.0 kg to 180.5±17.6 kg, and 164.2±23.2 kg to 182.5±25.6 kg, respectively. The majority of these improvements occurred between pre- and mid-testing. Vertical jump height also increased significantly in all three groups, but only from pre- to mid-testing. From pre- to mid-testing, values in the NP, PL, and PNL groups from 61.0±8.0 cm to 63.5±7.4 cm, 63.6±7.1 cm to 65.1±7.8 cm, and 59.1±11.2 cm to 61.0±10.8 cm, respectively. From mid-testing to post-testing, the vertical jump heights for the three groups either stayed the same or decreased non-significantly. The medicine ball toss increased significantly from pre- to post- for the
PL group from 537±49 cm to 570±45 cm. For the NP and PNL groups, the medicine ball toss increased nonsignificantly from 566±53 cm to 577±45 cm and 556±73 cm to 576±53 cm, respectively. All three groups appeared to show similar strength improvements after 12 weeks of training. The results of this study demonstrated that all three periodization models were effective at increasing strength and jumping ability from week one to six. After week six, there appeared to be very little improvement, possibly due to the high training level of these athletes. A population with as much training experience as these athletes may show initial improvements due to off-season detraining and then require a longer amount of time to improve their already substantial strength and power levels.

According to the results of these studies, whether implementing a linear or non-linear periodization strategy, the results appear to be comparable. In some studies, non-linear periodization yielded desired improvements either equal to or greater than linear periodization models. For the sake of this study, the importance of equating total volume load suggests that the subjects should follow a linear increase in relative tonnage each week. So long as the weekly total volume load is increasing linearly across all subjects, the within-week periodization can follow an undulating style.

**Daily Readiness to Train Measurements**

As weekly total volume increases within a training program, daily readiness markers and recovery will be affected with the accumulation of fatigue. This section of the literature review focuses on the variables that reflects the subjects’ changes in readiness to train and their recovery following previous training stimuli.
**Rating of Perceived Exertion (RPE).** One monitoring tool used to evaluate athlete readiness is the Borg Rating of Perceived Exertion used to aid in the prescription of exercise intensity (Baechle & Earle, 2015; Borg, 1998; Hoffman, 2002). The two Borg RPE scales most commonly used in exercise management and evaluation are referred to as the “Borg CR-10 scale” and the 6-20 scale which is referred to as the “Borg RPE” scale (Borg, 1998). The CR-10 scale indicates the perceived exertion where 0 is rated as “no exertion at all” and 10 being “extremely hard”, where the corresponding values on the Borg RPE scale are 6 and 20, respectively (Hoffman, 2002). Correlation has been made between the 6-20 scale and heart rate as it is reflection of central fatigue, and has been most commonly used in prescribing cardiovascular exercise intensities (Taylor, et al., 2000). In activities which induce more peripheral fatigue, such as resistance training, the Borg CR-10 scale has been used more commonly (Day et al., 2004; MacIntosh & Rassier, 2002). Self-reported RPE has been analyzed in detail in many resistance training studies in attempts to quantify each set within a training session (Gearhart et al., 2002; Lagally et al., 2004) and of the overall training session (Day et al., 2004; Lagally et al., 2007; Sweet et al., 2004).

In an analysis of the reliability of the 0-10 Borg RPE scale, Day et al. (2004) attempted to quantify the intensity of an entire resistance training session, and each resistance training set within each session. The study sample was comprised of 21 male and female subjects in their early 20’s with a minimum of six months of resistance training experience. Each of the subjects participated in six separate resistance training sessions over the course of a week, with the sessions divided into two days of high intensity, two days of moderate intensity, and two days of low intensity training. At the end of each set, the subjects reported their RPE values and then once more at the end of the entire training
session each day. When comparing the given RPE values to the training sessions prescribed, the results suggested that the CR-10 is a reliable measure of a resistance training session’s intensity, and that monitoring the RPE of the entire training session is just as effective as reporting the RPE of each individual set.

Another study comprised of 20 male and female subjects in their 20’s was conducted using the 15-point 6-20 RPE scale by Gearhart, et al. (2002), with subjects who had at least three weeks of resistance training experience. The design of this study had all subjects complete both a high intensity and a low intensity training protocol, where RPE was reported after every repetition in the high intensity protocol and again after every third repetition in the low intensity protocol. In both high- and low-intensity training sessions, subjects performed seven exercises with reported results showing higher RPE values for the high intensity protocol and the low intensity protocol. This suggests that the 6-20 RPE scale is also effective at measuring perceived exertion of a resistance training session (Gearhart et al., 2002).

While there may be a personal bias when using self-reported RPE scales, studies have repeatedly shown that RPE may provide valuable, reliable data when considering the assessment of training session intensity. Whether using a 6-20 RPE scale for more aerobic based activities, or a Borg 0-10 RPE scale for resistance training, both are reliable, so long as the subject is honest in their self-reported evaluations (Day et al., 2004; Gearhart et al., 2002).
**Performance Testing.** A marked decrease in performance is often a primary indicator than an individual has reached a state of non-functional overreaching or overtraining and has led to the use of simple performance measures as a way to easily administer tests to practically measure when an individual may be overreaching or at risk of entering a state of overtraining (Halson, 2004; Hoffman, 2000). These performance tests have been researched for over two decades, with tests ranging from variable sprint lengths, one-repetition maximum strength tests, vertical jumps, dynamic movements, reaction time tests, and repetition until failure tests (Alcaraz et al., 2008; Fry et al., 1994a; Fry et al., 1994b; Fry et al., 2000; Hoffman et al., 2000; Warren et al., 1992). How well each test may carry over to a particular individual’s sport or fitness goals may vary, with some being better indicators than others in some instances. For the purpose of this review, focus was maintained more so on performance testing with regards to resistance training programs.

In a small research study of six men by Fry et al. (2000), an attempt was made to monitor the onset of overreaching during a resistance training program. The participating male subjects, ages 22 to 33 years old, took part in a three-week high intensity resistance training program, with performance tests prior to program’s initiation, and again at the end of each training week. A battery of performance tests was conducted, including lower body reaction time, vertical jump, two sprint variations, a lateral agility test, and a back squat one-repetition maximum test, which was selected because it was the primary exercise of the resistance training program.

By the end of the three-week training intervention, performance tests showed both increases and decreases, as well as stagnation and lack of change from week to week, with no consistency across subjects. Lower body reaction time did increase overall by the end of
the study, but without any statistical significance. Vertical jump showed no significant increases or decreases, however there was a recorded significant increase in non-counter-movement vertical jumps. Sprint tests showed significant increases in time for both 9.1-m and 36.6-m distances tested, with an average of 7.18% and 4.09% increase in sprint times for the respective distances. The mean 1RM back squat values showed significant increases between the pre-intervention test and following the completion of week one where training consisted of one day of three sets of 10 reps and another day of three sets of five repetitions, but did not show any significant change for the remainder of the three-week study where training consisted of much higher intensities performing two sets of one rep at 95% of 1RM. While not clearly indicating overtraining as defined by decrease in performance while some test measures improved, and some showed no change, it has been suggested that plateaus in performance could also reflect overreaching (Lehmann, 1993; Stone, 1991). This study was also limited by its short duration, and the increases in performance measures could be attributed to developing familiarity with the tests if they did not have a significant training history or exposure to the performance tests prior to this study.

Summary

When comparing the effectiveness of both training periodization modalities, studies have shown nonlinear undulating periodization to be just as effective, if not more effective than the more common method of linear periodization when evaluating the increases in strength and performance (Baker et al., 1994; Buford et al., 2007; Hoffman, et al., 2009; Rhea, et al., 2002a). It has been suggested that a main factor relating to the efficacy of undulating periodization is its ability to decrease the probability of stimulating individuals to the point of reaching a state of overtraining (Peterson, 2008). It has been well documented
that overreaching can indeed leave the individual to express decreases in performance contrary to the objective of training (Armstrong, 2002; Baechle & Earle, 2015; Borselen et al., 1992; Bushie et al., 2007; Urhausen et al., 2002). This dilemma could be avoided if there were a well-established set of tools that could detect and prevent unplanned overreaching and overtraining from occurring (Costa et al., 2005; Fry, & Kraemer, 1997; Fry et al., 1994; Meeusen et al., 2004; Moore et al., 2007; Snyder et al., 1993; Warren et al., 1992). However, the largest noticeable difference in training programs is the daily volume load. While a linear program may steadily increase total volume load each with similar relative loads and intensities between training sessions that week, an undulating program cannot equate for volume and intensity each day within a week simply due to the definition of the program having a level of stimulus that changes from day to day. However, volume load can certainly be equated between block and non-linear programs over the course of a week in a pre-planned undulated program. It would be important to consider the total volume over the course of the week, and what is the upper tolerable limit that can be reached before non-functional overreaching or overtraining sets in.

