MONITORING CHANGES IN RESISTANCE TRAINING PERFORMANCE FOLLOWING OVERLOAD AND TAPER MICROCYCLES

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ABSTRACT

During competition preparation, a common practice of strength athletes is to utilize a short-term overload period followed by a taper to enhance strength performance. Three studies were conducted to evaluate changes in repetition velocity, estimated repetitions to failure (ERTF), and smartphone-derived heart rate variability (HRV) across overload and taper microcycles. The first study examined changes in bench press average concentric velocity (ACV) recorded during a load-velocity profile assessment consisting of loads ranging from 40-85% of one-repetition maximum (1RM). Additionally, this study investigated whether the load-velocity relationship could accurately predict bench press 1RM. Following an overload microcycle (PostOL), ACV of the load-velocity profile was significantly reduced compared to baseline (BL), however 1RM was unchanged. Following the taper (PostTP), ACV had returned to BL, while 1RM was significantly higher than PostOL and BL. The load-velocity profile was unable to accurately predict 1RM; however, the near perfect correlations suggest that it may be used to assess recovery and adaptation to resistance training. The second study evaluated the accuracy of ERTF during a bench press repetitions-to-failure assessment with 70% 1RM. There was no difference between ERTF and actual repetitions-to-failure (ARTF) during BL and PostOL; however, ARTF were significantly higher than ERTF at PostTP. Further, PostTP ARTF and ERTF were both significantly higher than PostOL, while ARTF were also higher than BL. Thus, the accuracy of ERTF is dependent on the proximity to muscular failure. The third study evaluated changes in HRV across overload and taper microcycles. Additionally, this study
investigated the intra-day reliability of HRV measured upon waking (HRV_M) and upon arriving to the training facility (HRV_T). HRV_M decreased significantly at PostOL, and returned back to baseline at PostTP. While HRV_T followed a similar trend, there were no statistical difference across BL, PostOL, and PostTP. There were large to very large correlations between HRV_M and HRV_T during BL and PostOL, while the relationship at PostTP was not significant. Smartphone derived HRV, recorded upon waking, was sensitive to resistance training loads across an overload and taper microcycle in competitive strength athletes, whereas HRV taken just before the training session was not.
DEDICATION

This dissertation is dedicated to my Lord and Savior, Jesus Christ. It is only through His strength that I am able to complete this dissertation and I know that He is preparing me for great things in the future (Ephesians 2:10). Secondly, I want to dedicate this dissertation to my beautiful wife, Hannah. You are the one that challenged me to get out of my comfort zone and pursue my passion. Through every step of this journey, you have provided encouragement and wisdom, as well as support me mentally, emotionally, and financially. I am so thankful to have you as my wife, and I could not have achieved this without you. Lastly, this dissertation is dedicated to my family. To my parents, Terry and Bridget Williams, the culmination of this work began with the work ethic and the values that you taught me during my childhood. I am blessed to have great role models and parents that encouraged and believed in me. Thank you for all of your love and support throughout all of the years. To my brother, Wesley, I am proud to be your brother and look forward to seeing the great things you will accomplish. To my parents-in-law, Doyle and Kellie Dailey, thank you for your support over the past 6 years. You have welcomed me into the family with open arms and given me unconditional love and support. Thank you for your consistent prayers and words of encouragement during my graduate studies. To my brother-and sister-in law, James and Melissa Dailey, thank you for all of your thoughts, prayers, and help throughout this time in my life. The both of you have been such a big support system for Hannah and I, and I look forward to moving closer and spending more quality time together. To my precious niece, Noa Jane, you have been wonderfully and beautifully made and God is going to
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LIST OF ABBREVIATIONS AND SYMBOLS

1RM  one-repetition maximum
ARTF actual repetitions to failure
ACV  average concentric velocity
ACV\(_{40}\)  average concentric velocity at 40% of 1RM
ACV\(_{55}\)  average concentric velocity at 55% of 1RM
ACV\(_{70}\)  average concentric velocity at 70% of 1RM
ACV\(_{85}\)  average concentric velocity at 85% of 1RM
BL  baseline testing
CE  constant error
E1RM  estimated one-repetition maximum
ERTF estimated repetitions to failure
ES  effect size
HRV  heart rate variability
HRV\(_M\)  heart rate variability measured upon waking
HRV\(_T\)  heart rate variability measured upon arriving at the training facility
lnRMSSD  natural logarithm of the root mean square of successive R-R interval differences
MVT  minimal velocity threshold
PostOL post-overload testing
PostTP  post-taper testing
PRS  perceived recovery status
PWFS  pulse wave finger sensor
RPE  rating of perceived exertion
sRPE  session rating of perceived exertion
$\text{ACV}_{1\text{RM}}$  average concentric velocity for the one-repetition maximum
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CHAPTER 1

INTRODUCTION

Maximal strength is the ability to generate force through a maximal voluntary contraction of a specific muscle or group of muscles (25). Strength is a trainable skill that serves as the foundation of power output and rate of force development which is necessary for optimizing performance in many sport related skills such as jumping, sprinting, and changing direction (26). In fact, the sport of powerlifting consists of the ability to display maximal strength during dynamic resistance exercises. In a powerlifting competition, these strength athletes will perform a one-repetition maximum (1RM) in the back squat, bench press, and deadlift. Therefore, powerlifters and other athletes utilize various resistance training strategies to enhance maximal strength.

One training strategy used by powerlifters is periodization, a method of organizing training into sequential phases and cyclical time periods in order to optimize performance and minimize the potential for overtraining (4, 20, 27). Periodized resistance training is more effective at enhancing muscular strength compared to non-periodized training (22), because of the strategically structured overload and recovery periods within the periodized plan. The overload period provides a training stimulus above the habitual level that causes a disruption in homeostasis. This training stimulus produces two residual effects which are referred to as fitness after-effects and fatigue-after effects (3). The difference between these two after-effects is termed preparedness (4, 10). During a period of intensified training, both fitness- and fatigue-
after-effects increase; however, fatigue increases at a faster rate causing a decline in preparedness. During a taper, in which the training stimulus is reduced, fatigue will decline at a faster rate than fitness, allowing for an increase in preparedness (21). Tapering has been shown to increase 1RM bench press and back squat by 2-3% in well-trained athletes (16). This supercompensation in strength is believed to be due primarily to enhanced neural effects such as increased motor unit recruitment, increased rate of firing, and greater motor unit synchronization (10, 11, 21). While this approach is superior to non-periodized training, it is still unable to account for individual differences in work capacity and rate of adaptation. Therefore, monitoring resistance training performance is necessary for developing an individualized training approach.

Monitoring the training process is important to determine whether the athlete is adapting well to the training program, as well as detecting excessive fatigue that may lead to non-functional overreaching or overtraining (12). The different monitoring strategies currently used to quantify stress imposed from resistance exercise are classified as internal and external load measures. Internal load quantifies the relative physiological or psychological stress imposed (12). Internal load is primarily assessed by subjective measures such as rating of perceived exertion (RPE), Perceived Recovery Status (PRS), and wellness questionnaires; however, objective measures, such as heart rate variability (HRV), are capable of quantifying internal physiological stress. External load uses objective measures such as volume load, repetition maximums, and repetition velocity to quantify the quality and quantity of work being performed. While these methods are being used by coaches and athletes in the field, research on many of these practical monitoring tools is limited and currently there is no consensus regarding the optimal approach (24).
Repetition velocity is an external load measure that can provide an objective assessment of neuromuscular fatigue. Previous research demonstrated that repetition velocity decreases with each additional repetition performed during a set of resistance exercise (15, 23). Izquierdo et al. observed a progressive decline in repetition velocity during sets to concentric failure with loads varying from 60 – 75% of 1RM. Additionally, the average concentric velocity (ACV) on the last successful repetition at each load was identical (0.17 – 0.18 m∙s\(^{-1}\)). This suggested that repetition velocity could be used to monitor neuromuscular fatigue within an exercise session.

In a recent paper, Jovanovic and Flanagan (18) suggested that the load-velocity relationship could be used to assess daily preparedness, as well as estimate a daily 1RM (E1RM). If these methods are accurate, they would be able to gauge fatigue and adaptation to a resistance training program. Based on the near perfect relationship between load and repetition velocity (17), an individual load-velocity profile consisting of 4-6 sets ranging from 30-85% of 1RM can be recorded for each athlete (18). During each repetition, the athlete should perform the concentric phase of the movement with maximal velocity. The same protocol can be performed during the warmup of each training session and results can be compared to determine daily preparedness. Increases in ACV could indicate adaptation, while decreases in velocity could indicate fatigue. This approach can be taken a step further to calculate an E1RM. Using the load-velocity profile and the ACV measured during a previous 1RM attempt or the last repetition of a repetitions to failure assessment, individual regression equations can be developed to predict 1RM. The E1RM can be compared week to week to determine fatigue or adaptation to the training program. Whereas this approach is hypothesized to be effective, there is no research evaluating this approach as a practical monitoring tool.
A second potential tool for monitoring resistance training performances is the RPE scale. RPE is a commonly used subjective measure capable of quantifying the internal stress imposed from resistance exercise. In previous years, the CR-10 RPE scale has been used to determine the intensity of an exercise set, as well as the intensity of the exercise session (24). However, more recently, an RPE scale based on repetitions in reserve was developed because of reporting error that may occur using the CR-10 scale (28). This novel RPE scale links an RPE value with a number of repetitions remaining to concentric muscular failure (13). This approach increases the accuracy of RPE reporting, as previous research demonstrated that resistance-trained subjects were able to accurately estimate repetitions to failure.

Hackett et al. (9) found a near perfect relationship between estimated repetitions to failure (ERTF) and actual repetitions to failure (ARTF) in the bench press (r = 0.95) and back squat (r = 0.93). Additionally, the mean difference between ERTF and ARTF across the 5 sets of bench press were 1 repetition or less. In a study examining the perceptual ability of competitive powerlifters, Helms et al. found strong to very strong relationships between RPE based on repetitions in reserve and percentage of 1RM in the squat (r = 0.91), bench press (r = 0.88), and deadlift (r = 0.91) (14). Furthermore, strong inverse relationships between RPE and ACV (r = -0.79 to -0.87) were observed in each of the powerlifts. While this suggests that perceived exertion and ERTF can accurately gauge training intensity within a single exercise bout, using these perceived measures to determine fatigue and adaptation to resistance training is warranted. Hackett et al. (8) noted that ERTF may be used for these purposes. Athletes can perform a set of repetitions with a constant load and record their ERTF. The same protocol can be performed during the following training session. An increase in ERTF would indicate adaptation, whereas a
decrease would indicate fatigue. If accurate, this approach would serve as a valuable, non-fatiguing approach to monitoring daily preparedness for resistance exercise.

Lastly, HRV is a potential monitoring tool that provides an objective, physiological reflection of cardiac-autonomic regulation. Previous research has demonstrated that HRV is capable of assessing fatigue and recovery following an intense resistance training session (2). However, until recently, HRV measurements were not practical in a field setting as they required lengthy recording procedures and expensive laboratory equipment (5). Recent technological advances have provided the capability of measuring ultra-short HRV via smartphone application (6). In addition, smartphone-derived HRV appears to be sensitive to changes in training load in team sports (7) and Olympic sport athletes (8). Whether smartphone-derived HRV is useful for competitive powerlifters to track changes in training load during an overload period and taper remains unknown.

Currently, HRV recordings are suggested to upon waking (1); however, this approach may lead to poor compliance. As such, it may be more practical to record HRV prior to the day’s training session. Previous research demonstrated high intra-day reliability (ICC = 0.96) of ultra-short duration HRV measures (19). In this study, HRV measures were recorded 10 minutes apart and HRV, which provides little indication whether HRV would be reliable if taken before an afternoon training session. Therefore, examining the reliability of smartphone-derived HRV taken upon waking and prior to training is warranted.

The purpose of this dissertation was to evaluate the efficacy of three practical monitoring tools to assess internal and external loads. The specific study aims were as follows:

*Study1:* 1) To determine the effect of an overload microcycle and taper on bench press ACV during warmup sets with increasing loads and, 2) to determine if the load-velocity
relationship can accurately predict bench press 1RM following a preparatory, overload, and taper microcycle.

It was hypothesized that ACV would decrease following the overload and return to baseline or increase above baseline following the taper. Further, it was hypothesized that there would be no difference between E1RM and actual 1RM during each test session.

**Study 2:** To evaluate the accuracy of ERTF following an overload microcycle and taper. It was hypothesized that there would be no difference in ERTF and ARTF during each test session.

**Study 3:** 1) To determine the effect of an overload microcycle and taper on smartphone-derived HRV and, 2) to examine the reliability of smart-phone derived HRV measured upon awakening and right before training.

It was hypothesized that waking HRV measures (HRV\textsubscript{M}) and pre-training HRV measures (HRV\textsubscript{T}) would decrease following the overload and return to baseline or increase above baseline following the taper. Further, it was hypothesized that smartphone-derived HRV would demonstrate high reliability between morning and pre-training recordings.

**REFERENCES**


CHAPTER 2

CHANGES IN BENCH PRESS VELOCITY FOLLOWING OVERLOAD AND TAPER MICROCYCLES

ABSTRACT

The purpose of this study was to quantify the effect of an overload microcycle and taper on bench press velocity, and to determine if the load-velocity relationship could accurately predict one-repetition maximum (1RM). Fifteen powerlifters participated in resistance training structured into a preparatory microcycle, overload microcycle, and taper. At the end of each microcycle, subjects completed a 1RM assessment consisting of warmup sets at 40%, 55%, 70%, and 85% of a previously established 1RM. The average concentric velocity (ACV) was recorded during each warmup set and using the established load-velocity relationship, an estimated one-repetition maximum (E1RM) was calculated. Compared to baseline testing (BL), the ACV of the warmup sets were significantly lower following the overload (PostOL) (ES = -0.58 to -0.81, p < 0.05), but had returned to baseline following the taper (PostTP). At PostTP, 1RM (136.5 ± 44.8 kg) was significantly higher than BL (131.7 ± 44.7 kg, p < 0.01) and PostOL (128.4 ± 42.0 kg, p < 0.01). Bland-Altman analysis indicated that E1RM was consistently higher than 1RM (CE = 3.3 kg to 7.2 kg) and the limits of agreement were extremely wide (lower = -7.5 kg to -15.0 kg; upper = 20.4kg to 23.9kg) during each of the testing sessions. However, near perfect correlations (r = 0.99 to 0.98) were seen between E1RM and 1RM during BL, PostOL, and PostTP. The load-velocity relationship established from submaximal sets did not accurately predict 1RM. However, the near perfect relationship between E1RM and 1RM suggests that the load-velocity
relationship may be useful for monitoring fatigue and adaptation during resistance training programs.

**Key Words:** Velocity Based Training, Athlete Monitoring, Autoregulatory Resistance Training, Powerlifting

**INTRODUCTION**

Traditional resistance training programs often prescribe training loads based on percentages from a previously established one-repetition maximum (1RM). A limitation of this method is the daily variability in strength that occurs from training and non-training related stressors. For example, Zourdos et al. showed that a daily back squat 1RM in well-trained powerlifters and weightlifters was highly variable over 37 consecutive days (40). A suggested alternative to prescribing training loads based on %1RM is to use daily repetition velocity to estimate 1RM (E1RM). This method may account for daily fluctuations in strength and allow for a more effective exercise prescription (37). For instance, the practically perfect relationship between load and velocity (2) allows for the calculation of E1RM for a specific exercise using submaximal loads. Estimating 1RM during a warmup set would allow strength and conditioning professionals a non-fatiguing method to monitor recovery and adaptation from previous exercise sessions. Observing an increasing trend in E1RM would indicate supercompensation from the training stimulus, while decreased E1RM would signify fatigue accumulation. Additionally, calculating a daily E1RM based on the load-velocity relationship of warmup sets would provide an updated 1RM which could be used to prescribe prescription training loads. Jidovtseff and colleagues confirmed the ability to accurately predict bench press 1RM using the load-velocity relationship in the bench press (24). However, the results of this study were limited to the Smith
machine bench press and more research is warranted to determine if the load-velocity relationship validly predicts 1RM in the more commonly used free weight bench press.

