A COMPARATIVE STUDY OF STRENGTH IMPROVEMENTS IN AUTOREGULATORY TRAINING

By

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ABSTRACT

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INTRODUCTION: Autoregulation training is a system of periodization based on an individual athlete's physiological and mental state. This method attempts to match readiness with training stimulus to adjust for specific adaptations. Autoregulatory progressive resistance exercise (APRE) is a method by which athletes increase strength based on daily and weekly variations in performance, and has been shown to be a highly effective method for improving strength. The efficacy of various forms of autoregulatory training incorporating subject input, in-session performance, and pre-session performance have not been compared, particularly attempting to use physiological performance variables to determine readiness and the subsequent training stimulus.

PURPOSE: The purpose of the study was twofold: to attempt to determine if peak velocity is an appropriate and predictive measure of readiness and training session performance, and to compare the efficacy of autoregulatory progressive resistance exercise (APRE) and a velocity-based progressive resistance exercise (VAR) protocol for improvements in 1RM strength in the barbell back squat and barbell bench press exercises.

METHODS: 16 subjects were randomly assigned to one of two groups: APRE (n=7), in which subjects progressed linearly from low load/high volume to high load/low volume and VAR (n=9), in which training loads were dictated by objective pre-session peak velocity performance. Subjects reported to the laboratory for a familiarization session, 18 workout sessions (3 nonconsecutive days per week for 6 continuous weeks) and a post-testing session. Pre-testing and post-testing sessions consisted of 1RM testing, and anthropometric assessments. At the start of each session, subjects completed a Likert readiness questionnaire, as well as 2 sets of 3 repetitions of maximal effort barbell jump squats at ~20% 1RM and maximum effort speed bench press at ~20% 1RM, with peak concentric velocity recorded for all repetitions. Analysis of variance (ANOVA) was used to determine differences between groups. Independent samples t-tests were used to determine differences in subject characteristics and baseline levels of strength. Pearson product moment correlations were used to determine relationships between readiness variables and individual session performance. Statistical significance was accepted at $p \leq 0.05$.

RESULTS: There was a significant improvement in back squat 1RM and bench press 1RM over the course of the study for both groups ($F = 56.062$, $p < 0.001$, and $F = 34.607$, $p < 0.001$, respectively). There was no significant difference in initial strength levels between the two groups for barbell squat or barbell bench press. No interaction between pre/post-testing and time (time x group) was found for the back squat (APRE: 13.284 ± 5.307 kg vs. VAR: 15.624 ± 9.032 kg, $F = .367$ [$df = 14$], $p = 0.554$) or for the bench press (APRE: 11.016 ± 7.341 kg vs. VAR: 7.56 ± 5.319 kg, $F = 1.198$ [$df = 14$], $p = 0.292$. For VAR, a significant relationship was found between peak velocity performance and mental and physical readiness ($p < 0.001$). For APRE, a significant positive relationship was found between barbell jump squat and speed bench velocity ($r = 0.473$, $p < 0.001$), and mental and physical readiness ($r = 0.825$, $p < 0.001$). A significant negative relationship was observed between barbell jump squat velocity and mental and physical readiness ($r = -0.265$, $p = 0.002$ and $r = -0.301$, $p < 0.001$, respectively). A significant relationship was observed between mental and physical readiness and in-session performance for both groups. There was no interaction observed between groups relative to training session for jump squat peak velocity performance (ANOVA: $F = 0.771$, $p = 0.740$). There was an interaction observed between training session and group for peak speed bench press velocity (ANOVA: $F = 1.857$, $p = 0.023$). VAR showed a significant improvement in speed bench press peak velocity. There was a statistically significant interaction between training session and training group (ANOVA: $F = 7.544$, $p < 0.001$) for average volume load performed between groups.

CONCLUSION: To our knowledge, this is the first study to compare autoregulatory training dictated by objective pre-session performance measures with previously established autoregulatory protocols. Both groups demonstrated improved 1RMs over the course of training. No significant differences were observed between groups in 1RM changes, suggesting that both programs were equally effective in improving 1RM strength during a 6-week training cycle. The relationships between the subjective measures of readiness and peak velocity suggests that they may associate with some aspects of physical performance, and may have predictive power for acute resistance training performance. Further research is needed to determine the best practical application of these relationships, especially regarding which factors to measure, what type of change over time can be considered significant, and their relative predictive power for subsequent training performance.

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Chapter I: Introduction

Background

Autoregulation training is a system of periodization based on an individual athlete's physiological and mental state. This method attempts to match readiness (or the physical and mental state of being fully prepared to engage in physical activity) with training stimulus to adjust for specific adaptations. Autoregulatory progressive resistance exercise (APRE) is a method by which athletes increase strength by progressing at their own pace based on daily and weekly variations in performance, and has been shown to be a highly effective method for improving strength compared to linear periodization methods.