The review of the literature has shown that some easily administered tests to evaluate and identify overreaching and overtraining include training session ratings of perceived exertion (Foster et al., 1998; Hoffman et al., 2000; Snyder et al., 1993; Urhausen et al., 2002), and simple performance tests (Alcaraz et al., 2008; Fry et al., 1994a; Fry et al., 1994b; Fry et al., 2000; Hoffman et al., 2000; Warren et al., 1992).

Measures that have shown promise in identifying overreached or soon to be considered overreached individuals have included training session rating of perceived exertion (Foster et al., 1998; Hoffman et al., 2000; Snyder, et al., 1993; Urhausen et al.,
2002), and simple performance tests (Alcaraz et al., 2008; Fry et al., 1994a; Fry et al., 1994b; Fry et al., 2000; Hoffman et al., 2000; Warren et al., 1992). Research indicates that the usefulness of training readiness measures hinges on their ability to distinguish when to decrease training volumes and intensities to optimize the training stimulus, resulting in continuously improved performance and avoidance of non-functional overreaching, and overtraining syndrome.

While many of these measures have been used in an attempt to identify either aerobic or resistance training athletes who may be overreaching, they have not been combined in an attempt to find an athlete-specific maximal recoverable volume of resistance training. The goal of the present study is to provide tools to define this athlete-specific limit and correlate it to other standard physical fitness measures, such as a 1 repetition maximum back squat and initial work capacity.
Chapter III
Methods and Procedures

Introduction

The purpose of this study was to develop a novel approach to determining weekly volume loads with the use of daily readiness markers as reference points within the program to determine the maximal recoverable volume. More specifically, to predict the upper tolerable limit of a subject’s recoverable resistance training volume and through the use of a regression equation, find a correlation to a previously measured point of reference. This was achieved by having subjects record the RPE following each of their training sessions, and conducted performance tests, which included bar speed during a back squat measured using a Tendo Sports Machine Tendo Unit (Trénčin, Slovak Republic), and a vertical jump on an AMTI Force Plate (Advanced Mechanical Technologies, Inc.; Watertown, MA, USA), at various points throughout the study. These measurements were all used to identify signs of overreaching as weekly changes in volume load and volume load accumulation over the course of the training program were recorded. These performance tests were conducted at the beginning of the first training session each week, as well as before and after the training program intervention. In addition to the performance tests, subjects’ 1RM back squat, bench press, deadlift and overhead press were also conducted pre- and post-training to measure any changes in maximal strength.

Description of Study Sample
The sample consisted of 14 male students from Western Washington University who volunteered to participate in the study (\(\overline{X} \pm SD;\) age = 21.29 ± 1.53 years; body weight = 77.77 ± 8.05 kg; height = 1.77 ± 0.08 m; training age = 4.09 ± 1.90 years). Each subject was familiar with the back squat, bench press, and deadlift exercises with a minimum one year of resistance training. Subjects had no previous history of orthopedic injuries that would cause exercise selection limitations. Participants were instructed to not perform any other resistance training in addition to this program and to abstain from cardiovascular activity prior to weight training sessions and testing sessions. Cardiovascular activity as a warm up prior to resistance training sessions was included in the training program prescription.

**Design of the Study**

A multiple participant multiple regression study was conducted to determine an equation to find a relationship between a maximal recoverable volume and the previous physical markers and performance measures, such as the relative strength (RS) defined as the 1 repetition maximum (1RM) back squat divided by body weight, and starting work capacity (VL_initial) as predictors of maximal recoverable volume. Two 1-repetition maximum tests were completed, one before the training intervention began, and another optional 1RM test after the completion of the training program, following an unloading period to allow subjects to recover following the training program. The unloading period consisted of two sets of three repetitions at 60% of 1RM on back squat, bench press, deadlift, and overhead press. The performance tests of vertical jump and bar velocity during a back squat at 80% of 1RM were performed during the testing day, as well as at the beginning of each training week as a method of evaluating readiness as well as recording self-reported RPE values at the end of each training session.
Data Collection Procedures

**Instrumentation.** Maximum strength was measured using 1-repetition maximum lifts for the back squat, bench press, deadlift and overhead press in the Applied Biomechanics Lab on the campus of Western Washington University inside the squat rack, on the available bench and on the deadlift platform. The vertical jump was conducted on an AMTI Force Plate (Advanced Mechanical Technologies, Inc.; Watertown, MA, USA). These tests required the use of a stop watch to control rest periods, and a standard 20-kilogram Olympic barbell, locking barbell collars, and standard Olympic free-weight plates. Barbell velocity was measured using a Tendo Sports Machine Tendo Unit (Trencin, Slovak Republic) which had been previously validated in a study by Garnacho-Castaño et al. (2015).

**Measurement techniques and procedures.** The researcher began with an introduction of the study and its time commitment to the subjects. Before any testing or training was conducted, the participants were informed of the testing procedures and provided with an informed consent document to sign (Appendix B), approved by the Western Washington University Internal Review Board, who approved the study. The participants were informed that they would be participating in a study including four days per week of resistance training, for up to 10 weeks. The researcher made it clear that if subjects missed more than three training sessions as prescribed, it would result in them being dropped from the study. They would be welcome to complete the training program; however, their data could no longer be included in the study. It was explained to the subjects
that the first four training sessions would be monitored and assisted by the researcher. This was done to ensure that the correct technique was used according to NSCA guidelines and that the participants were following the correct acute training variables (volume, intensity, and rest periods) (Baechle & Earle, 2015). Depth of the squat was standardized and explained to the participants as the crease of the hip being lower than the top of the knee, or when the femur was parallel to the ground. If the subject typically squatted to any depth lower than the described minimum, they were encouraged not to change their practiced squatting pattern, and that level of depth should not change for the duration of the study. If participants wanted help or assistance with additional workouts, the researcher made himself available to do so. After the completion of each workout, the participants filled in the session rating of perceived exertion (RPE) on a provided table. The correct use of this scale was explained at the initial training session (Borg, 1998).

Subjects began testing in the Applied Biomechanics Laboratory of Western Washington University to perform the vertical jump under the supervision of the lead researcher, following an appropriate dynamic warm-up provided by the researcher. The vertical jump was conducted by having the subject stand on the AMTI Force Plate, with a PVC pipe in their hands across their shoulders like they would in a back squat. When ready, they would then use a countermovement before jumping as high as possible. The PVC pipe was used to control for arm-swing in a countermovement jump, which had been previously validated as a method for testing vertical jump height without the need for familiarization as a reliable method for comparing force variables (Moir et al., 2005). The ground reaction forces, time from beginning of the jump to toe-off, and mass of the subject were used to calculate vertical height displacement via the impulse-momentum relationship. The vertical
jump test was performed three times with an upper limit of 4-minutes rest between trials, with a minimum rest of one minute between attempts. The best of the three trials was recorded for each subject. This testing process occurred once before the training program began, and was repeated at the beginning of each training week for the duration of the training program.

One-repetition maximum (1RM) lifts using the back squat, bench press, and deadlift were performed by each participant at the beginning of the study. Subjects had the option to participate in re-testing their 1RM lifts following a mandatory week-long unloading period after training was completed if they were interested. This was performed in the Applied Biomechanics Laboratory or in the Wade King Student Recreation Center under the supervision of the lead researcher. The protocol for accomplishing this involved a light dynamic warm up followed by a light 10 repetition set on the exercise that was being tested. The load was then increased according to the NSCA guidelines for 1RM testing until a 1RM was attained (Baechle & Earle, 2015). These guidelines can be found in Appendix C.

These maximum strength performance tests were conducted a total of two times in the study. This included at the beginning of the study, and at the conclusion of the study.

**Training Program Description.** After initial testing, subjects were asked to perform three repetition squats at 80% of the established 1RM while monitoring the velocity of the movement for the concentric portion of each repetition via the Tendo Unit connected to the barbell, and repeated sets until the average velocity of a three-rep set decreased by 7% compared to the best average set of that session, at which point the session was completed. On consecutive days, this was repeated with the bench press, deadlift, and overhead press,
with a rest day between the bench press and deadlift testing days. The total volume load, expressed as sets, multiplied by repetitions, multiplied by weight or load in kilograms, was used to establish a starting training volume, and divided by 1000 to be expressed in terms of metric tons, or tonnage. Volume load was increased each week by 17% until the cessation of the program, with the exercise load starting at 67.5% of 1RM, and increasing each week by 2.5-5% of 1RM. Sets and reps for each following week were prescribed accordingly to ensure a 17% increase in total volume load from the previous week, depending on the initial work capacity of each subject identified in the first week of training. An example can be found in table 1 of Appendix D. Subjects trained 4 days per week with a minimum of 24 hours between sessions, with sessions taking place on Monday, Tuesday, Thursday, and Friday. Training sessions consisted of one of the main lifts, such as the back squat, bench press, or deadlift, followed by one multi-joint accessory movement depending on the main lift, and one single- joint or abdominal auxiliary exercise. A sample of the training week program layout can be found in Table 2 of Appendix E.