Indeed, velocity-based approaches are finding popularity in the sport of powerlifting. Instead of using a previously attained 1RM, athletes are using the average concentric velocity (ACV) from submaximal warmup sets to calculate a daily E1RM. According to Jovanovic and Flanagan, in order to effectively predict 1RM from using the load-velocity relationship, an exercise-specific minimal velocity threshold (MVT) must be known for each athlete (25). The MVT is the ACV of the last successful repetition in a set performed to exhaustion while attempting to perform the repetition with maximal concentric velocity. MVT varies among exercises (19, 22) but is noted to be identical in a 1RM or a multiple repetition maximum (RM) set. Therefore, MVT can be determined by the assessment of either a 1RM (ACV_{1RM}) or multiple repetition maximum (RM) set. Once the MVT is known for a specific exercise, an E1RM can be calculated from the ACV recorded during 4-6 submaximal sets with progressively increasing loads (25). Using the load-velocity relationship and MVT, an individualized regression equation can extrapolate an E1RM. Using this estimate, the athlete can determine exercise-specific loads for each training session. This form of autoregulation is theorized to provide greater individualization of training. As previously mentioned, a daily E1RM is proposed to serve as an objective monitoring tool for the athlete. Comparing week-to-week estimates can provide objective feedback regarding recovery and adaptation from training, which can assist in peaking for a competition.

Based on the strong relationship between repetition velocity and %1RM (15), a decrease in ACV at an absolute load may indicate fatigue, whereas an increase in ACV at an absolute load may indicate improved performance. This is important because athletes will intensify training to
induce functional overreaching when peaking for a competition. For example, when an overload period is followed by a reduction in volume, a supercompensation in performance may occur (4, 6, 16, 33, 34). While this strategy may be effective for enhancing performance, individual responses may vary based on length and intensity of the overload period. Therefore, having an objective monitoring tool (i.e., repetition velocity) to measure fatigue and adaptation may enhance the peaking process.

Previous investigations have shown that acute fatigue acquired during a training session significantly reduces the ACV for a given load within a set and among subsequent sets (22, 36). However, the relationship between load and ACV after fatigue has accumulated over multiple training sessions—such as that during an overload period—has not been determined. Therefore, the primary purpose of this study was to: 1) determine the effect of an overload microcycle and taper on bench press ACV during warmup sets with increasing loads and 2) determine if the load-velocity relationship can accurately predict bench press 1RM. We hypothesized that the ACV for each submaximal load would decrease following the overload microcycle, and return back to baseline or increase following the taper. Additionally, we hypothesized that there would be no difference between E1RM and 1RM across each testing session.

METHODS

Experimental Approach to the Problem

This study examined the effect of an overload microcycle and taper on the load-velocity relationship for the bench press. A load-velocity profile was developed for each subject by completing 3 repetitions at 40%, 2 repetitions at 55%, and 1 repetition each at 70% and 85% of 1RM. The highest ACV was recorded for each load. Following these warmup sets, subjects
completed a 1RM assessment. The ACV of the successful 1RM attempt was recorded as the ACV\(_{1RM}\). Using the load-velocity profile (ACV\(_{40}\), ACV\(_{55}\), ACV\(_{70}\), and ACV\(_{85}\)) and the ACV\(_{1RM}\), an E1RM was calculated for each subject using the methods outlined by Jovanovic and Flanagan (25). The same protocol was completed following a 4-day overload microcycle, and again after a 6-day taper. A new 1RM was attempted following overload and taper; whereas the loads used during the warmup sets remained constant.

**Subjects**

Fifteen resistance-trained subjects (men: n=12; women: n=3) were recruited to participate in this study (Table 2.1). All subjects were competitive and recreational powerlifters. Competitive powerlifters are individuals who have previously competed in a sanctioned powerlifting competition, while recreational powerlifters have not competed, but perform each of the powerlifts (back squat, bench press, and deadlift) at least once a week. Subjects were recruited from the University of Alabama and a local powerlifting training center. All subjects were healthy, non-smoking volunteers who were classified as low or moderate risk according to the guidelines established by the American College of Sports Medicine (ACSM) (31). To minimize any confounding effects associated with age-related differences in skeletal muscle recovery between younger and older individuals, only subjects between the ages of 18-40 years were included in this study (30).

All prospective subjects completed an exercise screening questionnaire, PAR-Q, and health history questionnaire to determine if they met the inclusion criteria. To qualify for inclusion in the study, subjects had to have at least one year of resistance training experience and meet the national qualifying requirements for drug-tested athletes established by the United
States Powerlifting Association (1). The powerlifting totals were gathered from a previous competition or test session. Additionally, all subjects were free from cardiovascular, metabolic, neurological, or musculoskeletal disorders that would affect the study results. Prior to participation, all subjects signed a written informed consent document approved by the local Institutional Review Board.

**Experimental Protocols**

During the initial visit, subjects’ standing height was measured using a stadiometer (SECA 67310, SECA©, Chino, CA) and weight was determined using a digital scale (Tanita BWB-800, Tanita©, Arlington Heights, IL). Body composition was assessed using dual-energy X-ray absorptiometry (Lunar Prodigy, General Electric Healthcare, Madison, WI). Subjects were provided instruction regarding the resistance training program and performance measures administered during the study.

*Resistance Training Protocol*

Within one week after the initial visit, subjects reported to a weight training facility to begin the 3-week resistance training program. The training program consisted of a preparatory microcycle, overload microcycle, and taper. Before participating in each training session, each subject’s perceptual recovery was determined using the Perceived Recovery Status (PRS) scale. After indicating their perceived recovery, subjects completed a full-body, dynamic warmup that was standardized across each session. All training sessions were monitored by a Certified Strength and Conditioning Specialist.

The preparatory training microcycle consisted of 3 non-consecutive days over a 5-day period using a total-body program (Table 2.2). Training loads were determined using the rating
of perceived exertion (RPE) scale based on repetitions in reserve (RIR) (18). This scale has been validated as a method of gauging resistance training intensity in novice and experienced lifters (19, 41). During the preparatory microcycle, subjects were instructed to complete the prescribed number of repetitions for each set at an RPE 6 to RPE 8. On the fifth day of the preparatory week (BL), baseline tests were performed before completing the third resistance training session.

Two days after BL, subjects began an overload week of resistance training, with the purpose of overreaching. Resistance training was performed on 4 consecutive days using a total-body program (Table 2.2). Daily undulations in training volume and intensity were programmed to include high load and high volume training as a means of inducing central and peripheral fatigue. All sets were performed using repetition maximums and training loads were adjusted to ensure all sets were performed to muscular exhaustion. If participants reached muscular failure before completing the required repetitions in a given set, the load was reduced for the subsequent sets to ensure the desired training volume was obtained. If subjects completed the prescribed repetitions and perceived more repetitions were remaining, loads were increased for the subsequent set. On the fifth day of the overload week (PostOL), subjects completed the same assessments administered during the initial baseline testing session. To minimize any confounding effects for time of day, subjects completed the PostOL assessments during the same time of day as BL. Following the overload test session, subjects received 48 hours of rest before tapering.

The taper week consisted of 2 non-consecutive days of training over a 4-day period. Each day contained the same total body exercises used in the overload week; however, total training volume was substantially reduced (Table 2.2). In an attempt to enhance performance, only small reductions in training intensity were programmed (17, 32, 34). Training loads were adjusted to
90% and 85% of the average load used during the day 3 and day 4 of the overload week. Taper performance measures were recorded on the fifth day of the taper week (PostTP). Each subject performed the same measures at the same time of day as performed at BL and PostOL.

Prior to arrival of each test session, subjects were instructed to refrain from caffeine at least 4 h and alcohol at least 24 h prior to testing. A 24-h recall was used to determine recent food and supplement consumption as well as compliance with pre-test instructions. Before participating in performance testing, subjects rated their perceptual recovery using the PRS scale as described in the next section.

*Internal and external load parameters*

Before each training and test session, subjects recorded a PRS score. The PRS scale is a subjective rating from 0 to 10, with 0-2 representing poor recovery and anticipating poor performance, 4-6 consisting of moderate recovery and expecting normal performance, and 7-10 representing high recovery and expecting increased performance. This scale has been validated as a useful tool in monitoring fatigue and performance in anaerobic exercise (27, 38). The subjects were informed of the purpose of the PRS scale and read specific instructions on how to interpret the scale. Additionally, session rating of perceived exertion (sRPE), a metric capable of quantifying the global rating of internal load (10, 29, 37), was collected 15 minutes following the completion of each training session (26). Using a modified CR-10 RPE scale (10), subjects were asked to indicate the difficulty of their workout in which a value near 0 suggests easy training and a value near 10 suggests very hard training. In addition to internal load measures, external loads were calculated to quantify the amount of work performed during each microcycle. Repetition volume was quantified as the total number of repetitions completed. Volume load was
determined by multiplying the load lifted by the repetitions completed in a given set. The volume load could then be calculated for a specific exercise, training session, or training week.

**Velocity and Strength Assessments**

After the completion of a dynamic warmup, subjects completed a bench press protocol to establish an individualized load-velocity profile. All bench press assessments were performed on an instrumented bench (Forza Super Bench, Forza Strength Systems, Spokane Valley, WA) using a 20.4-kg powerlifting competition barbell (Rogue Fitness, Columbus, OH). Subjects were instructed on how to perform the bench press to meet United States Powerlifting Association (USPA) standards. Hand position on the barbell was recorded for each subject and maintained consistent for each trial.

Subjects began the assessment by performing 5 repetitions with an unloaded barbell. To establish the load-velocity relationship, a bench press protocol was developed based on the guidelines of Jovanovic and Flanagan (25). For this protocol, subjects completed 3 repetitions at 40% (ACV\(_{40}\)), two repetitions at 55% (ACV\(_{55}\)), and 1 repetition each at 70% (ACV\(_{70}\)) and 85% (ACV\(_{85}\)) of previously acquired 1RM. The ACV of each repetition was measured using a linear position transducer (GymAware PowerTool, GymAware, Kinematic Performance Technology, Canberra, Australia), which has been previously validated for measuring barbell velocity (21). The highest value was selected for ACV\(_{40}\) and ACV\(_{55}\). After each bench press set, subjects reported RPE and were given two minutes of rest before performing the next set with an increased load.

Two minutes after completing ACV\(_{85}\), subjects began 1RM bench press attempts. Each attempt was selected by the primary investigator using perceptual feedback from the subject and ACV of the previous attempt. All attempts were required to meet USPA standards. A 1RM was
determined based on the methods of Zourdos and colleagues (41): 1) subject reported a 10 RPE and primary investigator agreed a subsequent attempt would not be successful with a 2.3 kg load increase; or 2) subject reported a 9 or 9.5 RPE followed by a failed attempt with a 2.3 kg load increase. Rest periods comprised of 5 minutes for each 1RM attempt. All successful 1RM attempts were obtained with 4 attempts or less.

*Estimated one-repetition maximum (E1RM) calculation*

Based on the methods outlined by Jovanovic and Flanagan (25), a load-velocity profile was established for each subject at BL, PostOL, and PostTP. Additionally, subjects’ ACV_{1RM} was recorded during the 1RM assessment at BL. Using load-velocity profile for each test session and the baseline ACV_{1RM}, individual regression equations were developed in Excel 2013 (Microsoft Corporation, Redmond, WA) to predict 1RM for each testing session.

**Statistical Analysis**

Data were analyzed using SPSS Statistics version 24.0 (IBM Corporation, Armonk, NY). A one-way repeated measures analysis of variance (ANOVA) was used to compare mean differences for the ACV at each submaximal load across BL, PostOL, and PostTP. When appropriate, a Bonferroni post hoc analysis was used to determine where the mean differences occurred. Cohen’s $d$ effect sizes were calculated and Hopkin’s scale of magnitude was used where an effect size of 0-0.02 was trivial, 0.2-0.6 was small, 0.6-1.2 was moderate, 1.2-2.0 was large, and $>2.0$ was very large (20). Pearson product moment correlations ($r$) were used to assess the relationship of the E1RM compared to actual 1RM. Correlation coefficients between 0 to 0.30 were considered small, 0.31 to 0.49 moderate, 0.50 to 0.69 large, 0.70 to 0.89 very large, and 0.90 to 1.00 near perfect (20). A 2 × 3 repeated measures ANOVA was used to compare
mean differences between the E1RM and 1RM across each of the test sessions. Paired samples t-tests with a Bonferroni adjusted critical value were used to determine where the mean differences occurred. This procedure involved dividing the p-value by the number of comparisons (i.e., 0.05 / 6 = 0.008). Therefore, significance for the paired samples t-tests was set at p < 0.008. Additionally, Bland-Altman plots were used to identify the agreement between E1RM and actual 1RM (5). For sRPE and PRS data, a Friedman’s test was used to determine mean differences across BL, PostOL, and PostTP sessions. If significance was found, Wilcoxon signed rank tests were performed to determine where differences occurred. Data are presented as mean ± SD and the level of significance was set at p < 0.05.

RESULTS

Load-Velocity Relationship

The means and SDs for ACV_{40}, ACV_{55}, ACV_{70}, and ACV_{85} at BL, PostOL, and PostTP are presented in Table 2.3. A significant decrease in ACV_{55}, ACV_{70}, and ACV_{85} occurred at PostOL compared to the BL values (p < 0.05, ES = -0.59 to -0.84). At PostTP, ACV_{40}, ACV_{55}, ACV_{70}, and ACV_{85} significantly increased compared to PostOL (p < 0.05, ES = 0.46 to 0.70), but was not different from BL (p > 0.05, ES = -0.14 to 0.15). Individual changes in ACV and 1RM are presented in Figure 2.1. The ACV was calculated as the mean of the load-velocity profile (ACV_{40}, ACV_{55}, ACV_{70}, and ACV_{85}) at each test session. The mean and SDs for ACV_{1RM} at BL, PostOL, and PostTP were 0.12 ± 0.04, 0.10 ± 0.04, and 0.11 ± 0.04 m∙s^{-1}, respectively. There were no differences between ACV_{1RM} across test sessions and small effects were observed (p > 0.05, ES = -0.45 to 0.32).
**E1RM and 1RM Comparison**

Comparisons of E1RM and 1RM values are depicted in Table 2.4. There was no condition (1RM vs. E1RM) × time (session) interaction effect (p = 0.21). There was a significant difference between 1RM and E1RM at BL (p = 0.002, ES = 0.16), yet no difference occurred at PostOL and PostTP (p > 0.008, ES = 0.08 to 0.09). E1RM at BL was no different than PostOL E1RM (p = 0.017, ES = -0.16). E1RM at PostTP was significantly higher than PostOL E1RM (p < 0.008, ES = 0.20), but not different from BL E1RM (p = 0.361, ES = 0.04). Following the taper, 1RM was significantly higher than Post OL and BL 1RM (p < 0.008, ES = 0.11 to 0.19). Figure 2.2 depicts the Bland-Altman plots for BL, PostOL, and PostTP. The 95% confidence intervals (CE ± 1.96 SD of residual scores [E1RM – 1RM]) ranged from 22.0 above, to -7.5 below the CE of 7.2 kg during baseline testing; from 20.4 above to -13.7 below the CE of 3.3 kg during overload testing, and 23.9 above to -15.9 below the CE of 4.4 kg during taper testing (Figure 2.2 and Table 2.4). The trend between the difference and mean of the E1RM and 1RM were not significant (p > 0.05) for any test session, suggesting no proportional biases existed. Pearson’s correlation coefficients were near perfect between E1RM and 1RM during each test session (r = 0.98 to 0.99).

**Internal and External Loads**

The means and SDs for internal and external loads are presented in Table 2.3 Compared to the preparatory microcycle, total volume load and bench press volume load were significantly higher during the overload, with very large effects. Levels of exertion were significantly higher and perceived recovery was significantly lower during the overload compared to the preparatory...
microcycle. Total training volume was significantly reduced during the taper compared to overload. Compared to baseline, total training volume during the taper decreased, while bench press training volume increased. Additionally, lower levels of exertion and higher perceived recovery scores were reported during the taper compared to the baseline and overload microcycles.