To more accurately define daily exertion, both coaches and researchers have begun assigning resistance training loads using a rating of perceived exertion scale (RPE). Recent evidence indicates an athlete's ability to properly assess RPE improves with experience and training status (47), suggesting that exertion alone may not be appropriate. Instead, a combined scale of RPE and repetitions in reserve (RIR) may be a more appropriate measure of resistance training intensity. Reactive Training Systems have employed these scales in practice (49). Recently, Zourdos et al. (53) examined the scale at various intensities, recording average velocity of each repetition, and found a strong inverse relationship between average velocity and RPE at all percentages. The observed relationship suggests that using RPE to gauge RIR seems to be a practical and effective method to autoregulate intensity relative to percent one repetition maximum (1 RM), and may serve as a potentially unifying measure for different aspects of autoregulation.

To date, no studies have employed physiological or performance variables to determine readiness or assign training loads, however, strength coaches and practitioners have begun using velocity based training (VBT) as a more effective means of monitoring training than percent 1 RM alone. A very strong relationship (r values of 0.95 or greater) has been shown between external load and concentric velocity (21). The mean concentric velocity at a corresponding percent 1 RM has been shown to remain consistent across all subjects regardless of maximal strength levels (21), and is highly predictive of relative load (16). Velocity is also related to measures of mechanical and metabolic fatigue, showing high correlations ($r = 0.91$ and greater) with decrements in countermovement jump height and the accumulation of blood lactate (43). Thus, velocity measures appear to be an important indicator of systemic performance and readiness, and can be used as a valuable prescription tool.

The efficacy of various forms of autoregulatory training incorporating subject input, in-session performance, and pre-session performance have not been compared, particularly attempting to use physiological performance variables to determine readiness and the subsequent training stimulus.

Purpose Statement

The purpose of the study was twofold: to attempt to determine if peak velocity is an appropriate and predictive measure of readiness and training session performance, and to compare the efficacy of autoregulatory progressive resistance exercise and a velocity-based progressive resistance exercise protocol for improvements in 1RM strength in the barbell back squat and barbell bench press exercises.

Hypothesis

We hypothesized that the velocity-based method of autoregulatory training, in which programming variations due to objective pre-session performance are implemented, will lead to greater improvements in strength than an autoregulatory progressive resistance exercise protocol.

Chapter II. Review of Literature

Introduction

Periodization is defined as the deliberate manipulation of the acute program variables (choice of exercise, order of exercise, intensity, volume, and rest) in an effort to maximize sport performance (13). Classic periodization models (known as linear periodization) typically follow a progression of microcycles which progress from high volume and low intensity to low volume and high intensity, with the intention of improving hypertrophy, strength, and power. This method of training has consistently shown to be effective for improving performance, especially when compared to non-periodized programs (13). However, linear periodization assumes that all athletes respond to stress in a similar manner, and fails to take numerous variables into account (i.e. sleep, psychological stress/readiness, diet, training status, etc.) which can impact daily performance. If an athlete does not suitably respond to a particular program, pre-determined loads become inappropriate and lead to a suboptimal training environment. In any strength training program, the goal is to deliver optimum training and recovery in order to lead to adaptation, improved strength, and improved performance. Determining optimal training and recovery is of paramount importance to understanding training efficacy. While there is no golden standard in programming for strength gains, the principle of progressive overload underlies any successful program. Progressive overload is defined as progressively placing greater than normal demands on the exercising musculature, typically through manipulation of training frequency, volume, and intensity (2). Simply put, in order to continue to adapt, the body must be subjected to greater stress than before, "shocking" the neuromuscular system into response and adaptation. While the level of this response and adaptation to any program is wildly individualized, Hans Selye's General Adaptation Syndrome has elucidated a consistent, systemic response to all types of stress (44).

The human body is constantly interacting with its external environment, encountering stressors, external stimuli that challenge homeostasis and lead to an internal stress response. This involves a multitude of complex systemic and local processes, the full mechanisms of which vary widely individual to individual. Work by the endocrinologist Hans Selye attempted to unify various aspects of the nonspecific physiological response to stress via the General Adaptation Syndrome (44). The General Adaptation Syndrome states that all organisms respond to stress in the same basic reactive pattern, regardless of the stressor mode. This response manifests itself in three general stages: Alarm Reaction, Stage of Resistance, and Stage of Exhaustion. The alarm reaction is the immediate systemic reaction to a stressor, and is analogous to the "fight or flight" response. At this time homeostasis is upset and resistance to the stressor is diminished. If the stress continues, the stage of resistance is entered. At this time the body begins to adapt and modify systemic behavior, reducing the effect of the stressor and increasing resistance and performance under stress (44).

If the stress is continually imposed, the body will eventually enter the final stage of exhaustion. At this point the stressor has continued long enough to override positive adaptations from the resistance stage, and resistance to the stressor is eventually diminished and lost. Homeostasis is severely upset, the body can no longer cope with the applied stress, and numerous deleterious effects can occur, including injury, pathology, etc.

Linear Periodization and GAS

Linear periodization models assume that this general adaptation is occurring, and that over time through periods of training, progressive overload, and recovery, the body adapts and performance improves (2). However, the General Adaptation Syndrome is a *non-specific*, systemic response theory, and depends on the interaction of nearly every system in the human body.