The beginning of each microcycle began with a back squat training session, which consisted of working up to 80% of the subject’s 1RM that was performed for 3 repetitions while peak single-repetition bar velocity and average bar velocity of all six repetitions were measured using the Tendo Unit potentiometer, before continuing with the prescribed training plan for that microcycle. These peak and average bar velocities were compared each week to the original peak single-rep velocity and average velocity found during the initial testing phase as a readiness indicator and performance measure. Vertical jump testing was also recorded at this time, prior to squatting each week after the dynamic warm-up was performed.
The total numbers of repetitions, % of 1RM, sets, total number of sets increased for all subjects from the previous week. Subjects were instructed to keep a workout log for each training session to ensure that they were aware of the weights they used for every set on each exercise. A copy of this log was given to each participant and it was explained how to use the log effectively. This ensured that the subjects knew exactly what weights they were prescribed, but also helped the researcher in compiling the subject’s RPE following each session.

Subjects were given the training log to fill in their rating of perceived exertion (RPE) following every training session using the Borg CR-10 scale, and at the end of the week the researched calculated an average RPE of the four training sessions. This was done in an attempt to monitor any changes in perceived effort while using the same percent 1RM for the week. A copy of this training log can be found in Appendix F.

The training program was discontinued when subjects reached a state of overreaching, as defined by a 10% decrease from the previous best performance in any two of the three performance tests, consisting of the peak and average bar velocities during a back squat three repetition set at 80% of 1RM, and vertical jump height. Another variable used to track changes in training status readiness included the subject’s RPE scores. Changes in this variable were used as an additional indicator of overreaching in support of the performance measures if a significant change between the initial and final training weekly average RPE scores was found. Subjects had the option of discontinuing the program once they reached a determined state of overreaching, or continuing to follow a resistance training program under the direction of the lead researcher, that would include a week-long unloading phase once they reached a state of overreaching, followed by a week
of 1RM testing. Resistance training programming under the direction of the research would cease after the 10-week mark, if the subject elected to continue training after overreaching.

Data Analysis

The pre-training data were compared with post-training data to see if there was any correlation among all the subjects’ total volume achieved (VL_total) by the end of the training program and their final week volume achieved (VL_final), and their pre-training performances measures, such as their relative strength (RS) (1RM squat divided by body weight), and first week total volume achieved (VL_initial). Researchers conducted a multiple regression analysis (significance level was set at $\alpha = 0.05$) to determine if there was any predictive relationship between the total volume load, and their previous performance markers, and to develop an equation to predict tonnage lifted in the final week and total tonnage over the course of the study that can be achieved prior to overreaching from pre-training volume load achieved in their first week of testing. Subjects’ 1RM strength on the back squat, bench press, deadlift and overhead press were also measured to monitor any strength changes for those interested in retesting their 1RM tests following an unloading period to allow for proper recovery after the subjects reached their maximum recoverable volume, however these changes were 1RM strength were not a part of the regression analysis. An independent t-test was used to compare the relative strength of the whole group and the relative strength of the subjects who elected to participate in the optional retesting of 1RM strength to ensure they represented to difference from the whole group, with a significance level set at $\alpha = 0.05$. Paired samples t-test was used to compare the change in RPE following the first week of training and the final week of training, with a significance level set at $\alpha = 0.05$. All of the statistics were calculated by using Microsoft Excel 2010.
(Microsoft Corp., Redmond, Washington, USA) and SPSS version 21 (IBM Corp., Armonk, New York, USA).
Chapter IV

Results and Discussion

Introduction

The purpose of this study was to use a multiple regression analysis to determine a prediction equation using relative strength (RS) and initial volume load (VL_initial) to predict maximum recoverable volume as the highest single-week volume (VL_final), and the total volume load accumulated over the course of the training program (VL_total). Initial volume load was determined by having the subjects perform sets of three repetitions at 80% of 1RM for the back squat, bench press, deadlift, and overhead press on separate days, until the average set bar velocity decreased 7% from their best. The summation of the total sets achieved for each exercise × three repetitions per set × the load on the bar in pounds for each exercise was the initial volume load in pounds. Relative strength was determined by dividing the subject’s previously established 1RM back squat by their body weight. Each week, the subject’s volume load increased by 17% until they were deemed as functionally-overreached, which was determined when two of three weekly performance tests decreased by 10% of their best testing results, at which point they were moved to an unloading phase ending their participation in the study. The performance tests performed at the beginning of each week included a maximum vertical jump height of three attempts calculated using a force plate, single-rep peak barbell velocity during two sets of three reps at 80% of 1RM in the back squat, and the average barbell velocity of all six reps tested. The volume load of the last week of training prior to being deemed as functionally-overreached represented the subject’s VL_final, and the summation of volume load of every week of training represented
the subject’s VL_total. For each regression analysis, the significance level was set at $\alpha = 0.05$. Paired samples t-test was used to compare the change in RPE following the first week of training and the final week of training, with a significance level set at $\alpha = 0.05$. Complete statistical analysis tables can be viewed in Appendix H.

**Subject Characteristics**

Fourteen male subjects aged 19 to 24 (21.29 ± 1.53) years volunteered to participate in this study. All subjects were healthy students of Western Washington University who were actively participating in resistance training, and had at least one-year experience with the back squat, bench press, deadlift, and overhead press. There was a wide range of relative strength, as measured by 1RM back squat (1RM BS) divided by body weight (1.73 ± 0.37). Further baseline measures of the group are provided in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Subject Characteristics.</th>
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<tr>
<td></td>
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<tr>
<td>Mean</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (m)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
</tr>
<tr>
<td>1RM BS (kg)</td>
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</table>
Relative Strength (1RM BS/BW)* (%) 

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<tr>
<td>1.73</td>
<td>0.37</td>
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</tbody>
</table>

*1RM BS: 1 repetition maximum back squat, BW: body weight

Results

Upon completion of the training programs, the average VL_total achieved was 167,020 ± 56,333.16 lbs. accumulated over the course of 5.14 ± 0.99 weeks. The average VL_final achieved was 45,509.5 ± 13,812.07 lbs. in their final week of training.

Multiple regression analysis. Two forced entry multiple regression analyses were conducted, with both VL_initial and RS as predictors for VL_total, and VL_final. This model revealed that VL_initial and RS significantly predicted both VL_total (F[2,11] = 52.88, p < 0.001, R2_adj. = 0.89), and VL_final (F[2,11] = 59.54, p < 0.001, R2_adj. = 0.90). However, T-tests revealed that only VL_initial contributed to the prediction, as RS was not a significant predictor of either VL_final (t(13) = 0.773, p = 0.456) or VL_total (t(13) = 0.152, p = 0.882). Therefore, a linear regression was conducted using only VL_initial to predict VL_final and VL_total. The results revealed that VL_initial alone significantly predicted both VL_total (F[1,12] = 115.11, p < 0.001, R2_adj. = 0.898) and VL_final (F[1,12] = 122.60, p < 0.001, R2_adj. = 0.903). The prediction equations below are a result of the regression models calculated.

\[ VL_{total} (lb) = -57614.62 + 2705.23 \times RS + 7.95 \times VL_{initial} (lb) \]
\[ VL_{\text{final}} \ (lb) = -11745.80 + 3187.56 \times RS + 1.87 \times VL_{\text{initial}} \ (lb) \]

\[ VL_{\text{total}} \ (lb) = -55448.94 + 8.04 \times VL_{\text{initial}} \ (lb) \]

\[ VL_{\text{final}} \ (lb) = -9194.04 + 1.98 \times VL_{\text{initial}} \ (lb) \]

The above equations were calculated in total pounds lifted. In order to express the predicted values for VL_total and VL_final in metric tons lifted, the value would be divided by 2,205 lbs.

Table 2 Average weekly Volume Load, Rating of Perceived Exertion (RPEave), Peak Velocity (Vpeak), Average Velocity (Vave), and Jump Height.