DISCUSSION

The purpose of the investigation was to determine the effect of overload and taper microcycles on the ACV during the bench press. Our main findings supported our hypothesis that ACV would decline after the overload microcycle and return to baseline following the taper. The overload microcycle consisted of high frequency, intensity, and volume training using multi-joint resistance exercises. Previous research has shown that this type of training results in impaired neuromuscular function and performance (13, 35). At PostOL, ACV_{55}, ACV_{70}, and ACV_{85} were significantly lower (p < 0.05) than BL indicating neuromuscular fatigue. Additionally, the measurements of internal load suggested high levels of exertion and poor recovery occurred during the overload microcycle. Similar findings occurred in a 12-week resistance training study where PRS values were lower during an overreaching phase (4.6 ± 0.8) compared to the 8-week preparatory phase (7.1 ± 0.8) (39).

It has been suggested that when carefully planned periods of overload are followed by a taper, a phenomenon known as the “rebound effect” may occur (11). Based on the fitness-fatigue model, a reduction in training volume allows for fatigue to dissipate at a faster rate than fitness, resulting in the ability to express the enhanced fitness characteristic (8, 32, 33). In the present study, the taper consisted of significantly lower training volumes compared to the overload
(Table 2.3). This reduction in training volume allowed for enhanced recovery noted by significantly lower levels of exertion and higher perceived recovery compared to the overload microcycle. These improvements in internal load parameters indicated that subjects perceived they were recovered, and objective external load assessments confirmed recovery and adaptation.

Following the taper, \( ACV_{40} \), \( ACV_{55} \), \( ACV_{70} \), \( ACV_{85} \) were significantly higher compared to PostOL, and had rebounded back to BL. Similarly, the taper produced a significant increase in 1RM compared to the PostOL 1RM. While there was no difference in ACV between PostTP and BL, the taper produced a significant increase in 1RM relative to BL which indicates that the subjects experienced a “supercompensation” in bench press strength. Similarly, 1RM bench press increased by 2% in elite Basque ball players following a 16-week training program and 4-week taper (23). In the present study, PostTP bench press 1RM increased by 6.4% and 3.7% compared PostOL and BL. Additionally, PostTP bench press ACV increased by 7.2% to 17.8% above PostOL; however there was no difference compared to BL. Similar findings have been demonstrated in jump performance when 3 days of recovery followed a 6-day intensified resistance training microcycle (35). Based on these findings, it is recommended that a taper should follow an intensified period of training to maximize strength and power.

While 1RM and ACV followed a similar trend across each test session, it is important to note that individual variability in ACV and 1RM was observed (Figure 2.2). Seven of the fifteen subjects experienced an increase or no change in 1RM after the overload microcycle while two of those seven experienced an increase in ACV. At PostTP, thirteen of fifteen subjects increased 1RM above BL, yet only six subjects increased ACV. Each subject experienced an increased 1RM at PostTP compared to PostOL; however, the results varied from 2.3 to 15.9 kg. Similarly,
PostTP ACV remained unchanged or improved above PostOL values with changes ranging from 0.00 m·s$^{-1}$ to 0.15 m·s$^{-1}$.

The individual differences in velocity and maximal strength may be partly explained by the subjects’ intent to move each repetition with maximal velocity. During the overload, perceived fatigue was significantly higher than during the preparatory and taper microcycles. This perceived fatigue may have influenced the subjects’ motivation to perform each lift with maximal concentric velocity. For instance, the subject with the highest absolute and relative bench press suffered the greatest decrease in AVC (35%) following the overload, while 1RM decreased only slightly (3%) (Figure 2.1). While subjects were instructed and verbally encouraged to perform the concentric portion of each repetition with maximal velocity, it is possible that perceived fatigue may have led to submaximal efforts during warmup sets. Another possible explanation is that measures of velocity and power decrease to a greater extent than dynamic maximal strength following intensified resistance training (12, 14). This may explain the large decreases in ACV experienced by a few of the subjects at PostOL, while 1RM was unchanged. It is possible that the duration of the overload microcycle was not long enough to cause significant decreases in maximal strength. For example, a previous study showed that maximal strength was impaired following 6 days of intensified resistance training consisting of two training sessions per day (35). Similarly, Fry et al. noted strength decrements following a 2-week overreaching protocol (13). A longer period of overload than the 4 days used in the present study may have produced greater reductions in dynamic maximal strength.

In the present study, the load-velocity relationship tended to consistently over predict 1RM on average by 7.2 kg, 3.3 kg, and 4.4 at BL, PostOL, and PostTP, respectively. These findings support previous research demonstrating E1RM derived from the load-velocity
relationship significantly overestimated back squat 1RM (3). Similar to the procedures in the present study, Banyard and colleagues developed individual load-velocity profiles using 3 sets performed up to 60%, 80%, and 90% of 1RM. Individual variation was greatest in the low load protocol (60%), as predicted 1RM varied from 48% above to 6% below the actual 1RM. While the 90% protocol was considered the most reliable, predicted 1RM varied from 28% above to 6% below the actual 1RM. These results are supported by the findings of the present study where the 95% limits of agreement ranged from 20.4 kg to 23.9 kg above and 7.5 kg to 15 kg below the CE (Figure 2.2). The large spread suggests that predicting bench press 1RM from the load-velocity relationship is inaccurate due to the large variability in E1RM values. For example, based on the limits of agreement from PostTP, one could be 95% confident that a lifter with an E1RM bench press of 150 kg would have an actual 1RM between 135 kg (150.0 kg – 15.0 kg) and 173.9 kg (150.0 kg + 23.9 kg). Due to the large variability in predicting 1RM, it is not recommended that this method be used to determine a daily 1RM for exercise prescription.

This is the first study examining the utility of the load-velocity relationship to predict 1RM in the free-weight bench press. Previous studies investigating 1RM predictions based on load-velocity relationships were performed using a Smith machine (2, 7, 24). Using an undisclosed equation, Bosquet et al. predicted 1RM Smith machine bench press in a group of physical education students and teachers (7). Actual and E1RM were significantly different and E1RM consistently under predicted actual 1RM by 5.4 kg. This differs from the findings of the present study wherein E1RM overestimated actual 1RM by 3.3 kg to 7.2 kg. Differences in exercise modalities (free weights vs. Smith machine) may explain the discrepant results.

In a comparison between the two modalities, Cotterman et al. found free-weight 1RM bench press to be significantly higher than Smith machine 1RM bench press which may provide
a basis for a biased prediction. The free-weight bench press was used in the current study since it is more practical for athletes because of increased recruitment of synergistic muscles to maintain stability. Regardless of the modality, predicting 1RM from load-velocity relationships appears to be inaccurate.

It has been suggested that an E1RM derived from an individual load-velocity profile can be used to determine daily preparedness (25). In the current study, E1RM and 1RM were lower at PostOL compared to BL. After the taper, E1RM and 1RM increased above PostOL and BL. Additionally, the relationship between E1RM and 1RM during each test session was near perfect (Table 2.4). These findings support previous research resulting in nearly perfect correlations between E1RM and 1RM (r = 0.93 to 0.98) in the Smith machine bench press (7, 24) and very large to near perfect correlations (r = 0.78 to 0.93) in free weight back squat (3).

These strong positive correlations suggest that a decline in E1RM would indicate a decline in 1RM, and an increase in E1RM would indicated an increase in 1RM. Based on these results, calculating a daily E1RM may serve as a practical monitoring tool. Currently, a repetitions-to-failure or RM assessment is the most common method for assessing fatigue and adaptation during resistance training. Several regression equations have been developed to predict 1RM based on the number of repetitions completed with an absolute load. Similar to our findings, the E1RM derived from these prediction equations had a near perfect relationship (r = 0.99) with actual 1RM and high prediction errors (28).

A major disadvantage to performing repetition maximums frequently is the excessive fatigue that can accumulate when multi-joint exercises are taken to muscular failure (9). This approach seems impractical, as the metric used to assess fatigue may be in fact leading to greater amounts of fatigue. However, measuring ACV during submaximal sets below muscular failure
offers a non-fatiguing approach. Since both methods result in similar trends and prediction errors, it is suggested that the velocity derived E1RM would be a superior choice for monitoring daily preparedness. After establishing a baseline E1RM, future estimations can be compared to the baseline value. This would provide a non-fatiguing assessment for coaches to use during the warmup period, and training loads could be regulated based on the athlete’s recovery status. While this method may be used to assess daily preparedness, it should not replace an actual 1RM used for exercise prescription purposes. Future research should investigate the utility of daily E1RM to autoregulate resistance exercise within a periodized training plan.

The present study consisted of competitive strength athletes and therefore, the results of this study should not be extrapolated to recreationally trained or untrained populations. While competitive powerlifters train with the intention of increasing maximal strength, training methods may vary. Even when following a periodized training plan, different training phases produce different physiological adaptations. For instance, during a general preparatory phase, exercise specificity and training intensity are low, while training volume is high. This leads to enhanced work capacity and muscular endurance. However, during a competition phase, exercise specificity and intensity are high, while training volume is low, leading to enhancement in strength and power. Therefore, the previous training is capable of influencing the adaptation that occurs from the subsequent training. A limitation of the present study is that the subjects’ previous training methods and recovery status were not determined prior to study commencement, which may explain the differences in individual responses during velocity and strength testing. However, it must be noted that during the screening process, subjects were excluded if they had competed in a powerlifting competition 4 weeks or less prior to study commencement. Another limitation is that the results of this study are only applicable to the free
weight bench press. Future investigations are warranted to determine the effect of intensified resistance training on repetition velocity in multi-joint lower body exercises.

In conclusion, the ACV during submaximal bench press sets appears to decline following an overload microcycle and increases back to baseline following a taper. The high levels of exertion and poor recovery during the overload microcycle had minimal impact on bench press 1RM. However, following the taper, bench press 1RM supercompensated above PostOL and BL. Based on the Bland-Altman analysis, the load-velocity relationship did not accurately predict 1RM. The E1RM was consistently higher than the 1RM during each test session, and the wide limits of agreement suggest large variability in the prediction. However, the near perfect correlations between the two measures suggest that establishing a daily E1RM may be useful for monitoring fatigue and adaptation to training.

PRACTICAL APPLICATIONS

Velocity monitoring is a non-invasive way to objectively assess resistance exercise performance. The current study demonstrated that bench press ACV was negatively impacted by an intensified week of resistance training in which high levels of perceived fatigue were reported. Therefore, coaches can use the ACV of warmup sets recorded at the beginning of a training session to monitor fatigue and recovery from resistance training. Additionally, E1RMs derived from the ACV of warmup sets can be used to indicate daily preparedness. Once a baseline E1RM is established, future E1RMs can be compared to baseline to determine fatigue and adaptation. If E1RM declines and remains suppressed compared to baseline values, the coaches can adjust training loads to allow for increased recovery. Similarly, if E1RM increases and stays elevated above baseline values, this suggests the athlete is responding favorably to
training. Future studies should investigate this method of autoregulatory resistance exercise within a periodized training plan.

REFERENCES


Figure 2.1. Individual changes in ACV and 1RM between testing sessions. (A) The change in performance following the overload compared to baseline testing. (B) The change in performance following the taper compared baseline testing. (C) The change in performance following the taper compared to the post-overload testing. ACV was calculated as the mean of the ACV_{40}, ACV_{55}, ACV_{70}, and ACV_{85}. 

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Figure 2.2. Bland-Altman plots comparing the agreement between estimated (E1RM) and actual 1RM values during the A) baseline, B) post-overload, and C) post-taper test sessions. The solid lines represent the mean bias while the horizontal dashed lines represent the 95% limits of agreement. The dashed-dotted regression lines represent the trend between the differences and means, and accompanying regression equations with coefficients of determination ($R^2$) are presented.
Table 2.1. Descriptive characteristics of male and female powerlifters (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Body Fat (%)</th>
<th>Relative bench press</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (n=3)</td>
<td>27 ± 6</td>
<td>163.8 ± 3.3</td>
<td>70.3 ± 9.2</td>
<td>31.7 ± 3.8</td>
<td>0.8 ± 0.1</td>
</tr>
<tr>
<td>Males (n=12)</td>
<td>24 ± 6</td>
<td>178.8 ± 5.4</td>
<td>98.7 ± 14.2</td>
<td>23.8 ± 5.2</td>
<td>1.5 ± 0.2</td>
</tr>
<tr>
<td>Combined (n=15)</td>
<td>25 ± 6</td>
<td>175.8 ± 7.9</td>
<td>93.0 ± 17.6</td>
<td>25.4 ± 5.8</td>
<td>1.4 ± 0.4</td>
</tr>
</tbody>
</table>

SD = standard deviation; Relative bench press presented as baseline one-repetition maximum divided by body mass.
Table 2.2. Resistance training during the preparatory, overload, and taper microcycle.

<table>
<thead>
<tr>
<th>Microcycle</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preparatory microcycle</strong></td>
<td>Back squat, 3 × 5</td>
<td>Bench press, 3 × 5</td>
<td>Deadlift, 3 × 3</td>
<td>Back squat, 5 × 3</td>
<td>Baseline Testing</td>
</tr>
<tr>
<td></td>
<td>Bench press, 3 × 5</td>
<td>RDL, 3 × 8</td>
<td>Bench press, 3 × 5</td>
<td>Deadlift, 5 × 3</td>
<td>Back squat, 3 × 3</td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 8</td>
<td>Standing OHP, 3 × 8</td>
<td>RDL, 3 × 5</td>
<td>Bench press, 5 × 3</td>
<td>RDL, 3 × 5</td>
</tr>
<tr>
<td></td>
<td>Standing OHP, 3 × 8</td>
<td>Lat Pulldown, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>Standing OHP, 3 × 8</td>
</tr>
<tr>
<td></td>
<td>Lat Pulldown, 3 × 8</td>
<td>No Resistance Training</td>
<td>Barbell row, 3 × 8</td>
<td>Standing OHP, 3 × 8</td>
<td>No Resistance Training</td>
</tr>
<tr>
<td><strong>Overload microcycle</strong></td>
<td>Back squat, 3 × 9RM</td>
<td>Bench press, 3 × 9RM</td>
<td>Back squat, 5 × 5</td>
<td>Deadlift, 5 × 3</td>
<td>Overload Testing</td>
</tr>
<tr>
<td></td>
<td>Bench press, 3 × 9RM</td>
<td>RDL, 3 × 10RM</td>
<td>Bench press, 5 × 5</td>
<td>Bench press, 7 × 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 10RM</td>
<td>Standing OHP, 3 × 10RM</td>
<td>RDL, 3 × 5</td>
<td>Leg Press, 3 × 8</td>
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<tr>
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<td>Standing OHP, 3 × 10RM</td>
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<td>Lat Pulldown, 3 × 10RM</td>
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<tr>
<td></td>
<td>Deadlift, 5 × 5RM</td>
<td>Bench press, 4 × 7RM</td>
<td>Deadlift, 5 × 3</td>
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<tr>
<td></td>
<td>Bench press, 4 × 7RM</td>
<td>Leg press, 3 × 10RM</td>
<td>Back squat, 5 × 5</td>
<td>Back squat, 5 × 3</td>
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<tr>
<td></td>
<td>Leg press, 3 × 10RM</td>
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<td>Bench press, 5 × 5</td>
<td>Bench press, 7 × 3</td>
<td></td>
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<tr>
<td></td>
<td>Standing OHP, 3 × 8</td>
<td>Pull-up, 3 × 8RM</td>
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<td>Leg Press, 3 × 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pull-up, 3 × 8RM</td>
<td>No Resistance Training</td>
<td>Seated OHP, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
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<td></td>
<td>No Resistance Training</td>
<td>No Resistance Training</td>
<td>Barbell row, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
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<tr>
<td><strong>Taper microcycle</strong></td>
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<td>Bench press, 4 × 5</td>
<td>Deadlift, 3 × 3</td>
<td>Taper Testing</td>
<td></td>
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<tr>
<td></td>
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<td>RDL, 3 × 8</td>
<td>Bench press, 3 × 3</td>
<td></td>
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<tr>
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<td>RDL, 3 × 8</td>
<td>Standing OHP, 3 × 8</td>
<td>Leg press, 3 × 8</td>
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<tr>
<td></td>
<td>Standing OHP, 3 × 8</td>
<td>Lat Pulldown, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
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<tr>
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<td>No Resistance Training</td>
<td>Barbell row, 3 × 8</td>
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<td>No Resistance Training</td>
<td>No Resistance Training</td>
<td>No Resistance Training</td>
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</tbody>
</table>

OHP = overhead press; RDL = Romanian deadlift; *All sets performed to an RPE 6-8; **Load calculated as 90% and 85% of average load used during Days 3 and 4, respectively, of overload microcycle.
Table 2.3. Comparison of internal and external load parameters between training weeks (n=15).