Differences in genetics, age, gender, training status, nutrition, sleep, neuroendocrine function, and numerous other variables impact the magnitude and duration of the response between different individuals, even to the exact same stressor (2, 44). Athletes that have nearly identical anthropometric and physiological measures may respond differentially to the same exercises, loads, volumes, etc., with entirely different levels of resistance impacting the response and subsequent recovery from stress. Classic linear periodization models do not take these differences between individuals into consideration, instead assuming a uniform effect from a specific program. This oversight can become especially deleterious in team or group training situations, decreasing the individualization, and specificity of training and making it easy to under or overestimate the appropriate training stress. This increases the potential for injury and decreases potential performance.

Periodization and Maximal Strength

Maximal strength performance is typically measured via a 1-repetition maximum, or 1 RM, which is defined as the maximal load that can be lifted one time for a specific exercise (34). Classic periodization models assume a static 1 RM, and assign loads as a percentage (i.e. %RM). However, performing exercises with maximal or near-maximal loads is a type of stressor, and resistance (or tolerance) to heavy loads varies according to the principles of GAS (i.e. what phase of resistance the body is in) and a multitude of previously discussed variables that impact readiness and performance. Research by Flanagan and Jovanovic, in which 1 RM totals were estimated prior to each training session for a two-month training block, reported an approximately 18% variance above and below the previously observed 1 RM, or a 36% range in which 1 RM could fluctuate on a daily basis (15, 22). This is far too much of a variance to be ignored, and more advanced methods are needed to measure and account for such daily change.

Nonlinear, or undulating, periodization attempts to vary set and rep ranges in a weekly or bi-weekly manner. Rather than gradually progressing through hypertrophy, strength, and power, all three can be trained multiple times per microcycle. This approach can help avoid overuse injuries, prevent boredom, is considerably more flexible than linear periodization, and in some cases has been shown to be a more effective approach for maximizing gains (41). Greater effort is made to vary the type of stress, increasing stressor resistance and decreasing stressor exhaustion, but undulating periodization still does not measure or control for an athlete's physical or mental readiness on a day-to-day basis, and does not quantify stress response or recovery.

Autoregulation

Autoregulation training is a system of periodization that adjusts for an individual athlete's physiological and mental state. The athlete's condition is tested before every workout, with the results dictating the specific loads that athlete will use in a particular training session. This testing could include physiological or performance measures (heart rate variability, salivary testosterone/cortisol ratios, force or power production, rate of force development, concentric velocity, etc.) or subjective measures, such as energy level ratings, quality of sleep, or quality of diet (19, 33). Working set loads are also determined in-workout, based upon the number of repetitions performed during warm-up sets in an attempt to individualize training stimuli and maximize performance per cycle (32). While there are few research studies examining the efficacy of autoregulation training, current results suggest that it may be a more effective way of improving strength than traditional periodization methods (32).

Autoregulatory training can trace its history back to the progressive resistance exercise (PRE) method developed by Dr. Thomas DeLorme in the late 1940s and early 1950s (12, 48). A World War II army physician, DeLorme began experimenting with different rehabilitation protocols to combat the overwhelming number of injured servicemen. His original system included 3 sets of 10 repetitions using increasingly heavier loads determined by in-session performance. This allowed for a previously unparalleled systematic approach to individualized rehabilitation, in which patients could exercise at more aggressive intensities while safely accounting for daily variations in strength and performance. PRE proved to be appreciably more successful than previous, less intense, treatments, and soon became standard practice in military and civilian physical therapy (48).

Despite its enormous effect on physical therapy and resistance exercise prescription, the PRE system did not objectively determine when resistance should be increased, nor by how much (23, 24). In the late 1970s, Dr. Kenneth Knight et al. adapted the PRE system in an effort to more optimally prescribe increasing resistance concurrently with increases in quad strength, specifically for knee injury/rehabilitation in a clinical setting. This approach became known as the Daily Adjustable Progressive Resistance Exercise (DAPRE) technique, and gained attention for how quickly patients regained strength, regardless of the degree of deconditioning (23, 51). The exact set and rep progression is outlined in a 1985 report (24). Twenty-one male subjects used DAPRE as part of a knee rehabilitation and quadriceps strengthening program. Eight subjects were immobilized in a cast for 3-6 weeks due to reparative surgery for collateral ligament or meniscus tears. The other 13 subjects did not have surgery, but were also immobilized for 3 weeks or more due to similar injuries. Upon cast removal and the achievement of 90° range of motion at the knee, with a 10° or less limitation to full knee extension, patients exercised 6 days per week until a plateau of daily weight increases was observed. Four sets were performed per exercise, with percent loads based on a patient's 6 RM (see Table 1). Set 1 consisted of approximately 10 repetitions at half of a patient's 6 RM (aka 'optimal working weight') and set 2 consisted of 6 reps at 75% working weight. Set 3 used the full working weight, with the patient performing as many reps as possible. The number of repetitions performed determined the adjusted load for set 4 (see Table 2), with increased or decreased weight as necessary. The number of repetitions performed in set 4 also established the weight to be used during the next training session.