<table>
<thead>
<tr>
<th>Week</th>
<th>Volume Load (lb)</th>
<th>RPEave</th>
<th>Vpeak (m/s)</th>
<th>Vave (m/s)</th>
<th>Jump Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN  SD</td>
<td>MEAN</td>
<td>MEAN SD</td>
<td>MEAN SD</td>
<td>MEAN SD</td>
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<tr>
<td>1</td>
<td>27666 6667</td>
<td></td>
<td>0.639 0.058</td>
<td>0.610 0.054</td>
<td>39.98 6.55</td>
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<tr>
<td>2</td>
<td>30942 7661</td>
<td>5.13 0.76</td>
<td>0.659 0.053</td>
<td>0.614 0.056</td>
<td>38.67 5.59</td>
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<tr>
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<td>0.621 0.076</td>
<td>39.91 4.98</td>
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<td>0.669 0.074</td>
<td>0.621 0.076</td>
<td>40.52 5.34</td>
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<tr>
<td>7</td>
<td></td>
<td>0.584 0.061</td>
<td>0.552 0.067</td>
<td>40.22 6.59</td>
<td></td>
</tr>
</tbody>
</table>
Table 3 Displaying the average of all weekly performance tests, their percent change from the previous week, average weekly RPE and the absolute weekly change, as the relative volume load in tons increased by 17% each week.

<table>
<thead>
<tr>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>W6</th>
<th>W7</th>
</tr>
</thead>
<tbody>
<tr>
<td>ave % change in JH</td>
<td>-2.48%</td>
<td>3.61%</td>
<td>-2.22%</td>
<td>4.64%</td>
<td>-1.02%</td>
<td>-4.74%</td>
</tr>
<tr>
<td>Jump Height (cm)</td>
<td>39.98</td>
<td>38.67</td>
<td>39.91</td>
<td>39.07</td>
<td>39.77</td>
<td>40.59</td>
</tr>
<tr>
<td>ave % change in Peak V</td>
<td>2.96%</td>
<td>0.51%</td>
<td>1.31%</td>
<td>-0.25%</td>
<td>-2.83%</td>
<td>-19.11%</td>
</tr>
<tr>
<td>Peak V (m/s)</td>
<td>0.64</td>
<td>0.66</td>
<td>0.67</td>
<td>0.68</td>
<td>0.68</td>
<td>0.67</td>
</tr>
<tr>
<td>ave % change in aveV</td>
<td>0.60%</td>
<td>0.60%</td>
<td>2.44%</td>
<td>-2.18%</td>
<td>-4.25%</td>
<td>-19.17%</td>
</tr>
<tr>
<td>Ave V (m/s)</td>
<td>0.61</td>
<td>0.62</td>
<td>0.62</td>
<td>0.64</td>
<td>0.63</td>
<td>0.62</td>
</tr>
<tr>
<td>Ave RPE</td>
<td>5.13</td>
<td>5.72</td>
<td>6.52</td>
<td>6.94</td>
<td>7.79</td>
<td></td>
</tr>
<tr>
<td>Relative Tons</td>
<td>1</td>
<td>1.17</td>
<td>1.3689</td>
<td>1.601613</td>
<td>1.873887</td>
<td>2.192448</td>
</tr>
</tbody>
</table>

Table 4. Comparing RS between all subjects and those who elected to re-test their 1RM

*t*-Test: Two-Sample Assuming Unequal Variances

<table>
<thead>
<tr>
<th></th>
<th>1.956521739</th>
<th>1.956521739</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.716315711</td>
<td>1.805100243</td>
</tr>
<tr>
<td>Variance</td>
<td>0.142127659</td>
<td>0.136279481</td>
</tr>
<tr>
<td>Observations</td>
<td>13</td>
<td>7</td>
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<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>-0.509202539</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.309571509</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.770933396</td>
<td></td>
</tr>
</tbody>
</table>
Discussion

The two multiple regressions showed that RS and VL_initial were correlated to maximal recoverable volume as a significant prediction equation. This is in agreement with the experimental hypothesis that at least one marker, either a subject’s relative strength or initial volume load, will significantly predict maximal recoverable volume. However, a T-test analysis revealed that while the prediction equation itself was significant, RS was not a significant contributor to the prediction of either VL_final ($t(13) = 0.773, p = 0.456$) or VL_total ($t(13) = 0.152, p = 0.882$). Therefore, a linear regression using only VL_initial to predict VL_final and VL_total was conducted.

RS was expected to be a significant predictor variable, as it would take into account a subject’s experience and familiarity of the movement. Training age was thought to be too subjective. RS posed as an option to objectively consider how trained a subject was in the back squat, where subjects with more experience and training in the back squat may have a higher RS value than those less experienced.

One reason RS may not have been a significant predictor variable could be that all subjects’ starting work capacity was determined by testing at 80% of their relative 1RM back squat, and the volume load increased by 17% each week. Since the weights prescribed and the volume load each week were all based on relative percentages, the most variable number across the subjects was their starting work capacity.
The changes in the subject’s self-reported RPE increased linearly while the volume load increased each week. This was plotted to demonstrate the average change in RPE as the volume load increased by 17% each week. The average percent change in performance tests was plotted on a secondary axis to show the changes in performance from the previous week of training (Figure 1).

![Changes in Performance Tests & RPE as Weekly Volume Load Increases](image)

**Figure 1.** A graphical representation of the changes in RPE and percent changes of the performance tests over each week, as the relative tonnage achieved in week one was increased each week by 17%.

Performance tests include average percent change in single-repetition peak velocity (Vpeak), average percent change in six repetition average velocity (Vave), and average percent change in jump height.

The average percent change in the back squat average and peak barbell velocities showed a positive change over the first four weeks. Although RPE and total volume was
increasing, a positive adaptation was occurring (represented as any point value above the 0% line, which would equate to no change occurring). Each of the first four weeks, the subjects improved their barbell velocity, and did not show signs of fatigue having a negative effect on their performances until weeks five, six, and seven. No subject made it past the testing at the beginning of week seven, which is why no subject had any RPE values to report at the end of week seven.

The performance testing in the vertical jump did not follow the same trends as the barbell velocities. This may be due in part to the lack of practice among subjects in the vertical jump, which consisted of five total jumps each week including the two practice jumps. The back squat technique was practiced with considerably more repetitions each week, and increased in the number to total repetitions and load as the training program progressed.

In a study attempting to elicit overtraining responses through high-volume back squatting by Fry et al. (1994b), a battery of performance tests was administered each week including sprints, jumps, and 1RM strength tests. While the occurrence of overtraining was not reported during this four-week training prescription, performance test scores decreased after the first two weeks. While the findings of overreaching and overtraining differed in comparison to this study due to the parameters defining these training states, it is possible that the duration of the program by Fry et al. was simply not long enough, or the total volume load was not high enough.

Another study by Fry et al. (2000) sought to determine what types of performance would be affected when subjects were exposed to three weeks of high relative intensity
(percent of one repetition maximum) parallel barbell squats to the point of overtraining. Sprint times increased, and peak isokinetic squat force decreased after three weeks of high-intensity training. While the current study did not analyze sprint performances or squat force, it did consider performance variables such as squat velocity and ground reaction forces to calculate jump heights, which decreased following four weeks of training. Similar to Fry et al., the results of this study found after being exposed to more stimuli over a similar number of weeks, velocities and force outputs decreased.

While Urhausen et al. (2002) found only minor changes in RPE in athletes deemed overtrained through actual exercise intensity expressed in watts or measured by blood lactate concentration measures, statistical analysis of this study revealed a significant increase in RPE throughout the training duration until subjects were classified as functionally overreached. A study by Foster (1998) used a modified RPE where session RPE was multiplied by session duration. They found training load was successfully related to performance. This is similar to the findings of the current study. The largest decreases in performance testing followed the week of training with the largest change in RPE, as seen in the Table 3.

The data does suggest that functional overreaching was achieved, as demonstrated by a temporary decrease in performance. Subjects who chose to participate in a post-testing of their 1RMs were encouraged to do so under the supervision of the researcher following a week-long unloading period. The subjects who elected to retest their 1RMs strength showed an average increase of 6.15% in their 1RMs. Pre- and post-testing results of 1RM strength tests can be found in Appendix G. An independent t-test was conducted to compare the relative strength of the whole group against the group of subjects who elected to retest their
1RM, and no significant difference was found ($p > 0.05$), with the average RS of the whole group being 1.72 with a variance of 0.14, and a higher average RS of 1.81 in the retest group with a variance of 0.14.