<table>
<thead>
<tr>
<th></th>
<th>Microcycle (mean ± SD)</th>
<th>Comparison Statistics (p, ES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BL</td>
<td>OL</td>
</tr>
<tr>
<td><strong>External Load</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total VL (kg)</td>
<td>26853.5 ± 8123.9</td>
<td>55600.8 ± 16529.6</td>
</tr>
<tr>
<td>Bench press VL (kg)</td>
<td>4494.8 ± 1479.0</td>
<td>11845.9 ± 3753.3</td>
</tr>
<tr>
<td><strong>Internal Load</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sRPE</td>
<td>5.4 ± 1.2</td>
<td>8.5 ± 0.8</td>
</tr>
<tr>
<td>PRS</td>
<td>7.2 ± 1.2</td>
<td>5.3 ± 1.2</td>
</tr>
<tr>
<td><strong>Bench Press Velocity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACV&lt;sub&gt;40&lt;/sub&gt; (m·s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>0.92 ± 0.09</td>
<td>0.87 ± 0.13</td>
</tr>
<tr>
<td>ACV&lt;sub&gt;55&lt;/sub&gt; (m·s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>0.74 ± 0.09</td>
<td>0.68 ± 0.12</td>
</tr>
<tr>
<td>ACV&lt;sub&gt;70&lt;/sub&gt; (m·s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>0.58 ± 0.06</td>
<td>0.50 ± 0.12</td>
</tr>
<tr>
<td>ACV&lt;sub&gt;85&lt;/sub&gt; (m·s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>0.39 ± 0.06</td>
<td>0.34 ± 0.09</td>
</tr>
</tbody>
</table>

BL = Baseline; OL = overload; TP = Taper; VL = volume load; sRPE = session rating of perceived exertion; PRS = perceived recovery status; 1RM = one-repetition maximum; ACV<sub>40</sub> = average concentric velocity at 40% of one-repetition maximum; ACV<sub>55</sub> = average concentric velocity at 55% of one-repetition maximum; ACV<sub>70</sub> = average concentric velocity at 70% of one-repetition maximum; ACV<sub>85</sub> = average concentric velocity at 85% of one-repetition maximum, ES= effect size.
Table 2.4. Comparison between estimated (E1RM) and actual 1RM values during baseline, overload, and taper test sessions (n=15).

<table>
<thead>
<tr>
<th>Value</th>
<th>Mean ± SD</th>
<th>ES</th>
<th>r</th>
<th>SEE</th>
<th>CE ± 1.96 SD</th>
<th>Upper</th>
<th>Lower</th>
<th>Trend</th>
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</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1RM</td>
<td>131.7 ± 44.7</td>
<td>0.16</td>
<td>0.99</td>
<td>3.1</td>
<td>7.2 ± 14.8</td>
<td>22.0</td>
<td>-7.5</td>
<td>0.16</td>
</tr>
<tr>
<td>E1RM</td>
<td>138.9 ± 46.6§</td>
<td>0.16</td>
<td>0.99</td>
<td>3.1</td>
<td>7.2 ± 14.8</td>
<td>22.0</td>
<td>-7.5</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Overload</strong></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>1RM</td>
<td>128.4 ± 42.0</td>
<td>0.08</td>
<td>0.98</td>
<td>3.7</td>
<td>3.3 ± 17.1</td>
<td>20.4</td>
<td>-13.7</td>
<td>0.12</td>
</tr>
<tr>
<td>E1RM</td>
<td>131.7 ± 41.8</td>
<td>0.08</td>
<td>0.98</td>
<td>3.7</td>
<td>3.3 ± 17.1</td>
<td>20.4</td>
<td>-13.7</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Taper</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1RM</td>
<td>136.5 ± 44.8†‡</td>
<td>0.09</td>
<td>0.98</td>
<td>3.0</td>
<td>4.4 ± 19.5</td>
<td>23.9</td>
<td>-15.0</td>
<td>0.35</td>
</tr>
<tr>
<td>E1RM</td>
<td>141.0 ± 49.2‡</td>
<td>0.09</td>
<td>0.98</td>
<td>3.0</td>
<td>4.4 ± 19.5</td>
<td>23.9</td>
<td>-15.0</td>
<td>0.35</td>
</tr>
</tbody>
</table>

1RM = one-repetition maximum in kg; E1RM = estimated one-repetition maximum in kg; SD = standard deviation; ES = effect size SEE = standard error of the estimate; CE = constant error; § p < 0.05 vs. 1RM; † p < 0.05 vs. baseline testing; ‡ p < 0.05 vs. overload testing.
CHAPTER 3
ACCURACY OF ESTIMATING REPETITIONS TO FAILURE FOLLOWING OVERLOAD AND TAPER MICROCYCLES

ABSTRACT

The purpose of this study was to determine the accuracy of estimating repetitions to failure (ERTF) in the bench press exercise following an overload microcycle and taper. Fourteen well-trained subjects (2 women) completed 3 weeks of resistance training including a preparatory microcycle, overload microcycle, and taper. During baseline (BL), post-overload (PostOL) and post-taper (PostTP) testing, subjects performed a set of bench press consisting of 8 repetitions at 70% of baseline one-repetition maximum. After completing 8 repetitions and holding the barbell in the lockout position, subjects indicated their ERTF before continuing the set to concentric muscular failure, which was determined as the actual repetitions to failure (ARTF). A significant interaction was found for time (session) and condition (ERTF vs. ARTF) (p = 0.001). There were no differences between ERTF and ARTF at BL (3.3 ± 1.6 vs. 3.3 ± 1.1, p = 0.431) or PostOL (2.7 ± 1.7 vs. 2.5 ± 2.0, p = 0.336). However, ERTF and ARTF were significantly different at PostTP (3.9 ± 1.5 vs. 5.2 ± 2.3, p = 0.001). Additionally, ARTF at PostTP were significantly higher than PostOL and BL (both p < 0.008), whereas PostTP ERTF was significantly higher than PostOL ERFT only (p = 0.001). The Bland-Altman 95% limits of agreement indicated that ERTF was most accurate at PostOL, which may be because of fewer ARTF completed during this session. These results suggest that ERTF may be used to predict
changes in ARTF across training sessions; however this method is most accurate when ARTF in a set are smaller.

**Key Words:** Perceived Exertion, Athlete Monitoring, Autoregulatory Resistance Training, Powerlifting

**INTRODUCTION**

In preparation for a competition, athletes will attempt to intensify training as a means to induce functional overreaching (8, 14). Overreaching is the accumulation of stress leading to short-term decrements in performance. However, when followed by a taper, the athlete can experience a supercompensation in performance (2, 4, 27, 28). Currently, the ability to detect overreaching is limited and is most commonly indicated by a decrease in performance. In resistance training, a repetition maximum (RM) test is commonly used to assess performance. Autoregulatory Progressive Resistance Exercise (APRE) is a method that incorporates a set of repetitions to fatigue as a means of determining training loads for the subsequent training session. While this method has been shown to be effective (22), frequently performing sets to muscular failure with multi-joint exercises can lead to increased fatigue (6). While peaking for a competition, increased fatigue can reduce preparedness and potentially have a negative impact on subsequent training sessions or competition performance. Therefore, a key component of peaking for a competition is the ability to accurately monitor training loads without using tests that result in additional fatigue.

Monitoring resistance training loads is crucial to providing an optimal training stimulus and detecting the onset and progression of fatigue. One measure commonly used to quantify the internal load associated with the stress of resistance exercise is perception of exertion.
Historically, rating of perceived exertion (RPE) has been used to assess resistance exercise exertion, but due to its inability to accurately assess exertion levels during an exercise set to failure (11, 33), an alternative scale based on repetitions in reserve was developed (37). This scale appears to improve rating perceived exertion by adding a descriptor of repetitions remaining that corresponds to an RPE value. Zourdos et al. (37) found this scale to be a valid method of gauging resistance training intensity in a group of novice and experienced lifters performing squats. Additionally, they observed strong inverse relationships between RPE and repetition velocity in the back squat, bench press, and deadlift (16). As the load of the barbell increased, repetition velocity decreased and the repetitions in reserve decreased. Thus, RPE based on repetition in reserve appears to be useful in regulating training intensity for the lifts involved in powerlifting.

During a resistance training session, acute fatigue leads to impaired neuromuscular performance which increases the perception of effort for an absolute load lifted (31), and reduces the repetition velocity during a set and among subsequent sets (19). Hackett and colleagues investigated the effects of acute fatigue on estimated repetitions-to-failure (ERTF) during 5 sets of squat and bench press (11). A strong positive relationship was found between ERTF and actual repetitions-to-failure (ARTF) in the squat ($r = 0.93$) and bench press ($r = 0.95$). Interestingly, the accuracy of ERTF improved with each set indicating that as a subject accumulated more fatigue, they were better able to predict ARTF. It is possible that these improvements occurred because subjects were closer to muscular failure sooner with each set performed. While evidence suggests that ERTF can be used to determine acute fatigue within a single training session, the application of assessing ERTF following an intensified week of resistance training remains unknown. Therefore, the purpose of this study was to determine the
accuracy of ERTF following an overload microcycle and taper. We hypothesized that ERTF and ARTF would decrease following the overload and return back to baseline or increase following the taper. Additionally, we hypothesized that there would be no difference between ERTF and ARTF at each testing session.

**METHODS**

**Experimental Approach to the Problem**

Subjects performed a repetition to failure assessment with 70% of baseline bench press one-repetition maximum (1RM). During the set, subjects completed 8 repetitions before holding the barbell in a lockout position with elbows extended and verbally reporting their ERTF. Once a value was indicated, the subjects continued the set until reaching volitional exhaustion which was indicated by an inability to perform the concentric phase of the lift. The same protocol was completed following a four-day overload microcycle, and again after a six-day taper. Following the overload and taper microcycles, subjects attempted a new 1RM; whereas the loads used during the repetition-to-failure assessment remained constant. The accuracy of ERTF was determined by comparing to ARTF across all three test sessions.

**Subjects**

Fourteen resistance-trained participants (2 women) were recruited for this study (Table 3.1). Subjects were competitive and recreational powerlifters. Competitive powerlifters are individuals who have previously competed in a sanctioned powerlifting competition, whereas recreational powerlifters have not competed but perform each of the powerlifts (back squat, bench press, and deadlift) at least once a week. Subjects were recruited from the University of
Alabama and a local powerlifting training center. All subjects were healthy, non-smoking volunteers who were classified as low or moderate risk according to the guidelines established by the American College of Sports Medicine (25). To minimize any confounding effects associated with age-related differences in skeletal muscle recovery between younger and older individuals, only subjects between the ages of 18-40 years were included in this study (24).

All prospective subjects completed an exercise screening questionnaire, PAR-Q, and health history questionnaire to determine if they met the inclusion criteria. To qualify for inclusion in the study, subjects had to have at least one year of resistance training experience and meet the national qualifying requirements for drug-tested athletes established by the United States Powerlifting Association (1). The powerlifting totals used to determine study inclusion were gathered from a previous competition or test session. Additionally, all subjects were free from cardiovascular, metabolic, neurological, or musculoskeletal disorders that would affect the study results. Prior to participation, all subjects signed a written informed consent document approved by the local Institutional Review Board.

**Experimental Protocols**

During the initial visit, subjects’ standing height was measured using a stadiometer (SECA 67310, SECA®, Chino, CA) and weight was determined using a digital scale (Tanita BWB-800, Tanita®, Arlington Heights, IL). Body composition was assessed using dual-energy X-ray absorptiometry (Lunar Prodigy, General Electric Healthcare, Madison, WI). Subjects were provided instruction regarding the resistance training program and performance measures administered during the study.

*Resistance Training Protocol*
Within one week after the initial visit, subjects reported to a weight training facility to begin the 3-week resistance training program. This program consisted of a preparatory microcycle, overload microcycle, and taper. Before participating in each training session, each subject’s perceptual recovery was determined using the Perceived Recovery Status (PRS) scale. After indicating perceived recovery, subjects completed a full-body, dynamic warmup that was standardized across each session. All training sessions were monitored by a Certified Strength and Conditioning Specialist.

The preparatory training period consisted of 3 non-consecutive days over a 5-day period using a total-body program (Table 3.2). Training loads were determined based on the subjects’ ERTF. All exercise sets during the preparatory period were completed using a load that allowed the subject to have between 2-4 ERTF. On the fifth day of the preparatory week (BL), baseline assessments were performed before completing the third resistance training session.

Two days after BL, subjects began an overload week of resistance training, with the purpose of overreaching. Resistance training was performed on 4 consecutive days using a total-body program (Table 3.2). Daily undulations in training volume and intensity were used to incorporate high load and high volume training as a means of inducing central and peripheral fatigue. All sets were performed using repetition maximums and training loads were adjusted to ensure all sets were performed to muscular exhaustion. If participants reached muscular failure before completing the required repetitions in a given set, the load was reduced for the subsequent sets to ensure desired training volume was obtained. On the fifth day of the overload week (PostOL), subjects completed the same assessments administered at BL. To minimize any confounding effects for time of day, subjects completed PostOL at the same time of day as BL. Following PostOL, subjects received 48 hours of active rest before tapering.
The taper week consisted of 2 non-consecutive days of training over a 5-day period. Each day contained the same total body exercises used in the overload week; however, total training volume was substantially reduced (Table 3.2). In an attempt to enhance performance, only small reductions in training intensity were programmed (14, 26, 29). Training loads were adjusted to 90% and 85% of the average load used during days 3 and 4, respectively, of the overload week. Taper performance measures were recorded on the fifth day of the taper week (PostTP). Each subject performed the same measures at the same time of day as performed during BL and PostOL.

Prior to arrival of each performance testing session, subjects were instructed to refrain from caffeine at least 4 h and alcohol at least 24 h prior to testing. A 24-h recall was used to determine recent food and supplement consumption as well as compliance with pre-test instructions. Before participating in performance testing, subjects rated their perceptual recovery using the PRS scale as described in the next section.

Internal and External Load

Before each training and test session, subjects recorded a PRS score. The PRS scale is a subjective rating from 0 to 10, with 0-2 representing poor recovery and anticipating poor performance, 4-6 consisting of moderate recovery and expecting normal performance, and 7-10 representing high recovery and expecting increased performance. This scale has been validated as a useful tool in monitoring fatigue and performance in anaerobic exercise (21, 34). The subjects were informed of the purpose of the PRS scale and read specific instructions on how to interpret the scale. Additionally, session rating of perceived exertion (sRPE), a metric capable of quantifying the global rating of internal load (7, 23, 32), was collected 15 minutes following the completion of each training session (20). Using a modified CR-10 RPE scale (7), subjects were
asked to indicate the difficulty of their workout in which a value near 0 suggests easy training and a value near 10 suggests very hard training. In addition to internal load measures, external loads were calculated to quantify the amount of work performed during each microcycle. Repetition volume was quantified as the total number of repetitions completed. Volume load was determined by multiplying the load lifted by the repetitions completed in a given set. The volume load could then be calculated for a specific exercise, training session, or training week.