Table 1: The DAPRE technique*

Set	Portion of working weight	No. of repetitions
1	1/2	10
2	3/4	6
3	Full	Maximum**
4	Adjusted	Maximum***

* Adapted from Knight 1979
** Number of repetitions performed during the third set is used to determine the adjusted working weight for the fourth set according to Table 2 guidelines
***Number of repetitions performed during the fourth set is used to determine the adjusted working weight for the next day according to Table 2 guidelines

Table 2: Working weight adjustment guidelines*

No. repetitions	Adjustment to working weight for	
Performed	**Fourth set****	**Next day*****
0-2	- 2-5 kg and repeat set	
3-4	- 0-2 kg	Keep the same
5-7	Keep the same	+ 2-5 kg
8-12	+ 2-5 kg	+ 2-7 kg
13+…	+ 5-7 kg	+ 5-10 kg

* Adapted from Knight1979
** Number of repetitions performed during the third set is used to determine the adjusted working weight for the fourth set according to column 2 guidelines
***Number of repetitions performed during the fourth set is used to determine the adjusted working weight for the next day according to Table 3 guidelines

Patients averaged 8.0 ± 3.4 repetitions at a load of 18.0 ± 6.3 kg for their 4th set performed of knee extension exercises on the first day of rehabilitation. By the end of the DAPRE protocol (6.4 ± 2.2 days) patients averaged 6.7 ± 1.8 repetitions at 41.4 ± 8.0 kg on their 4th set of knee extensions, representing a 230% increase in working weight. The average strength increase per day was 4.3 ± 2.2 kg, or a 23.9% daily increase relative to first day strength. Thirteen subjects also exercised both their injured and uninjured legs using the DAPRE technique, and experienced a 69% and 141% increase in weight used between the 3rd set of the first day to the 4th set of the last day, and by the end of the protocol were using, on average, 93.2% of the weight for the injured leg relative to the uninjured leg. When compared to uninjured leg loads on the first day, patients' injured leg working loads on the 4th set of the final day averaged 134.7% of the original uninjured weight. These results represented substantially greater and more rapid strength returns than previous programs, and has been consistently implemented in a variety of rehabilitation settings (29).

Autoregulation and Resistance Training

Although considerable strength increases were seen using the DAPRE system for both the injured and uninjured legs, DAPRE was not adapted for healthy subject strength training until recently. Mann et al. modified DAPRE into a strength protocol known as Autoregulatory Progressive Resistance Exercise (APRE) and compared it to a linear periodization (LP) model for strength improvements in Division I college athletes (32). Twenty-three football players from the University of Missouri's 2004 and 2005 teams trained for 6 weeks during the preseason using either APRE (n = 12) or LP (n = 11) and were tested for improvements in estimated 1 RM bench press (5 repetitions or fewer to failure), estimated 1 RM squat (5 repetitions or fewer to failure), and the 225-pound bench press test (maximum number of repetitions performed). Like DAPRE, APRE loads are based on an optimal rep range, but variations were conceived in order to focus on specific areas of resistance training. This includes a 3 RM protocol for strength and power, a 6 RM for strength and hypertrophy, and a 10 RM for hypertrophy. This study employed the 6 RM method for the majority of the 6 weeks. In set 1, subjects performed 10 repetitions at 50% of the estimated

6 RM, and set 2 involved 6 repetitions at 75% 6 RM. Set 3 was performed to failure at 100% 6 RM, with the number of repetitions dictating the load used for set 4 (see Table 3). Set 4 performance would then establish the calculated 6 RM/initial resistance used for the next training session. This approach, of performing selected load ranges to failure, is used to constantly assess maximal performance on a daily basis, and allows for a constant approximation of maximal strength (i.e. 1 RM)

Table 3: APRE protocol for 6RM and set 4 adjustment*

Repetitions APRE Protocol for 6RM	**Intensity (% of 6RM)**
10x	50%
6x	75%
Maximum	6RM
Maximum	Adjusted weight
Repetitions for set 3 6RM routine adjustment	**Set 4 adjustment (lbs.)**
0-2	-5 to 10
3-4	0 to -5
5-7	No change
8-12	+5 to 10
13+	+10-15

*Adapted from Mann et al. 2010

The Linear periodization group protocol progressed from 3 sets of 8 repetitions at 70% 1RM, to 4 sets of 5 repetitions at 85% 1RM, with testing occurring the following week. Both groups performed the 225-pound bench press test one session per week, and performed similar accessory exercises on a weekly basis as well (dumbbell bench press, front squat, step-ups, lunges, glute-hamstring raises, Romanian deadlifts, etc.). There was no attempt made to match for volume or intensity, due to the different programming approaches and the APRE system of dictating loads based on specific session performance. Testing measures were compared to the final results from the off-season spring program.

At the end of the 6-week program, significantly different improvements were seen between the two groups. APRE subjects showed greater improvement in 1RM bench press strength (20.97 ± 23.16 lbs. vs. -0.09 ± 11.15 lbs. for LP) 1RM squat (43.32 ± 44.74 lbs. vs. 8.36 ± 34.85 lbs.) and 225-pound bench press repetitions performed (3.17 ± 2.86 repetitions vs. -0.09 ± 2.4 repetitions). Significant differences were reported at the 0.05 level. APRE was shown to be a more effective means of improving upper and lower body strength measures and upper body strength endurance compared to traditional linear periodization over the course of a 6-week program. This study was of particular note in that it featured a highly trained population, and still managed to elicit significant gains in strength. Programs of this kind warrant further exploration and research, especially in a trained population.