Given that the design of the training program was focused as a strength block, this increase in 1RM strength not only helps to validate the efficacy of the training program, but also that the accumulated fatigue was indeed functional overreaching, as the end goal of the training program was to increase maximal strength while determining the maximum recoverable volume. The subjects in this study not only recovered quickly following a single week of unloading, but also responded positively to the preceding training program after a brief exposure to high stimuli. Overtraining syndrome, on the other hand, has been described as non-functional, often taking several weeks to recover before returning to a previous state of performance (Armstrong, 2002; Borselen, 1992; Bushie, 2007; Fry, 1997; Lemyre, 2007; Stone, 1991). The findings of this study not only imply that the volume load achieved resulted in functional overreaching in the subjects, but also shows that the subjects were indeed able to recover from the maximum volume load accumulated within a single week of unloading.

**Limitations**

The subjects in this study were all male students of Western Washington University between the ages of 19 and 24 years old. Any findings of this study cannot be assumed to apply to females, or other males outside of this age group. While all subjects were required to have a minimum of one year of experience with resistance training and familiarity in the barbell back squat, bench press, deadlift, and overhead press, there was variety in training
age ranging from one to six years of experience, and relative strength ratio of 1RM back squat to body weight ranging from 1.21 to 2.33. Although this range in strength and experience did not show to have an effect on RS as a predictor variable, it does lend the successful application of the prediction equations found to a larger population. It could, however, have played a role in the subjects’ initial volume load testing results as the more experienced lifters may have achieved a larger starting volume load due to technical proficiency and exposure to higher volumes.

One concern of this study was a possible lack of adherence to the training program, which could potentially impact the results. Subjects did not skip training sessions as originally hypothesized, but some expressed interest in wanting to accumulate more volume than prescribed early in the training program.

During any of the performance tests, and the initial week of volume load testing, subjects were always coached and encouraged to move the barbell with maximum effort pertaining to their back squat velocities, and to jump as high as they could during their vertical jump tests. The differing levels of motivation within the subjects and their intentions to test and to train with the highest of intensity and focus is a limitation of this study. These differences in effort and motivation could influence the testing measurements and the adaptations made through the training program.

One potential limitation regarding the performance testing was the use of high-velocity movements as tested measurements during a strength phase training block. With chronic strength training, the pennation angle of the muscle fiber changes to a more oblique
angle which are not advantageous for the production of speed or high-velocities (Folland & Williams, 2007).
Chapter V
Summary and Conclusions

Summary

The purpose of this study was to determine a prediction equation to identify maximum recoverable volume (MRV) with simple performance tests that could be easily administered. To do so, MRV was defined as the total volume load in tons lifted in the course of a single week and an entire training block until functional overreaching was reached. This MRV was defined as a volume load that a subject could recover from quickly, and respond positively to following the training program.

The parameters for defining functional overreaching in this study included a 10% decrease in any two of three performance tests, with increases in one repetition maximum strength testing as an indicator of a positive response to the training following an appropriate recovery period of unloading for a single week. Total volume load was increased each week by 17% from the starting work capacity, which was set as the total volume load of successful three-repetition sets at 80% of 1RM until bar velocities dropped by 7% or more.

Two forced entry multiple regressions were conducted to predict the maximum recoverable volume in a single week, and the accumulation of volume in a training block using relative strength and initial volume load as predictors. Further analysis illustrated that relative strength was not a significant variable in the prediction equation, and that when considering a subject’s maximum recoverable volume, the most significant predictor
analyzed in this study was their starting work capacity. Those capable of a higher initial volume load are likely to have a higher MRV.

**Conclusion**

The experimental hypothesis was confirmed in that both maximum recoverable volume load in a single week and over the course of a training block can be determined through a prediction equation derived from a linear regression analysis using initial work capacity. These prediction equations are statistically significant and accounted for a large majority of variance among subjects. These prediction equations may be useful when strategically applying a period of functional overreaching to avoid performance stagnation or break plateaus, as well as avoiding any incidences of overtraining syndrome.

**Recommendations**

**Future research.** While this study was conducted during a maximal strength phase, to better understand maximum recoverable volume, future research should be conducted during other block phases of training. More research is required in this area when considering the population examined in this study, whether that includes research on female subjects, different age groups, and more homogenous relative strength levels and training experience.

One aspect that should be included in future research is considering subjects’ training history. What type of training block they had just completed may have a significant effect on their ability to handle higher volumes or higher intensities. This study did not control for pre-training history, and required a low level of training age as the minimum required for inclusion into this study.
If this same testing protocol is used again in future research, it should be stressed that subjects should be constantly reminded and encouraged to move the barbell as fast as possible during the concentric phase of the movements. Failure to do so can lead to inaccurate performance testing results and MRV data, whether from underestimated maximum velocities if the subject did not give maximal efforts from the beginning of the study, or if the subject is deemed overreached under false pretenses due to lack of effort or motivation during testing.

This study focused on the MRV using resistance training only, and future research should be done on volume loads and fatigue accumulation with regards to resistance training when paired with sport skills practice for this to carry over to athletic populations in sports other than powerlifting. Future research should also be done in this area with regards to the weightlifting movements; the snatch and the clean and jerk. Movements such as these depend more on technique and bar velocity for a successful lift than the exercises conducted in this study, as well as a much lesser component of eccentric loading.

**Practical applications.** The prediction equations derived from this study could be beneficial to those who need to apply a functional overreaching strategy in order to overcome plateaus or stagnation in their resistance training adaptations, so long as an appropriate recovery period is also considered. These equations can be used to predict MRV of a training block, following the protocol executed in this study. For any person who has similar characteristics to the population in this study, who is particularly prone to non-functional overreaching, high fatigue accumulation, or injuries resulting from overuse or overtraining, these prediction equations may help to appropriately administer training volume loads. The findings and protocols of this study can certainly be used to increase
performance in 1RM resistance training within a six-week strength training block, the application of the prediction equations can be a useful tool in fatigue management, and in designing future resistance training programs.
References


Appendix A

Human Subjects Review Form and Responses
1. What is your research question, or the specific hypothesis?

Specific Aim: Develop a system of easily collected outcome measures in determining the appropriate level of training volume through readiness-adjusted tonnage for each week.
2. What are the potential benefits of the proposed research to the field?

When designing any resistance training program, general principles of progression, overload, and specificity are a crucial foundation. Any resistance training program designed for an individual should accomplish specific goals and be built with the specific purpose to achieve them with intensities that overload and push the individual to super-compensate and adapt. The intensities and demands placed on the individual should increase progressively as the individual becomes adapted to the stimuli (Baechle & Earle, 2015). However, progression is not always maintained in a steady fashion with constant improvements over time (Baechle & Earle, 2015). It is important that the resistance training programs take some form of periodization, and not just a random assortment of load and volume, in order to prevent stagnation. Periodization itself is the structuring and organization of planned variations in specificity, intensity, and volume over phases or “periods” of training (Baechle & Earle, 2015). The avoidance of stagnation and plateaus in positive adaptations is a primary purpose of applying periodization, and thus increases the effectiveness of the time spent training (Baechle & Earle, 2015; Fleck, 1999; Hoffman, 2002; Kraemer, 2007).

When evaluating the effectiveness of training programs, a focus on avoiding stagnation and plateaus is often as important as avoiding overtraining. On one side of the spectrum, a lack of novel stimuli will not yield any progress in the adaptations derived from training, while an over application of training stress may lead to negative effects, such as overtraining. One method of monitoring the amount of stimulus from resistance training is to track the total volume load, expressed as tonnage defined as summation of sets times repetitions multiplied by the load for that set.

When programmed with proper application, overreaching protocols can have positive effects to break performance plateaus, however it could also be detrimental to the individual’s performance if used incorrectly, which outlines the difference between functional and non-functional overreaching. Overreaching itself is often described as a physiological state in which an individual ceases to make performance increases, or even experiences a temporary performance decrease when training stimuli is too high for a prolonged period of time with volumes and intensities that are unmanageable at that given time (Armstrong, 2002; Baechle & Earle, 2015; Borselen, 1992; Bushie, 2007).

When non-functional overreaching is left unmanaged for some time without a decrease in training intensity, training volume, or both, subjects may transition into a state of chronic fatigue known as overtraining syndrome (Hoffman, 2002). Overtraining syndrome is a more severe state than non-functional overreaching, in which, some cases have taken several weeks or months of recovery before the individual returns to his/her previous state (Armstrong, 2002; Borselen, 1992; Bushie, 2007; Fry, 1997; Lemyre, 2007; Stone, 1991; Urhausen, 2002). Symptoms of overtraining include increases in resting heart rate, muscle soreness and pain, with decreases in sport performance, maximal power output, muscular strength, appetite, as well as other symptoms such as weight loss, irregular sleep patterns, decreased willingness to train, irritability, and frequent illness (Armstrong, 2002; Borselen, 1992; Fry, 1997; Stone, 1991; Urhausen, 2002).