One-Repetition Maximum (IRM) Assessment

On the fifth day of each week subjects completed a 1RM bench press assessment. All bench press assessments were performed on an instrumented bench (Forza Super Bench, Forza Strength Systems, Spokane Valley, WA) using a 20.4-kg powerlifting competition barbell (Rogue Fitness, Columbus, OH). Subjects were instructed on how to perform the bench press to meet United States Powerlifting Association standards (1). Hand position on the barbell was recorded for each subject and maintained consistent for each trial. Subjects began the assessment by performing five progressive warm-up sets in the bench press before attempting a 1RM. The first set consisted of 5 repetitions with an unloaded barbell, followed by 3 repetitions at 40%, 2 repetitions at 55%, and 1 repetition each at 70% and 85% of previously acquired 1RM. During each bench press attempt, the subjects would un-rack the barbell with assistance from a spotter. After receiving a secure hand off, the barbell was lowered to the chest and held motionless with a definite and visible pause. Once the primary investigator determined the bar was motionless, a verbal “press” command was given and the subject proceeded to press the barbell to the lockout position. Subjects were given verbal encouragement to press the barbell with maximal velocity on each repetition.
Two minutes after completing the one repetition at 85% of 1RM, subjects began 1RM bench press attempts. Each attempt was selected by the primary investigator using measured repetition velocity and perceptual feedback (i.e., ERTF) from the subject. The average concentric velocity (ACV) was measured using a linear position transducer (GymAware PowerTool, Kinematic Performance Technology, Canberra, Australia), which has been previously validated for measuring barbell velocity (18). The velocity feedback was used to objectively assess each attempt and subsequent loads were selected based on reported ACV for competitive powerlifters in the bench press (16). Additionally, a 1RM was determined based on the methods of Zourdos and colleagues (37): 1) Subject reported a 10 RPE and primary investigator agreed a subsequent attempt would not be successful with a 2.3-kg load increase or 2) subject reported a 9 or 9.5 RPE followed by a failed attempt with a 2.3-kg load increase. If the subject failed to complete the concentric portion of the lift or did not pause on the chest, the attempt was deemed unsuccessful.

Repetitions-to-Failure Assessment

Following attainment of a successful 1RM bench press, each subject was provided ten minutes of passive rest. After the recovery period, the subjects completed a bench press repetition to failure assessment with 70% of baseline 1RM. Based on the relationship between % 1RM and repetitions allowed, 70% of 1RM should allow for approximately 11 repetitions before reaching muscular fatigue (12). After receiving a secured handoff, the subjects performed 8 repetitions, adhering to the same guidelines provided during the 1RM assessment. Following the completion of the 8th repetition, the subjects held the barbell in the lockout position with elbows fully extended for approximately 5 seconds. During this time, subjects were asked to verbalize their ERTF. After indicating their ERTF, subjects continued performing repetitions until volitional exhaustion which was indicated by the inability to perform the concentric phase of the
lift. Subjects were instructed to perform the concentric phase of each repetition as explosively as possible. Spotters provided verbal encouragement and provided assistance in safely removing the barbell from the subject after reaching muscular failure.

**Statistical Analysis**

Data were analyzed using SPSS Statistics version 24.0 (IBM Corporation, Armonk, NY). A 2 × 3 repeated measures analysis of variance (ANOVA) was used to compare mean differences between ERTF and ARTF across the testing sessions performed at BL, PostOL, and PostTP. Paired samples t-tests with a Bonferroni adjusted critical value were used to determine where the mean differences occurred. This procedure involved dividing the p-value by the number of comparisons (i.e., 0.05 / 6 = 0.008). Therefore, significance for the paired samples t-tests was set at p < 0.008. A one-way repeated measures ANOVA was used to compare means for total repetitions and 1RM across each test session. When appropriate, a Bonferroni post hoc analysis was used to determine where the differences between means occurred. For measures of internal and external load, the Friedman’s test was used to compare differences. Additionally, this non-parametric test was used to test difference for non-normally distributed data. If significance was found in the Friedman’s test, a Wilcoxon signed rank test was performed to determine where differences occurred.

Cohen’s effect sizes were calculated and Hopkin’s scale of magnitude was used where an effect size of 0-0.02 was trivial, 0.2-0.6 was small, 0.6-1.2 was moderate, 1.2-2.0 was large, and >2.0 was very large (17). Bland-Altman plots were created to assess the agreement between ERTF and ARTF at each of the time points (3). Data are presented as means ± SD and the level of significance was set at p < 0.05.
RESULTS

ERTF and ARTF Comparison

Data for ERTF and ARTF at BL, PostOL, and PostTP are presented in Table 3.3. A significant interaction was found for condition (ERTF and ARTF) and time (BL, PostOL, and PostTP) (p = .001). ARTF was significantly higher than ERTF at PostTP (p = 0.001), but not at BL and PostOL. ARTF values ranged from 1 to 6 repetitions, and ERTF values ranged from 1 to 5 repetitions at BL. There was no difference between ERTF and ARTF at BL (p > 0.431, ES = 0.26). The overload microcycle resulted in a non-significant decrease in ERTF (p = 0.120, ES = -0.39) and ARTF (p = 0.012, ES = -0.64). ARTF values varied from 0 to 6, while ERTF varied from 0 to 5 at PostOL. There was no difference between ERTF and ARTF at PostOL (p = 0.37). Following the taper, ERTF and ARTF increased significantly compared to PostOL (p < 0.008, ES = 0.71 to 1.27). Compared to BL, ARTF at PostTP was significantly higher (p = 0.006, ES = 0.80); however, ERTF was not different (p = 0.120, ES = 0.44). There were statistically significant correlations between ERTF and ARTF at PostOL (r = 0.91, p < 0.01) and PostTP (r = 0.88, p < 0.01), while a non-significant moderate correlation was found at BL (r = 0.31, p = 0.27). Individual comparisons for ERTF and ARTF at BL, PostOL, and PostTP are presented in Figure 3.1.

Bland-Altman Error Analysis

The Bland-Altman plots are presented in Figure 3.2. The constant error (CE) between ERTF and ARTF at BL was -0.4, indicating that ERTF tended to under predict ARTF by 0.4 repetitions. In addition, the 95% limits of agreement varied from -3.6 to 2.9 repetitions. The CE
for between ERTF and ARTF at PostOL was -0.2 repetitions, and 95% limits of agreement varied from -1.4 to 1.8 repetitions. At PostTP, the CE for between ERTF and ARTF was -1.4 repetitions, and 95% limits of agreement varied from -3.7 to 1.0. The trends, which were calculated as the correlation between the x- (i.e., ARTF) and the y- (i.e., the difference between estimated and actual repetitions) axes of the Bland-Altman plot were statistically significant for baseline \((r = 0.75, p < 0.01)\) and taper testing \((r = 0.87, p < 0.01)\), but was not statistically significant during overload testing \((r = 0.47, p > 0.05)\).

**Repetition Maximum Results**

The total number of repetitions completed in the repetitions to failure assessment at BL, PostOL, and PostTP were 11.6 ± 1.6, 10.5 ± 2.0, 13.2 ± 2.3, respectively. Total repetitions were not different from PostOL to BL \((p = 0.07, ES = -0.60)\). Following the taper, total repetitions significantly increased above PostOL \((p < 0.01, ES = 1.27)\) and BL \((p < 0.05, ES = 0.83)\). The mean and SD for 1RM during BL was 137.9 ± 39.3 kg. PostOL 1RM was 134.3 ± 36.5 kg, which was not statistically significant from baseline \((p = 0.22 ES = -0.08)\). At PostTP, 1RM increased to 142.9 ± 38.9 kg, which was significantly higher than PostOL \((p < 0.01, ES = 0.19)\) and BL \((p < 0.05, ES = 0.11)\).

**Internal and External Loads**

Total volume load and bench press volume load during the preparatory microcycle were 27952.6 ± 7180.7 kg and 4693.3 ± 1311.3 kg, respectively. Mean and SDs for perceived recovery and sRPE were 7.1 ± 1.2 and 5.4 ± 1.2, respectively. Total volume load and bench press volume load during the overload microcycle was 57634.3 ± 15209.7 kg and 12362.1 ± 3296.6 kg.
kg. These external loads were significantly higher than baseline values (p < 0.01, ES = 2.50 – 3.06). Perceived recovery during the overload microcycle was 5.3 ± 1.2, which was significantly lower than BL values (p < 0.01, ES = 1.50). Additionally, sRPE values increased to 8.5 ± 0.7, which was significantly greater than baseline (p < 0.01, ES = 3.22). Total volume load and bench press volume load during the taper were 19060.1 ± 4570.4 kg and 5130.0 ± 1412.8 kg, respectively. These external loads were significantly lower than overload (p < 0.01, ES = -2.85 to -3.43). Compared to the preparatory values, total volume load was significantly lower (p < 0.01, ES = -1.48), while bench press training volume was significantly higher (p = 0.02, ES = 0.32). During the taper, perceived recovery scores increased to 8.3 ± 1.2, which was significantly greater than overload (p < 0.01, ES = 2.52) and BL scores (p < 0.01, ES = 1.03). Additionally, sRPE values during the taper decreased to 3.6 ± 1.4, which was significantly lower than overload (p < 0.01, ES = -4.48) and BL values (p < 0.01, ES = -1.10).

DISCUSSION

The purpose of this investigation was to assess the accuracy of ERTF following an overload microcycle and taper in competitive and recreational powerlifters. The primary finding was that our hypothesis that there would be no difference in ERTF and ARTF during each test session was partially supported by the results of this study. A significant interaction was found for time (test session) and condition (ERTF and ARTF), with ARTF being significantly higher than ERTF at PostTP. At BL and PostOL, ERTF and ARTF were not significantly different and the magnitude of effect was trivial. Our hypothesis that ARTF would decline following the overload and return to baseline or increase following the taper was supported. Although non-significant, the overload microcycle produced small to moderate decreases in ERTF and ARTF.
compared to BL. At PostTP, ERTF and ARTF significantly increased above PostOL. ARTF at PostTP were significantly greater than BL ARTF indicating a positive adaptation in bench press performance. While PostTP ERTF increased above PostOL indicating subjects perceived improved performance, PostTP ERTF did not accurately predict the PostTP ARTF. Not only were the means values statistically different, but Cohen’s $d$ statistic indicated a moderate practical difference. Additionally, ERTF at PostTP tended to consistently under predict ARTF by 1.4 repetitions, and the wide 95% limits of agreement indicated large errors occurred in the estimations. Based on the 95% limits of agreement (-3.7 to 1.0), a person who reported 5 ERTF would be expected to obtain an ARTF of approximately 4 repetitions (5 - 1) to approximately 8 repetitions (5 + 3.7).

At PostOL, the CE was smaller and the 95% limits of agreement were tighter compared to BL and PostTP. Based on the PostOL 95% limits of agreement, a person who reported 5 ERTF would be expected to obtain an ARTF of approximately 3 repetitions ($5 - 1.4$) to 6 repetitions ($5 + 1.8$). At PostOL, only one participant had experienced a difference between ERTF and ARTF > 1 repetition; whereas 7 participants at BL and 6 participants at PostTP had a repetition difference > 1 repetition (Figure 3.2). This discrepancy could possibly be explained by the higher number of ARTF completed at BL and PostTP compared to PostOL (3.6 and 5.2 vs. 2.5). This suggests that the further a lifter is away from muscular failure, the more difficult it will be to accurately gauge how many repetitions are remaining until reaching muscular failure.

Similar findings were reported by previous research examining the accuracy of ERTF in a group of bodybuilders performing 5 sets of bench press with a similar repetition-to-failure protocol (11). Hackett et al. concluded that the accuracy of the ERTF was dependent on the number of ARTF. During the first two sets, ARTF was significantly higher than ERTF with small to
moderate magnitude of difference. However, as the subjects became more fatigued, the number of ARTF decreased and the accuracy of ERTF improved. In the present study, subjects were most fatigued following the overload microcycle, and the lowest number of ARTF occurred at PostOL. Additionally, the Bland-Altman analysis indicated that the PostOL CE was low, the 95% limits of agreement were tighter, and the magnitude of effect between ERTF and ARTF was trivial. In a follow up study, Hackett et al. supported their previous findings that ERTF accuracy progressively decreased as ARTF increased (10). When ARTF was 0-5 repetitions, the error of ERTF was < 1 repetition. However, when ARTF was 7-10 repetitions, the error significantly increased to > 2 repetitions. For this reason, the RPE scale based on repetition in reserve was developed using ranges and descriptors for scores ≥ 4 repetitions remaining (15). For instance, the scale contains an RPE rating of 5-6 to quantify 4-6 repetitions remaining until failure, and an RPE 3-4 would indicate a light effort in which the probability of accurately estimating repetitions in reserve would likely be poor. In the current study, RPE was not reported during the repetition to failure assessment. Nevertheless, our findings support previous research that demonstrates that ERTF was most accurate the closer the set is to concentric muscular failure.

Previous research has suggested that ERTF can accurately determine acute neuromuscular fatigue during an exercise session (11). During 5 sets of bench press, a subsequent decrease in ERTF and ARTF occurred until subjects were no longer able to reach the prescribed repetition goal during set 5. This decline in ERTF and ARTF indicates that neuromuscular fatigue increased with each additional set. Based on the strong relationship between ERTF and ARTF (r = 0.95), Hackett et al. concluded that ERTF may be used to assess preparedness between training sessions (11). Preparedness is the difference between fitness and fatigue after-effects (5). Following an intense training session, fitness and fatigue both increase,
but the ability to express fitness is masked by a larger increase in fatigue. However, following a recovery period, fatigue dissipates at a faster rate than fitness allowing for enhanced performance. The ability to determine daily preparedness is a crucial aspect of the monitoring process, and may be necessary for providing the appropriate training stimulus for achieving peak performance.

Currently, repetition maximums serve as the most common method for objectively assessing preparedness for resistance exercise. Performing a repetition maximum assessment is a time intensive process, which requires multiple personnel to ensure the safety of the participant. Frequently performing multi-joint exercises to or beyond concentric muscular failure can result in increased muscle damage and excessive metabolic stress (6), which decreases force production (9, 30). In addition, this approach may increases the risk of over-training and developing overuse injuries (35, 36). Therefore, using a repetition maximum assessment to frequently gauge fatigue and adaptation to resistance exercise is impractical, as it may induce greater fatigue leading to reduced performances in subsequent training sessions or competitions. An alternative approach would consist of performing a resistance exercise set using a fixed load and determining changes in ERTF from session to session. An increase in ERTF would be indicative of positive adaptations to training, while decreases in ERTF may suggest excessive fatigue.

The purpose of the present study was to determine changes in ERTF and ARTF following an overload and taper resistance training microcycles. Following the overload, there was a small to moderate decrease in ERTF (ES = -0.39) and ARTF (ES = -0.64) despite large changes in perceived recovery (ES = -1.50). The non-significant change in ARTF was accompanied by a trivial non-significant decrease in 1RM (ES = -0.08). The overload week of training consisted of
high intensity and high volume resistance training that was expected to impair resistance training performance. Previous research demonstrated that 6 days of intensified resistance training, consisting of morning and afternoon training sessions, resulted in increased perceived fatigue and a decrease in maximal dynamic strength (30). Additionally, Fry et al. observed significantly decreased squat 1RM following a 2-week overtraining squat protocol (9). In contrast, the present study did not find significant changes in bench press 1RM following a 4-day overload. The previous studies (9, 30) contained over twice the number of intensified training sessions as the present study. It is possible that the 4-day overload microcycle was not long enough to result in excessive neuromuscular fatigue that would lead to drastic changes in resistance training performance.

Following the taper, subjects experienced very large improvements in perceived recovery and also achieved significant increases in total repetitions to failure and 1RM compared to PostOL. These findings support previous research by Raeder et al. wherein perceived fatigue decreased and dynamic strength increased following 4 days of passive recovery (30). In the present study, the taper consisted of a significant decrease in bench press and total training volume, while maintaining moderate to high intensity (85-90% of repetition maximums). Another study has demonstrated that a one week taper significantly increased peak force output in competitive strength athletes (13). In the present study, the taper produced a 3.7% and 6.4% increase in 1RM compared to BL and PostOL, respectively. Additionally, subjects experienced a significant increase in ARTF. While there was a significant difference between ERTF and ARTF, ERTF was significantly higher at PostTP compared to PostOL indicating that subjects perceived increased performance following the taper. As previously mentioned, the discrepancy between ERTF and ARTF at PostTP may be explained by a greater number in ARTF making the
estimation more challenging. Therefore, we recommended that when using this method to assess preparedness, sets should be performed at an intensity where ARTF are closer to zero.