Autoregulation vs. Progressive Overload

Autoregulatory training can be considered, at the most basic level, a specific version of progressive overload training. Although autoregulatory training and linear periodization had not previously been compared before Mann et al., Herrick and Stone compared a PRE protocol to a linear periodization model over 15 weeks, using 20 untrained college-age women as subjects (20). Subjects were tested on 1 RM bench press and 1 RM squat performance. The linear periodization (PER) program followed a hypertrophy to strength to power progression, consisting of 8 weeks at 3 x 10RM, 2 weeks at 3 x 4RM, and 2 weeks of 3 x 2RM, with 1 week of active rest between cycles (aerobic training at low intensity). The PRE group trained at 3 x 6RM for the entire 15-week duration. Both groups used Borg's RPE scale to record and adjust intensity (4). Subjects who recorded below a 16 (hard to very hard) had the weight increased for subsequent training sessions (assuming all repetitions were performed). While both groups exhibited significant strength gains pre-to-post testing, no significant differences were found in 1 RM squat or bench press strength between the two groups at the conclusion of the 15-week program, which suggested that progressive overload techniques are not as effective as mentioned previously. However, several limitations of the study may have contributed to these results, which contradict the results of Mann et al. and previous research regarding linear periodization (13), and make true comparisons impossible. While the PRE group's program was consistent with the basic principles of progressive overload, the protocol is not truly autoregulatory in nature. Repetition numbers were not varied by set as in the APRE system, nor were loads adjusted in-session. Performing 'sliding sets' based on the subjective RPE response takes overload into account, but does not take subject readiness into account for load selection, and fails to create an objective measure of performance per session, or how to appropriately increase loads over time. Herrick and Stone also attempted to equate total volume of both load and repetitions between the two groups, while that was deliberately not the case in Mann's procedure, due to the individualized and variable nature of volume and intensity in such a program. Fifteen weeks is also a remarkably long time to maintain one set and repetition procedure, regardless of the training principles being applied, and it is quite possible that the subjects' adaptation to this system were great enough to plateau/mitigate the strength gains seen in other strength training or rehabilitation examples (13). Ultimately, the study design is not autoregulatory and therefore does not contradict the efficacy of such protocols. Further research comparing autoregulatory systems with methods of periodization is warranted, as well as comparing the efficacy of such systems based on program duration.

Autoregulation and Rating of Perceived Exertion

Other types of autoregulatory training have attempted to use RPE or similar measures as another tool for determination of in-session intensities.

Some debate exists as to the reliability of RPE as a performance measure, as Borg's original scale was designed for aerobic exercise, not resistance training (4). However, work such as that by Day et al. reported an intraclass correlation of 0.88 for CR-10 session RPE between resistance exercise bouts of varying intensity, and found that higher intensity loads were deemed more difficult than performing more repetitions at lighter weights (11). This has particular importance for periodizing programs in which maximizing strength is a priority, as was the case in the aforementioned training studies. Of interest for potential follow up research, as well as for strength and conditioning coaches, is the ability of RPE to reliably measure power or exercises in which velocity plays a role. Row et al. found that average RPE across subjects at varying loads for high velocity leg press strongly predicted the %1RM load being used (42). This allowed for the use of a load-RPE relationship, in which athletes could select intensities based on a pre-established and individualized RPE, and suggests that subjects may in fact be able to reliably predict their own state of readiness and aid in selecting optimum intensities for hypertrophy, strength, and power production.

In the forty-plus years since the inception of the Borg RPE scale, multiple variations have been implemented, including those using 10, 11, 15, and 20 points scales (27). Concern has been raised as to the correlations between scales, the validity of use in resistance training, and practical application, as many practitioners of autoregulatory training employ 10 points scales. Lagally and Robertson used the OMNI-RES RPE scale (see Figure 1 below), and compared the results to a 15 point Borg RPE following knee extensions performed at 50, 60, 70, 80 and 90% 1 RM. Validity coefficients between the two scales ranged from $r = 0.94$ to 0.97, suggesting a high relationship and that the two scales could be used interchangeably during resistance exercise (27). With a number of scales now validated for use in resistance training, it appears that nearly all methods of determining RPE can be used to appropriately rate relative intensity and prescribe training loads (5). However, it is reported that an athlete's ability to properly assess RPE improves with experience and training status (47), suggesting that exertion alone may not be appropriate. Instead, a combined scale of RPE and repetitions in reserve (RIR) may be a more appropriate measure of resistance training intensity. Such a scale has been utilized in strength and conditioning via the Reactive Training Systems (49). Recently, Zourdos et al. (53) examined the scale at various intensities, recording average velocity of each repetition, and found a strong inverse relationship between average velocity and RPE at all percentages. This suggests that using RPE to gauge RIR seems to be a practical and effective method to autoregulate intensity relative to percent 1 RM. Further investigation is needed as to the most effective and reliable measure or measures to be implemented in autoregulatory training practices, but these results show a promising potential for unifying different aspects of autoregulatory training to maximize sport performance.