It would be useful to develop methods of managing the training programs to avoid overtraining syndrome and effectively administer planned methods of functional overreaching.
when appropriate, such as in the case of a higher-level athlete who is in need of specialized stimuli for adaptation. How to go about applying a functional overreaching dose is an ongoing discussion amongst strength coaches, personal trainers, and those in charge of program design. It has been suggested that the use of monitoring the total volume load in tonnage of a program may decrease the risk of overtraining, so long as an upper tolerable limit has been identified, and increase the effectiveness and performance of the training cycle (Peterson, 2008).

While many strength coaches utilize methods of monitoring training programming details as well as the total volume load their athletes experience, respond positively to, and recover from, there is currently no way of determining exactly how much volume is normally beneficial.

This study will be considers the idea of defining an athlete’s relative maximum recoverable volume of resistance training in tonnage per week, as well as the cumulative tonnage over the course of the training program until subjects begin to demonstrate symptoms of non-functional overreaching. This will be done with the use of weekly readiness monitoring via performance measures to determine the total volume load achievable before non-functional overreaching ensues, and using a multiple regression model in order to predict this volume beforehand to yield more effective training programs and effective applications of functional overreaching.

3. What are the potential benefits, if any, of the proposed research to the subjects?

Individual subjects in this study will gain direct benefits by identifying their own personal maximum recoverable volume, which can be used to better plan future training programs, as well as receive free periodized training programming for 10 weeks.

4a. Describe how you will identify the subject population, and how you will contact key individuals who will allow you access to that subject population or database.

Subjects will be recruited via flyers posted on the WWU campus.

4b. Describe how you will recruit a sample from your subject population, including possible use of compensation, and the number of subjects to be recruited.

Subjects will be included only if they have no history of orthopedic injury requiring surgery. Subjects will be excluded from the study if they have less than one year of resistance training. A total of 40 subjects will be recruited.

5. Briefly describe the research methodology. Attach copies of all test instruments/questionnaires that will be used. Note: All attachments must be in final form; drafts are unacceptable.

The purpose of this study was to develop a novel approach to determining weekly volume loads with the use of daily readiness markers as reference points within the program to determine the maximal recoverable volume. More specifically, to predict the upper tolerable limit of a subject’s recoverable resistance training volume and through the use of a regression equation, find a correlation to a previously measured point of reference. This was achieved by having subjects monitor their average resting heart rate using a wireless Polar H7 Bluetooth
heart rate monitor (Polar Electro; Kempele, Finland) each morning and recording the duration of sleep from the previous night. Subject’s also recorded the RPE following each of their training sessions, and conducted performance tests, which included bar speed during a back squat measured using a Tendo Sports Machine Tendo Unit (Trécin, Slovak Republic), and a vertical jump on an AMTI Force Plate (Advanced Mechanical Technologies, Inc.; Watertown, MA, USA), at various points throughout the study.

These measurements were all used to identify signs of overreaching as weekly changes in volume load and volume load accumulation over the course of the training program were recorded. These performance tests were conducted at the beginning of the first training session each week, as well as before and after the training program intervention. In addition to the performance tests, subjects’ 1RM back squat, bench press and deadlift were also conducted pre- and post-training to measure any strength and power changes.

A one-way repeated measures analysis of variance (ANOVA) will be conducted to determine the effect of the training program on maximal strength. A multiple participant multiple regression study was conducted to determine an equation to find a relationship between a maximal recoverable volume and some of the previous physical markers and performance measures, such as the 1 repetition maximum (1RM) tests using the back squat, bench press and deadlift exercises, and vertical jump. The criterion for statistical significance will be set at the p < .05 level.

6. Give specific examples (with literature citations) for the use of your test instruments/questionnaires, or similar ones, in previous similar studies in your field.

One method used to monitor whether athletes are in a state of overtraining is by tracking and evaluating their resting heart rate. A few variable techniques have been practiced, such as measuring their resting heart rate upon waking and comparing if it has increased above baseline, or by monitoring the resting heart rate based on a moving average and determining its upward or downward trends. In some studies, it has been suggested that the latter of the two resting heart rate monitoring techniques is a more sensitive measure of overtraining (Dressendorfer, 1985; Jeukendrup, 1998; Jeukendrup, 1992).

Another monitoring tool used to evaluate athlete readiness is the Borg Rating of Perceived Exertion used to aid in the prescription of exercise intensity (Baechle & Earle, 2015; Borg, 1998; Hoffman, 2002). The two Borg RPE scales most commonly used in exercise management and evaluation are referred to as the “Borg CR-10 scale” and the 6-20 scale which is referred to as the “Borg RPE” scale (Borg, 1998). The CR-10 scale indicates the perceived exertion where 0 is rated as “no exertion at all” and 10 being “extremely hard”, where the corresponding values on the Borg RPE scale are 6 and 20, respectively (Hoffman, 2002).

A marked decrease in performance is often a primary indicator than an individual has reached a state of overtraining and has led to the use of simple performance measures as a way to easily administer tests to practically measure when an individual may be overreaching or at risk of entering a state of overtraining (Halson, 2004; Hoffman, 2000). These performance tests have been researched for over a decade, with tests ranging from variable sprint lengths, one repetition maximum strength tests, vertical jumps, dynamic movements, reaction time
tests, and repetition until failure tests (Alcaraz, 2008; Fry, 1994a; Fry, 1994b; Fry, 2000; Hoffman, 2000; Warren, 1992).

7. Describe how your study design is appropriate to examine your question or specific hypothesis. Include a description of controls used, if any.

The literature suggests that performance tests can be used as readiness indicators when monitoring subject’s response to training stimuli, and manage training load according to performance tests to avoid non-functional overreaching and overtraining. However, in previous studies, no correlation has been identified between maximum recoverable volume and subject’s beginning work capacity, maximum relative strength, and training age in order to predict upper tolerable limits.

8. Give specific examples (with literature citations) for the use of your study design, or similar ones, in previous similar studies in your field.

Decreases in performance is often used to monitor athlete readiness and as a primary indicator than an individual has reached a state of non-functional overreaching or overtraining. This has led to the use of simple performance measures as a way to easily administer tests to practically measure when an individual may be overreaching or at risk of entering a state of overtraining (Halson, 2004; Hoffman, 2000). These performance tests have been researched for over a decade, with tests ranging from variable sprint lengths, one repetition maximum strength tests, vertical jumps, dynamic movements, reaction time tests, and repetition until failure tests (Alcaraz, 2008; Fry, 1994a; Fry, 1994b; Fry, 2000; Hoffman, 2000; Warren, 1992).

While these other studies have used these similar performance tests as readiness indicators, no previous study has determined maximum recoverable volume using these readiness indicators to predict the upper tolerable limit of a subject’s recoverable resistance training volume through the use of a regression equation to find a correlation to a previously measured point of reference, such as a subject’s beginning work capacity, maximum relative strength, and training age.

9. Describe the potential risks to the human subjects involved.

Because multiple sets, repetitions, and exercises will be performed, there is a risk of developing muscle fatigue.

10. If the research involves potential risks, describe the safeguards that will be used to minimize such risks.

To minimize the risk of muscle fatigue, rest periods of a minimum 60 seconds following each set, and 5 minutes between exercises will be employed. A rest period of a minimum of 24 hours between training sessions will also be employed.

11. Describe how you will address privacy and/or confidentiality.

Each subject will be assigned a unique subject number. Only the principal investigator and his faculty advisor will have access to information matching particular data sets to individual
subjects. All protected health information (PHI) will be assigned the appropriate subject’s ID and identifiers will be removed to protect the subject’s confidentiality.

Each subject will be given a subject ID that will identify the study, and the subject’s number. For example, subject IDs will appear similar to that below:

MRV23

The above code indicates that this subject was involved in the study of determining an equation to calculate maximum recoverable volume (MRV), and that he/she was the 23rd subject tested (23).

Computer data files will be backed up on appropriate media (zip disks or CD’s) and kept locked in a filing cabinet in the Biomechanics Laboratory at Western Washington University.

12. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), please attach a clearance letter from an administrator from your research site indicating that you have been given permission to conduct this research. For pre-kindergarten to grade 12 level Protocol # ______________2 of 307/01/05 schools, an administrator (e.g. principal or higher) should issue the permission. For post-secondary level schools the class instructor may grant permission. For Western Washington University, this requirement of a clearance letter is waived if you are recruiting subjects from a scheduled class. If you are recruiting subjects from a campus group (not a class) at Western Washington University, you are required to obtain a clearance letter from a leader or coordinator of the group.

N/A

13. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), and you plan to take still or video pictures as part of your research, please complete a) to d) below:

a. Who have you contacted at the school district or organization involved, to determine the policy on the use of photography in the school or organization?

b. Explain how your research plan conforms to the policy on the use of photography in the school or organization.

c. Attach a copy of the school district or organization policy on the use of photography at the schools or organization.

d. Explain how you will ensure that the only people recorded in your pictures will be the ones that have signed a consent form.