It is worth noting that the present study included some limitations. First, the subjects were comprised of competitive and recreational powerlifters that frequently perform the bench press exercise. It is postulated that training experience is an important factor in rating exertion levels during resistance exercise. Zourdos et al. noted that experienced lifters were more accurate than novice lifters at indicating repetitions in reserve for the back squat (37). However, the findings of Hackett et al. suggest that training experience has no effect on the accuracy of ERTF when chest press ARTF were ≤ 5 repetitions (10). Second, the results of this study can only be extrapolated to the free-weight bench press. Performing a free-weight bench press requires a greater amount of skill and stability compared to a machine chest press, which may influence the accuracy of the ERTF. However previous research has suggested ERTF to be accurate in the free-weight bench press (11), as well as a pin loaded chest press machine (10). Third, the repetition to failure assessment was performed 10 minutes following the last 1RM attempt during each test session. It is possible that the fatigue accumulated from the previous 1RM attempts may have influenced the perception of the subjects and influence the accuracy of ERTF values. Furthermore, this may have impacted the motivation of the subjects to achieve true muscular failure during the assessment. To minimize this effect, the same load and recovery period was used during each test session in an attempt to control for these confounding effects. Lastly, we cannot exclude the possibility that the accuracy of the ERTF was influenced by individual goals set by the subjects. It is possible that subjects’ motivation to continue the set to muscular failure would diminish once the goal repetition was achieved. Similarly, the subjects may have indicated a lower ERTF in order to exceed their goal repetition. However, all participants in the present study were
competitive strength athletes that were familiar with training to muscular failure and spotters provided verbal encouragement to motivate subjects to reach concentric failure.

In conclusion, the accuracy of ERTF was highest PostOL when ARTF were closest to zero. During the BL and PostTP, the number of ARTF were higher which decreased the accuracy of ERTF. ERTF was sensitive to increases in dynamic strength that occurred following the taper. Although different from ARTF, ERTF was significantly higher than PostOL indicating subjects perceived a better performance. Based on these findings, using ERTF to assess preparedness will be most effective when ARTF are closer to zero.

PRACTICAL APPLICATIONS

This method offers a practical approach to assessing preparedness during a training session. Instead of performing a set of repetitions to failure, the athlete can be instructed to perform as many repetitions as possible until reaching an ERTF threshold (i.e., 2 repetitions shy of failure). The current use of this approach consists of performing a resistance exercise set to a prescribed repetition and then recording an ERTF value. However, we suggest prescribing a load and ERTF value for a specific set. This would consist of the athlete performing as many repetitions as possible until reaching the prescribed ERTF threshold. This approach is recommended because of the high inter-individual variability in repetitions completed to failure using a % of 1RM. In the present study, subjects performed the repetition to failure assessment with 70% baseline 1RM. Repetitions during baseline ranged from 9 to 14. Consequently, if one sets a fixed repetition number for the athlete to achieve before indicating their ERTF, they may reach failure before meeting the repetition goal or may be too far away from failure to accurately
estimate ARTF. Therefore, prescribing a load and an ERTF value would ensure the proper training stimulus is provided and increase the accuracy of the weekly repetition comparisons.

Based on the results of the present study and previous findings from Hackett et al. (10, 11) we recommend using an ERTF value of 2-3 repetitions. Less than 2 repetitions increases the risk of reaching muscular failure, but more than 3 repetitions increases the risk of inaccurate estimations. First, a baseline value should be established with a fixed load. For example, an athlete is prescribed a set of bench press at 100 kg with 2 ERTF. During the baseline assessment, the athlete achieves 8 repetitions with 2 ERTF. The following training session, the same protocol can be used to assess preparedness. Fatigue would be indicated if the athlete performs less than 8 repetitions, while adaptation would be indicated if more than 8 repetitions are achieved.

In addition to assessing daily preparedness, this approach may also be used in combination with the APRE method (22) to autoregulate training loads. Instead of performing repetitions to failure on set 3 of the protocol, an ERTF threshold can be prescribed. For example, on the third set of bench press, an athlete is prescribed 120 kg at 2 ERTF. The athlete performs 6 repetitions before perceiving 2 repetitions until concentric failure. These 6 repetitions can be added to 2 ERTF to give a total set repetition value of 8 repetitions. Using the 6RM adjustment scale provided by Mann et al. (22), the appropriate load adjustment can be determined for the subsequent set and training session. This form of autoregulatory training would allow for greater individualization of the training process, and ensure that training loads are adjusted based on the rate of adaptation for each athlete. Future research is warranted to examine the efficacy of this form of autoregulation within a periodized training plan.

REFERENCES


Figure 3.1. Individual estimated repetitions to failure (ERTF) and actual repetitions to failure (ARTF) during baseline, overload, and taper testing (n = 14).
Figure 3.2. Bland-Altman plots comparing the agreement between estimated repetitions to failure (ERTF) and actual repetitions to failure (ARTF) values during the A) baseline, B) post-overload, and C) post-taper test sessions. The solid lines represent the mean bias while the horizontal dashed lines represent the 95% limits of agreement. The dashed-dotted regression lines represents the trend between the differences and ARTF (n=14).
Table 3.1. Descriptive characteristics of male and female powerlifters (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Body Fat (%)</th>
<th>Relative bench press</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (n=2)</td>
<td>28.5 ± 6.5</td>
<td>164.1 ± 4.7</td>
<td>71.7 ± 12.6</td>
<td>33.8 ± 1.0</td>
<td>0.8 ± 0.0</td>
</tr>
<tr>
<td>Males (n=12)</td>
<td>24.2 ± 5.6</td>
<td>178.8 ± 5.4</td>
<td>98.7 ± 14.2</td>
<td>23.8 ± 5.2</td>
<td>1.5 ± 0.2</td>
</tr>
<tr>
<td>Combined (n=15)</td>
<td>24.8 ± 5.7</td>
<td>176.7 ± 7.4</td>
<td>94.8 ± 16.7</td>
<td>25.2 ± 6.0</td>
<td>1.4 ± 0.3</td>
</tr>
</tbody>
</table>

Relative bench press = baseline one-repetition maximum divided by body mass.
**Table 3.2.** Resistance training during the preparatory, overload, and taper microcycle.

<table>
<thead>
<tr>
<th>Microcycle</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preparatory microcycle</strong>*</td>
<td>Back squat, 3 × 5</td>
<td>Bench press, 3 × 5</td>
<td>Deadlift, 3 × 3</td>
<td>Bench press, 3 × 5</td>
<td>Baseline Testing</td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 8</td>
<td>Standing OHP, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td>Back squat, 3 × 3</td>
</tr>
<tr>
<td></td>
<td>Lat Pulldown, 3 × 8</td>
<td>No Resistance Training</td>
<td>Barbell row, 3 × 8</td>
<td>No Resistance Training</td>
<td>RDL, 3 × 5</td>
</tr>
<tr>
<td><strong>Overload microcycle</strong></td>
<td>Back squat, 3 × 9RM</td>
<td>Bench press, 3 × 9RM</td>
<td>Deadlift, 5 × 5RM</td>
<td>Back squat, 5 × 5RM</td>
<td>Overload Testing</td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 10RM</td>
<td>Standing OHP, 3 × 10RM</td>
<td>Bench press, 4 × 7RM</td>
<td>Bench press, 5 × 5RM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lat Pulldown, 3 × 10RM</td>
<td>No Resistance Training</td>
<td>Leg press, 3 × 10RM</td>
<td>RDL, 3 × 8RM</td>
<td>Bench press, 7 × 3RM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Seated OHP, 3 × 10RM</td>
<td>Standing OHP, 3 × 8RM</td>
<td>Leg Press, 3 × 8RM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Barbell row, 3 × 10RM</td>
<td>Pull-up, 3 × 8RM</td>
<td>Seated OHP, 3 × 8RM</td>
</tr>
<tr>
<td><strong>Taper microcycle</strong></td>
<td>Back squat, 3 × 5</td>
<td>Bench press, 4 × 5</td>
<td>Deadlift, 3 × 3</td>
<td>Bench press, 3 × 3</td>
<td>Taper Testing</td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 8</td>
<td>Standing OHP, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lat Pulldown, 3 × 8</td>
<td>No Resistance Training</td>
<td>Seated OHP, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
<td></td>
</tr>
</tbody>
</table>

OHP = overhead press; RDL = Romanian deadlift; *All sets performed with 2-4 estimated repetitions-to-failure (ERTF); **Load calculated as 90% and 85% of average load used during Days 3 and 4, respectively, of overload microcycle.
Table 3.3. Comparison between ERTF and ARTF values during baseline, overload, and taper test sessions (n = 14).

<table>
<thead>
<tr>
<th>Value</th>
<th>Mean ± SD</th>
<th>ES</th>
<th>CE ± 1.96 SD</th>
<th>Lower</th>
<th>Upper</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ARTF</td>
<td>3.6 ± 1.6</td>
<td>0.26</td>
<td>-0.4 ± 3.2</td>
<td>-3.6</td>
<td>2.9</td>
<td>0.75*</td>
</tr>
<tr>
<td>ERTF</td>
<td>3.3 ± 1.1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Overload</strong></td>
<td></td>
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</tr>
<tr>
<td>ARTF</td>
<td>2.5 ± 2.0</td>
<td>-0.12</td>
<td>0.2 ± 1.6</td>
<td>-1.4</td>
<td>1.8</td>
<td>0.47</td>
</tr>
<tr>
<td>ERTF</td>
<td>2.7 ± 1.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Taper</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ARTF</td>
<td>5.2 ± 2.3†‡</td>
<td>0.71</td>
<td>-1.4 ± 2.4</td>
<td>-3.7</td>
<td>1.0</td>
<td>0.87*</td>
</tr>
<tr>
<td>ERTF</td>
<td>3.9 ± 1.5§‡</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

ARTF = actual repetitions to failure; ERTF = estimated repetitions to failure; ES = effect size; SEE = standard error of the estimate; CE = constant error; § significantly different from ARTF; † significantly different from baseline testing; ‡ significantly different from overload testing; *significant trend (p < 0.05).
CHAPTER 4
INTER- AND INTRA-DAY COMPARISONS OF SMARTPHONE-DERIVED HEART RATE VARIABILITY ACROSS RESISTANCE TRAINING OVERLOAD AND TAPER MICROCYCLES

ABSTRACT

The purpose of this study was: 1) to determine if smartphone-derived HRV could detect changes in training load in competitive powerlifters during an overload microcycle and taper, and 2) to determine the reliability of HRV measured in the morning (HRV_M) and measured just prior to the day’s training session (HRV_T). Twelve competitive (male = 10, female = 2) strength athletes completed a week of overload resistance training followed by a taper week. The different training loads between each week were verified with session Rating of Perceived Exertion as follows: sRPE was 8.4 ± 0.6 during the overload and 3.6 ± 1.6 during the taper (p < 0.01). HRV_M and HRV_T were measured with a validated smartphone device during the baseline day (BL), the day following the overload (PostOL) and the day following the taper (PostTP). Compared to BL, HRV_M was significantly reduced at PostOL (p = 0.007, ES = -0.69), and increased back toward BL values at PostTP (p = 0.005, ES = 0.80 compared to PostOL). HRV_T was not statistically different between BL, PostOL, and PostTP (p > 0.008, ES = -0.39 to 0.41). There was a strong relationship between HRV_M and HRV_T at baseline (ICC = 0.71, p < 0.01) and overload (ICC = 0.65, p < 0.01), whereas a non-significant relationship was found following the taper (ICC = 0.44, p = 0.05). Bland-Altman analyses suggest extremely wide limits of agreement (Bias ± 1.96 SD) between HRV_M and HRV_T at BL (4.7 ± 15.2), PostOL (0.5 ± 16.9), and PostTP
(3.7 ± 15.3). Smartphone derived HRV, recorded upon waking, was sensitive to resistance training loads across an overload and taper microcycles in competitive strength athletes, whereas HRV taken just before the training session was not.

**Key Words:** Athlete Monitoring, Taper, Cardiac Autonomic Activity, Parasympathetic

**INTRODUCTION**

Athlete monitoring is a strategy that many strength and conditioning coaches use to assess fatigue and adaptation to training (18, 43). While intense training is a major physiological stressor experienced by athletes, other factors such as sleep, nutrition, and emotional state may add to the overall stress imposed (31). The accumulation of these stressors will require sufficient recovery, or else noticeable decreases in performance may be experienced (43).

An effective monitoring tool for athletes in training would need to be sensitive enough to detect important perturbations in homeostasis and provide adequate information needed to alter training loads to optimize recovery. Current methods of monitoring training loads can be classified by their ability to monitor internal or external load. External load represents the total work performed during training (18) and can be quantified using training volume. Monitoring external load has the potential to provide feedback needed for making informed decisions; however, it lacks the ability to assess the physiological and psychological responses to training, which is referred to as internal load.

Rating of perceived exertion (RPE) is a common method used to determine internal load. RPE, gathered from a single repetition or from an entire training session, can be used to assess an athlete’s perception of exertion (43). Psychometric questionnaires offer additional internal load options that provide subjective feedback on how training and non-training stressors are
impacting the athlete. Whereas these measures are valuable, combining them with objective, physiological measures should provide a better understanding of the overall stress imposed on the athlete (18). One physiological measure that is gaining popularity as a monitoring tool is heart rate variability (HRV).

HRV is the variation in time intervals between consecutive heartbeats and provides a physiological marker of autonomic regulation (2). The root mean square of successive normal-to-normal interval differences (RMSSD) is a parasympathetically-derived HRV marker that has been shown to be the most reliable metric of athletic monitoring. This non-invasive measure has been proposed to provide an objective assessment of training status (4, 9, 38, 46) and training load (12-14). Using HRV to monitor recovery status or even guide exercise prescription (25, 26) has generally been evaluated in laboratory settings because of the need for lengthy recording procedures and specialized laboratory equipment (10). Recently, the development of smartphone applications capable of accurately measuring HRV in mobile settings has made this assessment more practical and cost-effective (11). Previous research has demonstrated that smartphone derived HRV is sensitive to detect changes in training loads in soccer players (12, 13) and competitive swimmers (14).

For best results, it is recommended that athletes record HRV upon waking (4), though this approach may provide poor compliance. As such, it may be more practical to record HRV just prior to the day’s training session. However, it is unknown if HRV measures taken before exercise will be as sensitive of a recovery marker compared to the recommended morning measures.

Furthermore, while HRV has been shown to be an effective, non-invasive tool to monitor fatigue and recovery in endurance and sport team athletes (12, 35, 36, 46), investigations in
strength athletes are limited. Chen and colleagues examined HRV in competitive weightlifters 72 hours following a 2-h resistance training session (5). Frequency-domain measures of HRV accurately reflected recovery status and weightlifting performance following the training bout. While this indicates that HRV monitoring may be effective for objectively assessing fatigue and adaptation in strength athletes, the recording methods utilized in their study would be impractical for field application. Additionally, the weightlifters performed the intensified resistance training session after detraining for 10 days (5). This paradigm may influence the physiological responses to the training stimulus, as strength athletes seldom refrain from training while peaking for a competition. Instead, they may be more likely to engage in an overload period of resistance training followed by a taper in order to peak for competition. Because HRV measures just before training could lead to better compliance, the utility of these measures is important. However, it remains unknown whether HRV accurately reflects training and recovery state following a resistance training microcycle and taper and further, whether measures taken just before a training bout are as accurate as measures taken upon waking. Therefore, the purposes of this study were twofold: 1) to determine the effect of an overload microcycle and taper on smartphone-derived HRV and 2) to examine the reliability between HRV measures taken upon waking and those taken just prior to training.

METHODS

Experimental Approach to the Problem

This study examined the effect of an intensified week of resistance training and taper on HRV and investigated the reliability between two HRV measures, one upon waking and one prior to training. During the initial visit to the Exercise Physiology Lab, participants were
familiarized with the HRV recording procedures. Additionally, written instructions were provided to ensure consistent measurement procedures. Participants completed a 3-week resistance training program consisting of preparatory, overload, and taper microcycles. HRV measures were recorded at two time points on the 5th day of each week. The first measurement was self-recorded by each participant upon waking (HRV<sub>M</sub>) and the second measurement was self-recorded upon arriving at the training facility (HRV<sub>T</sub>). In addition to measuring HRV, participants completed a bench press one-repetition maximum (1RM) and bench press repetition-to-failure assessment in order to determine changes in sport-specific performance across overload and taper microcycles.