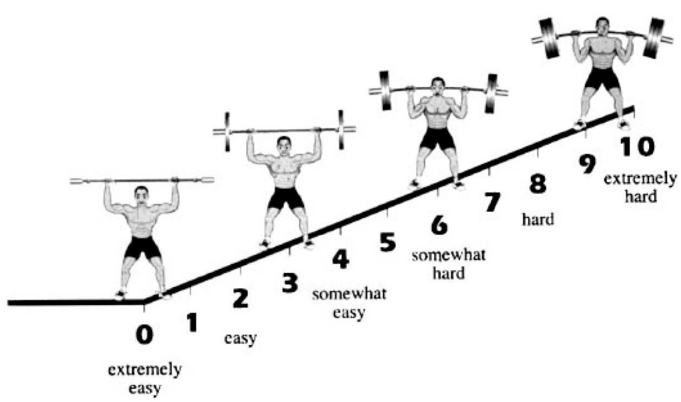

FIGURE 1. OMNI Perceived Exertion Scale for Resistance Exercise.

Adapted from Lagally and Robertson 2006

Athlete Readiness

Some forms of autoregulation also may test performance before every workout, with the results dictating the specific loads that athlete will use in a particular training session. This testing could include physiological measures (force production, barbell velocity, etc.) or subjective measures, such as energy level ratings, quality of sleep, or quality of diet (33). The goal of this pre-session performance testing is to determine athlete readiness, or the physical and mental state of being fully prepared to engage in physical activity. This allows athletes or subjects to gain awareness of their own performance capabilities prior to in-workout load adjustments, and attempts to further predict intensities and maximize performance, all while giving athletes greater input into their own training. The underlying assumption is that athletes (especially trained ones) already possess a strong ability to determine their own state of readiness and energy, perhaps better than any current known measures, and thus can help to optimize performance and prevent injury better than with in-session adjustments alone. McNamara and Stearne attempted to implement this practice (using a program which the authors termed "Flexible Nonlinear Periodization") using a beginner college weight training class (33). Sixteen subjects were randomly assigned to a nonlinear periodization group (NL, n = 8) or a flexible nonlinear group (FNL, n = 8) for a 12-week training program. Subjects trained twice per week, with a range of lower body (leg press, squat, deadlift, etc.), upper body (chest press, bench press, seated rows, lat pulldowns, etc.), and 'midsection' (back extensions, leg raises, etc.) exercises implemented. The 12 weeks were divided into three short mesocycles of 4 weeks each. In segment 1, both groups performed 7 sets of 7 different exercises, in segment 2, 10 sets of 10 exercises were performed, and in segment 3, 15 sets of 15 exercises were performed, with a specific number of exercises to be performed for the lower body, upper body, and midsection. Intensities varied in a nonlinear fashion between 10, 12, and 15RM. Both groups were given the same total volume, intensity, exercise number, and required exercises. The only difference was that the FNL group was allowed to choose which repetition range they wished to perform immediately before the workout, whereas the NL group did not. This choice was based upon a readiness/energy scale subjects would complete before exercising, with the number 0 representing no energy and 10 indicating high energy and motivation to train. FNL group members would then select the repetition range that he or she felt was the most appropriate given the readiness/energy level on that particular day. Subjects were pre- and post-tested in leg press 1 RM, chest press 1 RM, and long jump, and were tested for significant differences at the 0.05 level. The FNL group significantly improved in the leg press relative to the NL group, with average increases of 62 kg and 16 kg, respectively. However, no significant difference was found between groups for chest press or long jump.

These results can be explained in part by the program design. It is difficult to familiarize subjects for max testing after completing a protocol in which a 10 RM was the heaviest load used, and the researchers noted that the upper body received more volume than the lower body. It was the opinion of the authors that the upper body may have been "overtrained" and that the FNL program may not have been "robust" enough for the accumulated load, making it difficult to determine true chest press ability (33). No improvement was expected in the long jump testing due to program specificity, as the program was based upon low-velocity lifts, with little to no power training. Further research examining the role of autoregulatory training and/or flexible nonlinear training in improvements in power bears consideration. Despite the limitations of the methodology of the study, FNL periodization, in which subjects autoregulate based on daily readiness, may be more effective than classic linear progressions for improving measures of strength, particularly in the lower body.

Velocity-Based Training

Due to the numerous shortcomings of programming loads based on a percentage of previously determined 1 RM values, practitioners have sought better ways to objectively monitor appropriate training loads. One such approach that has become increasingly popular in the last few years is Velocity Based Training (VBT) (30, 31). VBT involves the use of devices that measure barbell displacement and time, calculating velocity and power if the external load is known. Velocity has been historically measured using a tether-based device, in which a tether line is attached from a ground based unit to the barbell, such as a Tendo unit (17). Recent improvements in both tether-based technology and video capture analysis have made velocity measured much easier, more valid, and more affordable than ever before, and has become an important training variable in elite performance development (22).