N/A

References


Costa, R. J. S., Jones, G. E., Lamb, K. L., Coleman, R., & Williams, J. H. H. (2005). The Effects of a High Carbohydrate Diet on Cortisol and Salivary Immunoglobulin A (sIgA) During a Period of Increase Exercise Workload Amongst Olympic and


exercise protocol to detect subtle differences in (over)training status. European Journal of Applied Physiology, 91, 140-146. doi: 10.1007/s00421-003-0940-1


Appendix B

Informed Consent
Western Washington University  
Consent to Take Part in a Research Study  
*Project: Determining the Maximum Recoverable Volume of Resistance Training in Tonnage during a Strength Phase*

You are invited to participate in a research study investigating the effects of volume load on recovery and performance. To improve upon previous studies, this analysis aims to objectively provide a direct comparison of the upper tolerable limits of resistance training volume and use a multiple regression model in order to predict this maximum recoverable volume. The results of this study will enhance our understanding of what limits can be reached in resistance training to yield more effective training programs and effective applications of functional overreaching.

I UNDERSTAND THAT:

This experiment will involve the completion of a series of tasks that include a brief, low intensity warm-up on a cycle ergometer, maximum vertical jump tests, resistance training with the intent to move the bar as fast as possible, and a brief low-intensity cool down. Additionally this experiment will require me to follow a resistance training program for up to 10-weeks, four days per week. My participation will require approximately 60 minutes of my time for each testing sessions, and each training session during the training program.

There may be risks during strength training and will be minimized by asking for a spotter when needed. I understand that exercise can lead to muscular soreness, cramping, pain, and fatigue. During testing, there is a risk of experiencing muscle soreness that should disappear after a period of rest. I understand that if exercise testing is painful, I can stop at any time. In addition, I am aware that I could experience delayed onset muscle soreness (DOMS) after the session that could last for 24-72 hours. The safeguards that will be used minimize potential muscle soreness include a warm-up, acclimation, and cool down period. If I feel like I cannot or should not perform any of these tasks, I could opt out from the participation in this study.

My participation is voluntary. I am able to withdraw from the study at any point in time without penalty.

All information is confidential. My signed consent form will be kept in a locked cabinet separate from any information tying me to this study. Only the primary researcher and assistants will have access to any data gathered in this study. My name will not be associated with any performances or relevant data to the study.

My signature on this form does not waive my legal rights of protection.

This experiment is conducted by Patrick Castelli under the supervision of Dr. Dave Suprak. Any questions that you may have about the experiment or your participation may be directed to the investigators at (425)381-5556.

If you have any questions about your participation or your right as a research participant, you can contact the WWU Human Protections Administrator (HPA), (360)650-3220. If during or after participation in this study you suffer from any adverse effect as a results of participation, please notify the researcher directing the study or the WWU Human Protections Administrator.

I have read the above description and agree to participation in this study.

________________________________________________________________________
Participant’s Signature  Date

________________________________________________________________________
Participant’s PRINTED NAME

Note: Please sign both copies of the form and retain the copy marked “Participant”
Appendix C

NSCA Guidelines for 1RM Testing Protocol
IRM Testing Protocol

1. Instruct the athlete to warm up with a light resistance that easily allows 5 to 10 repetitions.
2. Provide a 1-minute rest period.
3. Estimate a warm-up load that will allow the athlete to complete three to five repetitions by adding
   a. 10 to 20 pounds (4-9 kg) or 5% to 10% for upper body exercise or
   b. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercise.
4. Provide a two-minute rest period.
5. Estimate a conservative, near maximal load that will allow the athlete to complete two to three repetitions by adding
   a. 10 to 20 pounds (4-9 kg) or 5% to 10% for upper body exercise or
   b. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercise.
6. Provide a 2- to 4-minute rest period.
7. Make a load increase:
   a. 10 to 20 pounds (4-9 kg) or 5% to 10% for upper body exercise or
   b. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercise.
8. Instruct the athlete to attempt a 1RM.
9. If the athlete was successful, provide a 2- to 4-minute rest period and go back to step 7. If the athlete failed, provide a 2- to 4-minute rest period, then decrease the load by subtracting
   a. 5 to 10 pounds (2-4 kg) or 2.5% to 5% for upper body exercise or
   b. 15 to 20 pounds (7-9 kg) of 5% to 10% for lower body exercise
   AND then go back to step 8.

Continue increasing or decreasing the load until the athlete can complete one repetition with proper exercise technique. Ideally, the athlete’s 1RM will be measured within three to five testing sets.

Appendix D

Sample training program load increase for the back squat
<table>
<thead>
<tr>
<th></th>
<th>Wk 1</th>
<th>Wk 2</th>
<th>Wk 3</th>
<th>Wk 4</th>
<th>Wk 5</th>
<th>Wk 6</th>
<th>Wk 7</th>
<th>Wk 8</th>
<th>Wk 9</th>
<th>Wk 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back Squat</td>
<td>5x3 @ 80%, 2x5, 1x4 @ 67.5%</td>
<td>2x3 @ 80%, 3x5, 1x2 @ 72.5%</td>
<td>2x3 @ 80%, 4x5 @ 77.5%</td>
<td>2x3 @ 80%, 3x5, 2x4, 1x1 @ 80%</td>
<td>2x3 @ 80%, 2x5, 1x3 @ 82.5%</td>
<td>2x3 @ 80%, 4x4, 2x2 @ 60%</td>
<td>2x3 @ 80%, 1x4, 2x3, 3x3, 9x2, 1x1 @ 85%</td>
<td>2x3 @ 80%, 4x3, 2x2, 16x2, @ 87.5%</td>
<td>2x3 @ 80%, 2x4, 1x1 @ 90%</td>
<td></td>
</tr>
<tr>
<td>Good Morning</td>
<td>3x8 @ 55%</td>
<td>3x8 @ 57.5%</td>
<td>3x8 @ 60%</td>
<td>3x6 @ 62.5%</td>
<td>3x6 @ 65%</td>
<td>3x6 @ 67.5%</td>
<td>3x4 @ 72.5%</td>
<td>3x4 @ 75%</td>
<td>3x4 @ 77.5%</td>
<td></td>
</tr>
</tbody>
</table>
Appendix E

Weekly training program layout
<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back Squat</td>
<td>Bench Press</td>
<td>Deadlift</td>
<td>Standing Strict Press</td>
</tr>
<tr>
<td>Good Morning</td>
<td>BB Bent Over Row</td>
<td>Front Squat</td>
<td>Lat Pull Down</td>
</tr>
<tr>
<td>Planks</td>
<td>Triceps Extensions</td>
<td>Planks</td>
<td>Biceps Flexions</td>
</tr>
</tbody>
</table>
Appendix F