**Subjects**

Fifteen resistance-trained participants (men: n = 12; women: n = 3) were recruited to participate in this study; however 3 participants (men: n = 2; women: n = 1) were excluded from the analysis due to noncompliance with HRV<sub>M</sub> measures. The twelve participants were competitive powerlifters and recreational powerlifters. Competitive powerlifters were defined as individuals who have previously competed in a sanctioned powerlifting competition, whilst recreational powerlifters were defined as those who had not competed, but performed each of the powerlifts (back squat, bench press, and deadlift) at least once a week with the intent of increasing exercise-specific maximal strength. Participants were recruited from the university and a local powerlifting training center. All participants were healthy, non-smoking volunteers who were classified as low or moderate risk according to the guidelines established by the American College of Sports Medicine (32). To minimize any confounding effects associated
with age-related differences in skeletal muscle recovery between younger and older individuals, participants were all between the ages of 18-40 years (30).

All prospective participants completed an exercise screening questionnaire, PAR-Q, and health history questionnaire to determine if they met the inclusion criteria. To qualify for inclusion in the study, participants had to have at least one year of resistance training experience and meet the national qualifying requirements established by the United States Powerlifting Association (1). The powerlifting totals comprised of the participant’s highest squat, bench press, and deadlift were gathered from a previous competition or test session. Additionally, all participants were free from cardiovascular, metabolic, neurological, or musculoskeletal disorders that would affect the study results. Prior to participation, all participants signed a written informed consent document approved by the Medical Institutional Review Board at The University of Alabama.

**Experimental Protocols**

During the initial visit, participants’ standing height was measured using a stadiometer (SECA 67310, SECA®, Chino, CA) and weight was determined using a digital scale (Tanita BWB-800, Tanita®, Arlington Heights, IL). Body composition was assessed using dual-energy X-ray absorptiometry (Lunar Prodigy, General Electric Healthcare, Madison, WI). Participants were provided instruction regarding the resistance training program and performance measures administered during the study. Additionally, participants received the equipment needed to measure daily HRV as described in the next section.

*Heart Rate Variability*
HRV was self-recorded using a smartphone application (11) with a pulse-wave finger sensor (PWFS) (ithlete™, HRV Fit Ltd., Southampton, UK) that inserted into the headphone outlet of a smartphone or tablet device (20). The smartphone application processed the R-R intervals and calculated the log-transformed root mean square of successive R-R intervals (lnRMSSD). For easier interpretation, the application multiplied the lnRMSSD by twenty (lnRMSSDx20) to convert it to a value on a ~100-unit scale (11). The application did not allow for manual inspection of the R-R intervals, however it was equipped with irregular beat detection and a correction process (47).

After waking and elimination, participants prepared the equipment for HRV recording. The PWFS was connected to the smartphone device and the participants’ left index finger was inserted into the PWFS. Following a brief stabilization period, a 55-s recording of HRV was taken in a seated position with the participant’s left hand within 20 cm of their chest. Participants were allowed to breathe at their own pace during the measurement period, since lnRMSSD has been shown to be consistent under paced or spontaneous breathing (42).

**Resistance Training Protocol**

Within one week after the initial visit, participants reported to a weight training facility to begin the 3-week resistance training program. The preparatory training period consisted of 3 non-consecutive days over a 5-day period using a total-body program (Table 4.2). Training loads were determined using the rating of perceived exertion (RPE) scale based on repetitions in reserve (21). This scale has been validated as a method of gauging resistance training intensity in novice and experienced lifters (22, 48). All exercise sets during the preparatory period were performed between an RPE of 6 to 8. On the fifth day of the preparatory week (BL), baseline performance assessments were performed before completing the third resistance training session.
Two days after baseline testing, participants began an overload week of resistance training, with the purpose of overreaching. Resistance training was performed on 4 consecutive days using a total-body program (Table 4.2). Daily undulations in training volume and intensity were used to incorporate high load and high volume training as a means to induce central and peripheral fatigue. All sets were performed using repetitions maximums and training loads were adjusted to ensure all sets were performed to muscular exhaustion. On the fifth day of the overload week (PostOL), participants completed the same assessments administered during the initial baseline testing session. To minimize any confounding effects for time of day, participants completed the post-overload test session during the same time of day as the initial baseline testing. Following the post-overload test session, participants received 48 hours of active rest before tapering.

The taper week consisted of 2 non-consecutive days of training over a 4-day period. Each day contained the same total body exercises used in the overload week; however, total training volume was substantially reduced (Table 4.2). In an attempt to enhance performance training intensity remained high during the taper (19, 33, 40). Training loads were adjusted to 90% and 85% of the average load used during days 3 and 4, respectively, of the overload week. Post-taper performance measures were recorded on the fifth day of the taper week (PostTP). Each participant performed the same measures at the same time of day as performed during the BL and PostOL.

Prior to arrival at each performance testing session, participants were instructed to refrain from caffeine for at least 4 h, and alcohol at least 24 h prior to testing. A 24-h recall was used to determine recent food and supplement consumption as well as compliance with pre-test instructions. Before participating in performance testing, participants rated their perceptual
recovery using the PRS scale as described in the next section. After indicating their perceived recovery, participants completed a full-body, dynamic warmup that was standardized for each session. All training sessions were monitored by a Certified Strength and Conditioning Specialist.

**Internal and External Loads**

The PRS scale ranges from 0 to 10 with 0-2 representing poor recovery and anticipating poor performance, 4-6 consisting of moderate recovery and expecting normal performance, and 7-10 representing high recovery and expecting increased performance (28, 44). The participants were informed of the purpose of the PRS scale and read specific instructions on how to interpret the scale. The PRS scale was used each day during each training and testing session to assess perceptual recovery. Training loads were determined by calculating the weekly volume load (sets × repetitions × load) for all resistance exercises performed. In addition to volume load, training loads were quantified by collecting a session rating of perceived exertion (sRPE), a metric that is capable of quantifying a global rating of internal load (8, 29, 43). Each participant reported their sRPE 15 minutes following the completion of the training session (27), and session load was calculated by multiplying the sRPE value by total number of repetitions completed (29, 45).

**Bench Press Performance Assessments**

After completion of a dynamic warmup, participants completed a 1RM bench press assessment. All bench press assessments were performed on an instrumented bench press (Forza Super Bench, Forza Strength Systems, Spokane Valley, WA) using a 20.4-kg powerlifting competition barbell (Rogue Fitness, Columbus, OH). Participants were instructed on how to perform the bench press to meet United States Powerlifting Association standards (1). Hand position on the barbell was recorded for each participant and maintained consistent for each trial.
Participants began the assessment by performing five progressive warm-up sets in the bench press before attempting a 1RM. The first set consisted of 5 repetitions with an unloaded barbell, followed by 3 repetitions at 40%, 2 repetitions at 55%, and 1 repetition each at 70% and 85% of previously acquired 1RM. During each bench press attempt, the participants un-racked the barbell with assistance from a spotter. After receiving a secure hand off, the barbell was lowered to the chest and held motionless with a definite and visible pause. Once the primary investigator determined the bar was motionless, a verbal “press” command was given and the participant proceeded to press the barbell to the lockout position. Participants were given verbal encouragement to press the barbell with maximal velocity on each repetition.

Two minutes after completing the one repetition at 85% of 1RM, participants began 1RM bench press attempts. The weight for each attempt was selected by the primary investigator using measured repetition velocity and perceptual feedback (i.e., RPE) from the subject. The average concentric velocity (ACV) was measured using a linear position transducer (GymAware PowerTool, Kinematic Performance Technology, Canberra, Australia), which has been previously validated for measuring barbell velocity (24). The velocity feedback was used to objectively assess each attempt and subsequent loads were selected based on reported ACV for competitive powerlifters in the bench press (22). Additionally, a 1RM was determined based on the methods of Zourdos and colleagues (48): 1) participant reported a 10 RPE and primary investigator agreed a subsequent attempt would not be successful with a 2.3-kg load increase or 2) participant reported a 9 or 9.5 RPE followed by a failed attempt with a 2.3-kg load increase. If the participant failed to complete the concentric portion of the lift or did not pause on the chest, the attempt was deemed unsuccessful.
Ten minutes after a successful 1RM bench press, participants completed a bench press repetition-to-failure assessment with 70% of 1RM. Participants were instructed to adhere to the same bench press guidelines as performed during the 1RM attempts. ACV was recorded for each repetition during the set. Spotters assisted by providing assistance during the lift, but also provided verbal encouragement to ensure each repetition was performed with maximal concentric velocity and that muscular failure was achieved at the completion of the set. Muscular failure was determined by the inability to complete the concentric phase of the bench press.

Statistical Analyses

Data were analyzed using SPSS Statistics version 23.0 (IBM Corporation, Armonk, NY) and Excel 2013 (Microsoft Corporation, Redmond, WA). A 2 × 3 repeated measures analysis of variance (ANOVA) was used to compare mean differences between HRV_M and HRV_T across BL, PostOL, and PostTP. Paired samples t-tests with a Bonferroni adjusted critical value were used to determine where the mean differences occurred. This procedure involved dividing the p-value by the number of comparisons (i.e., 0.05 / 6 = 0.008). Therefore, significance for the paired samples t-tests was set at p < 0.008. A one-way repeated measures ANOVA was used to compare means for internal and external training loads, as well as bench press performance across BL, PostOL, and PostTP. A Bonferroni post hoc analysis was used to determine where differences in means occurred. For perceived measures (sRPE and PRS), Friedman’s test was used to compare differences between means across each of the test sessions. Additionally, a Wilcoxon signed rank test was performed to determine which means differed. Cohen’s d effect sizes (6) were calculated and interpreted using the following thresholds: 0 to 0.2 (trivial), 0.2 to 0.6 (small), 0.6 to 1.2 (moderate), 1.2 to 2.0 (large), >2.0 (very large) (23).
Intra-day reliability between HRV\textsubscript{M} and HRV\textsubscript{T} were analyzed using an intraclass correlation coefficient (ICC). The ICC was interpreted using the following thresholds: 0 to 0.30 (small), 0.31 to 0.49 (moderate), 0.50 to 0.69 (large), 0.70 to 0.89 (very large), and 0.90 to 1.00 (near perfect) (23). Additionally, Bland-Altman plots were generated to assess the agreement between HRV\textsubscript{M} and HRV\textsubscript{T} at each of the time points (3). Data are presented as means ± SD and the level of significance was set at p < 0.05.

RESULTS

Training Loads and Bench Press Performance

Total volume load during the preparatory, overload, and taper microcycles was 19,039.4 ± 5,283.5 kg, 52,836.0 ± 12970.8 kg, and 16,077.2 ± 3806.6 kg, respectively. Training volume during the overload was significantly higher than baseline volume load (p < 0.01, ES = 3.41). During the taper, total volume load was significantly lower than baseline and overload volume (p < 0.01, ES = -0.64 to -3.84). The sRPE values during the preparatory, overload, and taper were 5.3 ± 1.2, 8.4 ± 0.6, and 3.6 ± 1.5, respectively. Overload sRPE values were significantly higher than baseline values (p < 0.01, ES = 3.30). During the taper, sRPE value were significantly lower compared to baseline (p < 0.01, ES = -1.23) and overload (p < 0.01, ES = -4.20). Perceived recovery at BL, PostOL, and PostTP was 7.9 ± 0.8, 5.1 ± 2.1, and 9.0 ± 1.0, respectively. PRS values at PostOL were significantly lower than BL (p < 0.01, ES = -1.81). At PostTP, PRS was significantly higher compared to BL (p < 0.01, ES = 1.17) and PostOL (p < 0.01, ES = 2.39). The ACV at 70% of 1RM during the warmup sets (ACV\textsubscript{70}) for BL, PostOL, and PostTP were 0.56 ± 0.06, 0.47 ± 0.11, and 0.56 ± 0.09 m$\cdot$s\textsuperscript{-1}, respectively. Following the overload, ACV\textsubscript{70} was significantly lower than BL (p < 0.01, ES = -1.01). ACV\textsubscript{70} at PostTP had significantly increased
above PostOL (p < 0.01, ES = 0.90), but was no different from BL (p = 0.96, ES = 0.01). Means and SDs for bench press 1RM during BL, PostOL, and PostTP were 133.1 ± 40.3 kg, 131.0 ± 38.5 kg, and 139.3 ± 41.1 kg, respectively. There was no difference in 1RM between PostOL and BL (p = 0.57, ES = -0.05). Following the taper, 1RM increased significantly above BL (p < 0.01, ES = 0.15) and PostOL (p < 0.01, ES = 0.21). Repetitions completed during the repetitions-to-failure assessment during BL, PostOL, and PostTP were 11.8 ± 1.5, 10.8 ± 1.9, and 13.6 ± 2.2, respectively. There was no difference in repetitions-to-failure between BL and PostOL (p = 0.13, ES = -0.53). The total repetitions completed at PostTP were significantly higher than BL (p = 0.01, ES = 0.95) and PostOL repetitions-to-failure (p < 0.01, ES = 1.33).

**Inter-day HRV Comparisons**

Mean and SDs for HRV\(M\) and HRV\(T\) across each time point are presented in Table 4.3. There was no condition (HRV\(M\) and HRV\(T\)) \(\times\) time (BL, PostOL, PostTP) interaction (p = 0.36). HRV\(M\) at PostOL was significantly lower than BL HRV\(M\) (p = 0.007, ES = -0.69). After the taper, HRV\(M\) increased significantly higher than PostOL (p = 0.005, ES = 0.80), but was no different from BL (p = 0.737, ES = -0.10). HRV\(T\) was no different from baseline to PostOL (p = 0.13, ES = -0.39). There was no change in PostTP HRV\(T\) compared to Post OL (p = 0.076, ES = 0.41) and BL (p = 1.000, ES = 0.00). Figure 4.1 presents the individual measures of HRV\(M\) and HRV\(T\) during BL, PostOL, and PostTP.

**Intra-day HRV Comparisons**

Intra-day HRV comparisons are presented in Table 4.3. HRV\(M\) and HRV\(T\) showed large, to very large, correlations at BL (ICC = 0.71, 95% CI: 0.25 – 0.91, p < 0.01) and PostOL (ICC =
HRV_M and HRV_T were not related at PostTP (ICC = 0.44, 95% CI: -0.09 – 0.79, p = 0.05). Bland-Altman plots are presented in Figure 4.2. The constant error (CE) between HRV_M and HRV_T at BL was 4.7 units (lnRMSSDx20) and the 95% limits of agreement varied from -10.6 to 19.9. At PostOL, the CE between HRV_M and HRV_T was 0.5 units and the 95% limits of agreement ranged from -16.4 to 17.5. The CE between HRV_M and HRV_T at PostTP was 3.7 units and the 95% limits of agreement ranged from -11.7 to 19.0.

DISCUSSION

This study evaluated the changes in smartphone-derived HRV that was taken upon awakening in the morning and right before training on three days: 1) before and 2) immediately following a microcycle of overload training and 3) immediately following a taper microcycle in competitive powerlifters. The primary findings was that HRV_M decreased following the overload and returned back to baseline following the taper. There was no change in HRV_T across each of the test sessions.

The overload microcycle consisted of high-volume and high-intensity resistance training utilizing multi-joint exercises of squat, bench press, and deadlift. Previous investigations have demonstrated that this type of training can cause tremendous homeostatic perturbations that may lead to decrements in performance (41), which may be referred to as overreaching (19). Raeder et al. found that 6 days of intensified resistance training produced increases in muscle damage indicated by significantly elevated creatine kinase concentrations (41). Repetitive muscle contractions occurring during high-load, high volume, resistance training can compromise muscle fiber integrity involving damage of the sarcomeres and contractile proteins. Chen et al. noted a significant increase in muscle soreness and creatine kinase following an intense
resistance training session in a group of competitive weightlifters (5). Additionally, the participants’ experienced a significant decrease in HRV 24-h post-training.

In the present study, a 4-day overload microcycle was associated with a reduction in HRV M values compared to BL. While no physiological markers of muscle damage were taken, participants reported significantly lower PRS scores indicating poor recovery and expected decreases in performance. In the investigation by Chen et al., the reduction in HRV was mirrored by a reduction in weight lifting performance (5). Similarly, the present study observed a trend in HRV M that mirrored the trend in bench press performance. Following the overload microcycle, the ACV 70 was significantly lower than baseline values, while 1RM and repetitions-to-failure were unchanged. The discrepancy between changes in bench press velocity and 1RM may be explained by previous observations noting that measures of velocity and power tend to decrease earlier than measures of dynamic strength following intensified resistance training (15, 17). It is speculated that a longer duration of overload, such as in previous investigations (7, 16, 41), may have produced decrements in dynamic muscular strength.