VBT research shows an extremely high relationship between velocity and load. Jidovsteff, Harris, Crielaard, and Cronin examined the ability of the load-velocity relationship to accurately predict 1 RM in the bench press exercise (21). Using velocity measures from submaximal load-velocity profiling and 1 RM assessments, correlation analysis showed correlation coefficients of $r < 0.95$ in nearly all cases, indicating that velocity at a corresponding percent 1 RM stays consistent across subjects regardless of maximal strength. Gonzalez-Badillo showed a similar predictive relationship between percent 1 RM and corresponding velocities in the bench press, with R^2 values ranging from .993 to .999, even with a 9.3% average increase in 1 RM over the duration of the study (16). Thus, there is a nearly perfect relationship between percent 1 RM and velocity, i.e. all subjects would be expected to move the bar at nearly the same velocity at 60% 1 RM, regardless of the absolute load. When measuring velocity during non-ballistic (non-Olympic or closed kinetic chain) strength exercises such as the bench press and squat, mean velocity has been suggested as the more sensitive and appropriate measure for concentric phase velocity, due to the large amount of time spent decelerating the bar (10, 21, 22).

Traditional programming has often used percent 1 RM intervals designed to elicit gains in specific traits, such as muscular endurance, hypertrophy, strength, and power. In addition to the previously discussed load-velocity relationship, research has consistently shown both a load and velocity-specific response to training as well (7-9). Thus, similar zones have been developed which more accurately assign loads for training/making improvements in those same traits via velocities (see Figure 2 below).

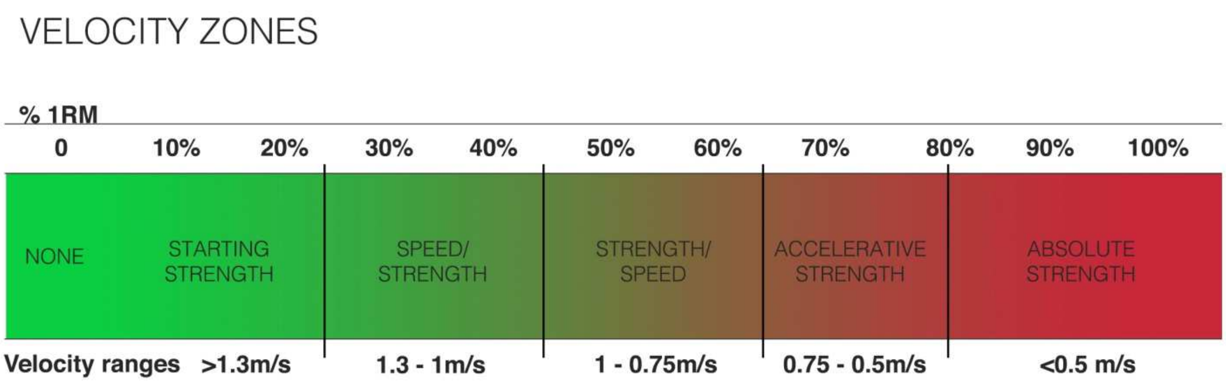

Figure 2. Velocity and %1 RM zones
Adapted from Mann 2015

Velocity and Autoregulation

While percent 1 RM is still a valid tool for selecting intensities, it is not possible to objectively determine if the weight being moved is at the appropriate load for a given session. Absolute strength/1 RM varies on a daily basis, but the relationship between strength and velocity does not; by measuring mean barbell velocities it is possible to *autoregulate* proper session loads for a given exercise and/or strength-velocity zone. By comparing session velocity performance to established norms, a "daily 1 RM" and daily readiness can be established using submaximal weights, allowing loads to be selected both pre-session and in-session based upon physiological state (22).

While the values listed in Table 4 give excellent approximate measures for expected velocities, mean velocities vary for different exercises and individual subjects. In order to establish baseline velocity performance for specific exercises and athletes, practitioners create a "load-velocity" profile, involving repetitions at a number of pre-determined relative loads for a given exercise. Work by Jovanovic and Flanagan recommend 4-6 increasing intensities, with loads ranging from 30-85% 1 RM and a large enough "spread" to ensure at least a decrease in velocity of 0.5 m/s between the lightest and heaviest loads (see Table 5) (21, 22).

Load/velocity profile protocol	
2-3 repetitions	30-40% 1RM
2 reps	40-50% 1RM
1-2 reps	60-70% 1RM
1 rep	70-80% 1 RM
1 rep	80-85% 1 RM