Weekly training log
<table>
<thead>
<tr>
<th>SUBJECT:</th>
<th>WEEK:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day 1</strong> Back Squat Max</td>
<td><strong>Day 2</strong> Bench Press Max</td>
</tr>
<tr>
<td>Sets</td>
<td>Reps</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Good Mornings</strong> 6 RM</td>
<td><strong>Bent Over Rows</strong> 6 RM</td>
</tr>
<tr>
<td>Sets</td>
<td>Reps</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><strong>Abdominals</strong></td>
<td><strong>Triceps Extensions</strong></td>
</tr>
<tr>
<td>Sets</td>
<td>Reps</td>
</tr>
<tr>
<td>3 to 4</td>
<td>8 to 12</td>
</tr>
<tr>
<td>RPE (1-10)</td>
<td><strong>Day 3</strong> Deadlift Max</td>
</tr>
<tr>
<td>Sets</td>
<td>Reps</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Front Squat</strong> 6 RM</td>
<td><strong>Lat Pull Downs</strong> 6 RM</td>
</tr>
<tr>
<td>Sets</td>
<td>Reps</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><strong>Abdominals</strong></td>
<td><strong>Biceps Flexions</strong></td>
</tr>
<tr>
<td>Sets</td>
<td>Reps</td>
</tr>
<tr>
<td>3 to 4</td>
<td>8 to 12</td>
</tr>
<tr>
<td>RPE (1-10)</td>
<td>RPE (1-10)</td>
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</table>
Appendix G
Pre- and post-training program testing of 1RM strength
<table>
<thead>
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<th></th>
<th>Pre-1RM</th>
<th>Post-1RM</th>
<th>% change</th>
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<tbody>
<tr>
<td><strong>MRV01</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squat</td>
<td>360</td>
<td>380</td>
<td>6%</td>
</tr>
<tr>
<td>Bench</td>
<td>275</td>
<td>290</td>
<td>5%</td>
</tr>
<tr>
<td>Deadlift</td>
<td>441</td>
<td>460</td>
<td>4%</td>
</tr>
<tr>
<td><strong>MRV02</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squat</td>
<td>263</td>
<td>275</td>
<td>5%</td>
</tr>
<tr>
<td>Bench</td>
<td>196</td>
<td>210</td>
<td>7%</td>
</tr>
<tr>
<td>Deadlift</td>
<td>270</td>
<td>330</td>
<td>22%</td>
</tr>
<tr>
<td>OHP</td>
<td>121</td>
<td>135</td>
<td>12%</td>
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<tr>
<td><strong>MRV06</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Squat</td>
<td>265</td>
<td>275</td>
<td>4%</td>
</tr>
<tr>
<td>Bench</td>
<td>185</td>
<td>195</td>
<td>5%</td>
</tr>
<tr>
<td>Deadlift</td>
<td>335</td>
<td>355</td>
<td>6%</td>
</tr>
<tr>
<td>OHP</td>
<td>120</td>
<td>130</td>
<td>8%</td>
</tr>
<tr>
<td><strong>MRV08</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squat</td>
<td>265</td>
<td>275</td>
<td>4%</td>
</tr>
<tr>
<td>Bench</td>
<td>215</td>
<td>225</td>
<td>5%</td>
</tr>
<tr>
<td>Deadlift</td>
<td>345</td>
<td>365</td>
<td>6%</td>
</tr>
<tr>
<td>OHP</td>
<td>133</td>
<td>140</td>
<td>5%</td>
</tr>
<tr>
<td><strong>MRV09</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Squat</td>
<td>325</td>
<td>340</td>
<td>5%</td>
</tr>
<tr>
<td>Bench</td>
<td>215</td>
<td>225</td>
<td>5%</td>
</tr>
<tr>
<td><strong>MRV10</strong></td>
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<td></td>
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<tr>
<td>Squat</td>
<td>405</td>
<td>435</td>
<td>7%</td>
</tr>
<tr>
<td>Deadlift</td>
<td>545</td>
<td>565</td>
<td>4%</td>
</tr>
<tr>
<td><strong>MRV11</strong></td>
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</tr>
<tr>
<td>Squat</td>
<td>385</td>
<td>405</td>
<td>5%</td>
</tr>
<tr>
<td>Deadlift</td>
<td>405</td>
<td>425</td>
<td>5%</td>
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<tr>
<td><strong>MRV15</strong></td>
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<tr>
<td>Squat</td>
<td>235</td>
<td>240</td>
<td>2%</td>
</tr>
<tr>
<td>Bench</td>
<td>200</td>
<td>205</td>
<td>2%</td>
</tr>
<tr>
<td>Deadlift</td>
<td>290</td>
<td>315</td>
<td>9%</td>
</tr>
</tbody>
</table>
**Average % Change in 1RM**  | **6.15%**  |
Appendix H

Statistical Analysis and SPSS Outputs
### T-Test aveRPE pre vs post

#### Paired Samples Statistics

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<thead>
<tr>
<th>Pair</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
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</thead>
<tbody>
<tr>
<td>RPE_pre</td>
<td>5.1339</td>
<td>14</td>
<td>.76029</td>
<td>.20320</td>
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<tr>
<td>RPE_post</td>
<td>6.9911</td>
<td>14</td>
<td>1.13029</td>
<td>.30208</td>
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</tbody>
</table>

#### Paired Samples Correlations

<table>
<thead>
<tr>
<th>Pair</th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE_pre &amp; RPE_post</td>
<td>14</td>
<td>.595</td>
<td>.025</td>
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</table>

#### Paired Samples Test

<table>
<thead>
<tr>
<th>Pair</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Mean</th>
<th>Std. Error Mean</th>
<th>Interval of the Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
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</thead>
<tbody>
<tr>
<td>RPE_pre - RPE_post</td>
<td>-1.85714</td>
<td>.91312</td>
<td>.24404</td>
<td>-2.38436</td>
<td>-1.32992</td>
<td>-7.610</td>
<td>13</td>
<td>.000</td>
<td></td>
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</tbody>
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### Model Summary

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<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.952</td>
<td>.906</td>
<td>.889</td>
<td>18796.97508</td>
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</tbody>
</table>

a. Predictors: (Constant), VL_initial, Relative_Strength

### ANOVA

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Regression</td>
<td>37368216809.524</td>
<td>2</td>
<td>18684108404.762</td>
<td>52.881</td>
<td>.000b</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>11</td>
<td>353326272.043</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>13</td>
<td>41254805802.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: VL_total
b. Predictors: (Constant), VL_initial, Relative_Strength

### Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>-57614.619</td>
<td>26367.656</td>
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<tr>
<td></td>
<td>Relative_Strength</td>
<td>2705.286</td>
</tr>
<tr>
<td></td>
<td>VL_initial</td>
<td>7.950</td>
</tr>
</tbody>
</table>

a. Dependent Variable: VL_total
### Multiple Regression VL_initial & Relative Strength to determine VL_final

**Variables Entered/Removed**

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VL_initial, Relative_Strength</td>
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</tr>
</tbody>
</table>

- **a.** Dependent Variable: VL_final
- **b.** All requested variables entered.

**Model Summary**

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.957&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.915</td>
<td>.900</td>
<td>4366.36485</td>
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</table>

- **a.** Predictors: (Constant), VL_initial, Relative_Strength

**ANOVA**

<table>
<thead>
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<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regression</td>
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<td>1135166298.078</td>
<td>59.541</td>
<td>.000&lt;sup&gt;b&lt;/sup&gt;</td>
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<td></td>
<td>Residual</td>
<td>11</td>
<td>19065141.960</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>13</td>
<td>2480049157.714</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **a.** Dependent Variable: VL_final
- **b.** Predictors: (Constant), VL_initial, Relative_Strength

**Coefficients**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>(Constant)</td>
<td>-11745.795</td>
<td>6124.965</td>
<td>-1.918</td>
</tr>
<tr>
<td></td>
<td>Relative_Strength</td>
<td>3187.556</td>
<td>4123.554</td>
<td>.085</td>
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<td></td>
<td>VL_initial</td>
<td>1.870</td>
<td>.229</td>
<td>.903</td>
</tr>
</tbody>
</table>

- **a.** Dependent Variable: VL_final
Linear Regression VL_initial to determine VL_total

<table>
<thead>
<tr>
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<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
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<tbody>
<tr>
<td>1</td>
<td>VL_initial</td>
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</tr>
</tbody>
</table>

a. Dependent Variable: VL_total
b. All requested variables entered.

Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>.952a</td>
<td>.906</td>
<td>.898</td>
<td>18015.72192</td>
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</tbody>
</table>

a. Predictors: (Constant), VL_initial

ANOVA

<table>
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<th>Model</th>
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<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>37360010966.238</td>
<td>115.108</td>
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<td>3894794835.762</td>
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<td>324566236.314</td>
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</tr>
<tr>
<td></td>
<td>Total</td>
<td>41254805802.000</td>
<td>13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: VL_total
b. Predictors: (Constant), VL_initial

d. The model summary shows a high R squared value of .906, which indicates a strong relationship between VL_initial and VL_total. The adjusted R squared is .898, which adjusts for the number of predictors in the model.

c. The ANOVA table indicates that the model is statistically significant (F = 115.108, p < .001), suggesting that the model predicts VL_total effectively.

c. The coefficients table provides the unstandardized and standardized coefficients, which can be used to understand the effect of each predictor on the dependent variable. The constant (VL_initial) coefficient is -55448.938 with a beta of .952, indicating a strong positive relationship.
### Linear Regression VL_initial to determine VL_final

**Variables Entered/Removed**

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>VL_initialb</td>
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</tr>
</tbody>
</table>

a. Dependent Variable: VL_final  
b. All requested variables entered.

**Model Summary**

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<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
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<td>.911</td>
<td>.903</td>
<td>4292.52148</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), VL_initial

**ANOVA**

<table>
<thead>
<tr>
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<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
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<td>2258940269.515</td>
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<td>18425740.683</td>
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<tr>
<td>1</td>
<td>Total</td>
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<td>13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: VL_final  
b. Predictors: (Constant), VL_initial

**Coefficients**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Constant)</td>
<td>-9194.039</td>
<td>-1.813</td>
<td>.095</td>
</tr>
<tr>
<td></td>
<td>VL_initial</td>
<td>1.977</td>
<td>.954</td>
<td>11.072</td>
</tr>
</tbody>
</table>

a. Dependent Variable: VL_final