The taper period consisted of reduced training volume and intensity to allow for fatigue dissipation and recovery (33, 39). During the taper, total volume load and sRPE was significantly lower than overload values. These load reductions caused a significant rebound in HRV M above overload values. Additionally, participants’ PRS values increased significantly indicating better perceived recovery. Bench press performance mirrored changes in HRV M, as PostTP 1RM, repetitions-to-failure, and ACV 70 were significantly higher than at PostOL. These findings support the results of Chen et al. wherein HRV and weightlifting performance increased following a recovery period (5). While similar results were observed in the present study, HRV measurements recorded by Chen et al. consisted of 5-minute measures utilizing an
electrocardiogram. In the present study, HRV was measured via a PWFS and smartphone application which highlights the practicality of the field device.

Previous studies have demonstrated that ultra-short, smartphone derived HRV were sensitive to changes in training loads in female soccer players (12, 13) and collegiate swimmers (14). This is the first study to examine the effect of smartphone derived HRV in strength athletes. The results of this study suggest that smartphone derived HRV is sensitive to changes in resistance training loads since 1RM bench press performance mirrored the changes in HRV_M across the overload and taper microcycles.

Advances in technology allow for more practical athlete monitoring. Smartphone derived HRV allows for HRV monitoring to be utilized by coaches and athletes in the field. It has been suggested that HRV measurements be recorded upon waking (4); however this approach may not be the most practical. For instance, upon-waking-measures require each athlete to have the necessary equipment needed (i.e., heart rate monitor and smartphone/tablet) to record HRV. An additional concern with upon-waking-measures is the difficulty in daily compliance experienced with most self-recorded measures (37). Therefore, smartphone derived HRV measurements recorded upon arriving at the training facility could be more practical than measures performed upon waking.

During baseline and overload testing, HRV_M and HRV_T showed very large to large correlations. At PostTP, no significant relationship was seen between HRV_M and HRV_T. Additionally, Bland Altman plots (Figure 4.2) showed extremely wide limits of agreement between HRV_M and HRV_T suggesting large individual errors between measurements. Our results contradict a previous investigation by Nakamura et al. wherein they found very high reliability of intra-day HRV measures (34). However, in their study, intra-day HRV measures were recorded
only 10-minutes apart and HRV measures were captured using a portable heart rate monitor and assessed using HRV computer software. In the present study, the time difference between HRV_M and HRV_T for some participants was as large as 10 hours. During this time, participants may have been exposed to non-training related stressors (i.e., academic or work stress) that could have masked the relationship between HRV_T and recovery. It appeared that HRV_M was more sensitive to changes in training loads than HRV_T. At PostOL, HRV_M was moderately and significantly lower, while the change in HRV_T from BL was non-significant and small. Additionally, HRV_M was significantly higher at PostTP compared to PostOL, as it rebounded toward baseline values. However, no significant differences were again found between PostTP and PostOL values of HRV_T. Thus, it appears that HRV_T measures are not as sensitive as HRV_M to detect the internal, physiological stress associated with changes in external training load.

Therefore, it is recommended that smartphone derived HRV should be recorded upon waking, as this method is most sensitive to changes in resistance training loads.

A potential limitation was that the participants’ previous training methods and recovery status were not determined prior to the preparatory microcycle. This may account for some of the intra-individual differences that existed in response to the standardized training program. During the screening process, participants were excluded if they had peaked for a competition within the past 4 weeks, and all participants included in the study were instructed to continue normal training while refraining from performing multi-joint exercises to muscular failure.

The present study examined changes in smartphone-derived HRV following a 4-day overload and one-week taper. Training strategies for intermediate to advanced strength athletes may include multiple overload weeks before tapering. Thus, future research is warranted to examine weekly changes in HRV during resistance training programs with longer periods of
overload. This approach would allow for calculations of weekly HRV mean and coefficient of variation. The coefficient of variation of the weekly mean HRV has been shown to be useful in assessing how individual athletes respond to training (12, 14). Therefore, future investigations should evaluate weekly changes in HRV mean and coefficient of variation across a resistance training program consisting of multiple weeks of overload followed by a taper.

In conclusion, smartphone-derived HRV, recorded upon waking, was sensitive to changes in training load across the overload and taper microcycles. Similarly, bench press performance mirrored the trend in HRV_M. While HRV_T followed a similar trend, the changes were not different between time points and the effect sizes were smaller compared to the changes in HRV_M. In addition, large individual differences existed between HRV_M and HRV_T at each of the three time points. This finding suggests that HRV recordings later in the day should be used with caution if seeking a surrogate to the preferred morning measures. Therefore, the results of this study suggest that smartphone-derived HRV when recorded upon waking is sensitive to changes in resistance training loads across overload and taper microcycles.

**PRACTICAL APPLICATION**

Smartphone derived HRV is a practical monitoring tool that is capable of objectively quantifying the internal strain of strength athletes during a brief period of overload training. Coaches and athletes are encouraged to use smartphone-derived HRV to monitor fatigue and recovery across resistance training microcycles. During an overload period, training methods are typically intensified to induce functional overreaching. Smartphone derived HRV measures can detect homeostatic perturbations that reflect a similar trend in resistance training performance. A decrease in HRV provides an early indication of excessive fatigue accumulation and impaired
performance. This would allow coaches or athletes to identify the appropriate time to taper.

Additionally, an increase in HRV back to or above baseline is indicative of recovery or adaptation to training. Therefore, smartphone derived HRV can provide a non-invasive method of determining preparedness in strength athletes during the training process. It is recommended that smartphone derived HRV measures are recorded upon waking, as they offer the most sensitivity to changes in training load. With the availability of heart rate monitoring devices and smartphone applications, less of a burden is placed on the athlete utilizing this approach.

REFERENCES


47. Wegerif SC. Method, system and software product for the measurement of heart rate variability. Google Patents, 2014.

Figure 4.1 Individual HRV responses during morning measures (HRV_M) and before testing (HRV_T) across baseline, overload, and taper test days (n=12).
Figure 4.2. Bland-Altman plots comparing heart rate variability recorded upon waking (HRV_M) and heart rate variability recorded upon arriving at the training facility (HRV_T) during the A) baseline, B) post-overload, and C) post-taper test sessions. The solid lines represent the mean bias while the horizontal dashed lines represent the 95% limits of agreement. The dashed-dotted regression lines represent the trend between the differences and means.
<table>
<thead>
<tr>
<th></th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Body Fat (%)</th>
<th>Relative bench press</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (n=2)</td>
<td>28.5 ± 6.5</td>
<td>164.1 ± 4.7</td>
<td>71.7 ± 12.6</td>
<td>33.8 ± 1.0</td>
<td>0.8 ± 0.0</td>
</tr>
<tr>
<td>Males (n=10)</td>
<td>23.7 ± 5.9</td>
<td>179.4 ± 4.2</td>
<td>96.9 ± 11.3</td>
<td>23.3 ± 5.3</td>
<td>1.5 ± 0.2</td>
</tr>
<tr>
<td>Combined (n=12)</td>
<td>24.5 ± 5.9</td>
<td>176.9 ± 7.2</td>
<td>92.7 ± 14.7</td>
<td>25.0 ± 6.3</td>
<td>1.4 ± 0.3</td>
</tr>
</tbody>
</table>

Relative bench press = baseline one-repetition maximum divided by body mass.
Table 4.2. Resistance training during preparatory, overload, and taper microcycles.

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preparatory</strong></td>
<td>Back squat, 3 × 5</td>
<td>Deadlift, 3 × 3</td>
<td>Deadlift, 3 × 3</td>
<td>Deadlift, 3 × 3</td>
<td>Baseline Testing</td>
</tr>
<tr>
<td>microcycle*</td>
<td>Bench press, 3 × 5</td>
<td>Bench press, 3 × 5</td>
<td>Bench press, 3 × 5</td>
<td>Bench press, 3 × 5</td>
<td>Back squat, 3 × 3</td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>RDL, 3 × 5</td>
</tr>
<tr>
<td></td>
<td>Standing OHP, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td>Standing OHP, 3 × 8</td>
</tr>
<tr>
<td></td>
<td>Lat Pulldown, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
<td>Lat Pulldown, 3 × 8</td>
</tr>
<tr>
<td><strong>Overload</strong></td>
<td>Back squat, 3 × 9RM</td>
<td>Deadlift, 5 × 5RM</td>
<td>Back squat, 5 × 5RM</td>
<td>Deadlift, 5 × 3RM</td>
<td>Overload Testing</td>
</tr>
<tr>
<td>microcycle</td>
<td>Bench press, 3 × 9RM</td>
<td>Bench press, 4 × 7RM</td>
<td>Bench press, 5 × 5RM</td>
<td>Bench press, 7 × 3RM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 10RM</td>
<td>Leg press, 3 × 10RM</td>
<td>Leg press, 3 × 8RM</td>
<td>Leg Press, 3 × 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standing OHP, 3 × 10RM</td>
<td>Seated OHP, 3 × 10RM</td>
<td>Standing OHP, 3 × 8RM</td>
<td>Seated OHP, 3 × 8RM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lat Pulldown, 3 × 10RM</td>
<td>Barbell row, 3 × 10RM</td>
<td>Pull-up, 3 × 8RM</td>
<td>Barbell row, 3 × 8RM</td>
<td></td>
</tr>
<tr>
<td><strong>Taper</strong></td>
<td>Back squat, 3 × 5</td>
<td>Deadlift, 3 × 3</td>
<td>Deadlift, 3 × 3</td>
<td>Deadlift, 3 × 3</td>
<td>Taper Testing</td>
</tr>
<tr>
<td>microcycle**</td>
<td>Bench press, 4 × 5</td>
<td>Bench press, 3 × 3</td>
<td>Bench press, 3 × 3</td>
<td>Bench press, 3 × 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RDL, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td>Leg press, 3 × 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standing OHP, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td>Seated OHP, 3 × 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lat Pulldown, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
<td>Barbell row, 3 × 8</td>
<td></td>
</tr>
</tbody>
</table>

OHP = overhead press; RDL = Romanian deadlift; *All sets performed to a RPE 6-8; **Load calculated as 90% and 85% of average load used during Days 3 and 4, respectively, of overload microcycle.
Table 4.3. Comparison between HRV\textsubscript{M} and HRV\textsubscript{T} values during baseline, overload, and taper test sessions (n = 12).

<table>
<thead>
<tr>
<th>Value</th>
<th>Mean ± SD</th>
<th>ICC</th>
<th>Lower</th>
<th>Upper</th>
<th>CE ± 1.96 SD</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRV\textsubscript{M}</td>
<td>82.9 ± 13.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRV\textsubscript{T}</td>
<td>78.3 ± 9.0</td>
<td>0.71*</td>
<td>0.25</td>
<td>0.91</td>
<td>4.7 ± 15.2</td>
<td>-10.6</td>
<td>19.9</td>
</tr>
<tr>
<td><strong>Overload</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRV\textsubscript{M}</td>
<td>75.0 ± 9.9†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRV\textsubscript{T}</td>
<td>74.4 ± 10.2</td>
<td>0.65*</td>
<td>0.14</td>
<td>0.89</td>
<td>0.5 ± 16.9</td>
<td>-16.4</td>
<td>17.5</td>
</tr>
<tr>
<td><strong>Taper</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRV\textsubscript{M}</td>
<td>81.9 ± 7.1§</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRV\textsubscript{T}</td>
<td>78.3 ± 8.0</td>
<td>0.44</td>
<td>-0.09</td>
<td>0.78</td>
<td>3.7 ± 15.3</td>
<td>-11.7</td>
<td>19.0</td>
</tr>
</tbody>
</table>

HRV\textsubscript{M} = heart rate variability taken upon waking; HRV\textsubscript{T} = heart rate variability taken upon arriving at testing facility; ICC = intraclass correlation; CI = confidence interval; CE = constant error; † significantly different from baseline (p < 0.05); § significantly different from overload (p < 0.05); * statistically significant correlation (p < 0.05).
CHAPTER 5

CONCLUSION

Resistance training is commonly used to enhance general physical preparation in sport athletes, and serves as the fundamental basis for the sport of powerlifting. Periodized resistance training plans typically incorporate periods of overload and recovery which are essential in peaking strength performance (7, 9, 10). However, individual rates of adaptation may vary and athletes may require different training loads to optimize specific adaptations (6). Athlete monitoring is an approach that assesses the internal and external loads imposed on an athlete and provides the ability for coaches to individualize the training process (4). Many different monitoring tools are currently being used in the field, yet limited research exists demonstrating the efficacy of these tools to assess daily preparedness for resistance exercise (8).

The most common method used to determine fatigue and adaptation to resistance exercise is performing repetition maximums; however this approach is not practical as it is fatiguing in and of itself (1). An alternative approach to objectively assess daily preparedness is monitoring repetition velocity during a warmup at the beginning of the training session (5). In addition, internal load measures may assist in quantifying the stress imposed from training. Estimating repetitions to failure is a subjective measure of internal load that has been suggested as a potential tool in determining preparedness within a resistance training program (3). Heart rate variability (HRV) is another promising internal load measure that can objectively detect physiological responses to training-related stressors (2). The previous literature has yet to
examine the efficacy of these potential monitoring tools across overload and taper resistance training microcycles.

The first study examined changes in the load-velocity relationship during bench press warmup sets ranging from 40-85% of one-repetition maximum (1RM). Average concentric velocity (ACV) significantly declined following the overload (PostOL) and returned back to baseline (BL) following the taper (PostTP). Additionally, this study investigated whether the load-velocity relationship could accurately predict bench press 1RM. The load-velocity relationship consistently over-predicted 1RM across each test session; however near perfect correlations existed between estimated 1RM and actual 1RM. This suggests that the load-velocity relationship can be used in assessing preparedness following overload and taper microcycles.

The second study evaluated the accuracy of estimating repetitions to failure (ERTF) across overload and taper microcycles. ERTF and actual repetitions to failure (ARTF) were similar across BL and PostOL. However, ARTF was significantly higher than ERTF at PostTP. ARTF at PostTP was significantly higher than BL and PostOL, whereas ERTF at PostTP was only significantly higher than PostOL. These findings suggest that ERTF can be used to gauge fatigue and adaptation to resistance training, wherein this approach is most accurate when ARTF are smaller.

The third study compared inter- and intra-day changes in smartphone-derived HRV across overload and taper microcycles. HRV measures recorded upon waking (HRV\textsubscript{M}) significantly decreased at PostOL and returned back to baseline at PostTP. HRV measures recorded upon arriving at the testing facility (HRV\textsubscript{T}) were unchanged across the training weeks. The intra-day comparisons revealed strong correlations at BL and PostOL between HRV\textsubscript{M} and
HRV$_T$, yet Bland-Altman 95% limits of agreement showed large errors between the two measures. HRV$_M$ was sensitive to changes in training load and followed a similar trend as bench press performance. Thus, smartphone-derived HRV measures recorded upon waking can be useful to assess daily preparedness for competitive strength athletes.

The collective findings of this dissertation demonstrate that repetition velocity, ERTF, and smartphone-derived morning HRV$_M$ were able to detect changes in training loads. Additionally, these measures followed similar trends as strength performance suggesting the ability to determine daily preparedness for strength athletes. Instead of being used independently, we recommended that these tools be utilized jointly as a means of athlete monitoring. Collectively, these tools can provide coaches with useful information needed to regulate weekly or phasic training loads, providing an individualized approach to the training process.

REFERENCES


APPENDIX
September 8, 2016

Tyler Williams
Department of Kinesiology
College of Education
The University of Alabama
Box 870312

Re: IRB Protocol # 16-017-ME
    “Monitoring Changes in Resistance Training Performance Following an Overload Microcycle and Taper”

Mr. Williams:

The University of Alabama IRB has received the revisions requested by the full board on 8/23/16. The board has reviewed the revisions and your protocol is now approved for a one-year period. Please be advised that your protocol will expire one year from the date of approval, 8/11/16.

If your research will continue beyond this date, complete the Renewal Application Form. If you need to modify the study, please submit the Modification of An Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, please complete the Request for Study Closure Form.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number. Please use reproductions of the IRB approved stamped consent/assent forms to obtain consent from your participants.

Good luck with your research.

Sincerely,

J. Grier Stewart, MD, FACP
Medical IRB Chair