Table 4. Load-velocity profile protocol
Adapted from Jovanovic and Flanagan 2014

The measured velocities at each load create an entire profile of observed and expected velocities at a given percent 1 RM. This profile allows for accurate estimation of 1 RM at submaximal loads, and can especially be used to monitor changes over time (i.e. improvements in strength and power), to select in-session loads that correspond to the correct strength-velocity zone, and to monitor daily readiness and fatigue (22, 30, 37). For example, an athlete may perform squats prior to a training session at one or more pre-determined loads from their individual load-velocity profile. If mean velocity is lower than expected, it is indicative of reduced maximal strength, low readiness, high fatigue, and low stress resistance. Mean velocities at or above those previously recorded are suggestive of increased maximal strength, high readiness, and high stress resistance. In both cases, autoregulatory adjustments can be made to increase or decrease training loads based upon the physiological state and specific needs of the athlete. This allows practitioners and coaches to understand how an athlete is performing on a given day. Training stress can be properly increased or decreased, objectively defining how hard to train when an athlete is performing well, or how much to back off when an athlete is at less than their best. Rather than attempting to control every single physiological variable which might impact performance, they are instead systemically accounted for in one simple measure, eliminating the guess work of individual stress tolerance and improving safety and performance. Sanchez-Medina and Gonzalez Badillo examined 3 sets of maximal reps to failure for the bench press and squat at 70, 75, 80, 85, and 90% 1RM, comparing the loss of mean velocity and countermovement jump height loss to metabolic measures of fatigue (blood lactate and ammonia accumulation) (43). Both mechanical measures strongly correlated to metabolic fatigue for both exercises, with the lactate relationship being particularly high at R values of 0.93-0.97, strongly suggesting that velocity performance can serve as a measure of overall physiological readiness and fatigue (43). Thus, velocity measures may serve as an important indicator of systemic performance and readiness, and can be used as a valuable prescription tool. Because of the load-velocity relationship, velocity performance at submaximal loads can be compared to established norms over time, in order to estimate 1 RM/maximal daily performance and readiness. Although mean velocity has been suggested as a more appropriate measure for performance over the entire concentric movement phase, peak velocity may be a more appropriate measure of daily readiness due in an effort to more sensitively quantify maximum performance ability. While practitioners have seen substantial success using VBT in this manner, there are currently no known studies investigating the efficacy of using velocity to autoregulate program loads for improvements in strength.

Summary

In recent decades efforts have been made to improve upon classic periodization models through a variety of means. Autoregulation as a method of proactively determining training volumes and intensities is still being explored, but early findings suggest that it has tremendous potential as a periodizing tool for strength coaches, trainers, and therapists. A great deal of work is needed to establish a literature base, and future research should focus on comparing the efficacy of in-workout adjustments (i.e. APRE) relative to pre-training readiness measures (i.e. FNL), as well as combining the two practices. Of particular interest is the potential for using velocity-based training as a holistic approximation of other physiological variables and its combination with APRE for dictating programming and training loads, as well as if an APRE protocol can be adapted for use in traditional power exercises and improvements in velocity and power production.

Chapter 3: MANUSCRIPT

Methods: Introduction

The goal of any strength-training program is to optimally balance training stress and recovery in order to elicit the necessary physiological adaptations to improve performance. For coaches and practitioners, determining optimal training and recovery is of paramount importance to their athletes.

Though strength training programs can vary greatly in structure and use of the acute program variables, the principle of progressive overload underlies any successful program. Progressive overload is defined as progressively placing greater than normal demands on the exercising musculature, typically through manipulation of training frequency, volume, and intensity (2). In order to continue to adapt, the body must be subjected to increasingly greater/continuously increasing stress to avoid accommodation or stagnation.

While the magnitude response and adaptation to any program is highly individualized, Hans Selye's General Adaptation Syndrome (GAS) has elucidated a consistent, systemic response to all types of stress (44). Selye's theory manifests itself in three general stages: alarm, resistance, and exhaustion. The alarm stage is analogous to "fight or flight", at which time stressor resistance is diminished. Resistance is the effect of the stressor and increasing performance under stress. Finally, exhaustion is represented in the overriding of positive adaptations and leading to deleterious effects of reduced performance. If the training stimulus and recovery are properly prescribed, stages of alarm and resistance are induced, and the individual will experience supercompensation (i.e. improved performance).

Periodization is defined as the deliberate manipulation of the acute program variables (choice of exercise, order of exercise, intensity, volume, and rest) in an effort to maximize sport performance (13). Traditional periodization models (also known as linear periodization) progress from high volume and low intensity to low volume and high intensity, with the intention of improving hypertrophy, strength, and power. Traditional periodization has been consistently validated as an effective method for improving performance, especially when compared to non-periodized programs (13). Traditional periodization models are based upon GAS, and assume a uniform response to a given training stress. However, GAS is a *non-specific* theory, and the individual response to training depends on numerous factors such as age, gender, hormonal profile, anthropometrics, training status, genetic expression, etc. These factors dictate the magnitude of the alarm, resistance, and supercompensation phases. Furthermore, non-training stresses such as academic/professional work, personal and familial relationships, mental health, etc., can impact recovery. Traditional periodization makes no attempt to measure the impact of these factors or the individual response to training, consequently resulting in inappropriate training stress and decreased training tolerance or readiness. Many of these factors can fluctuate constantly, and subsequently training tolerance will fluctuate as well. While undulating (also known as nonlinear) periodization models attempt to match some of this fluctuation with daily or weekly variances in volume and load, training stimulus is typically prescribed via 1 RM, which is assumed static over a training cycle. Work by Flanagan & Jovanovic suggested as much as an 18% daily variance in estimated squat 1 RM relative to pre-cycle performance, suggesting that other methods are needed to account for daily changes in performance ability (22).

Autoregulation training is a system of periodization based on an individual athlete's physiological and mental state. This method attempts to match readiness with training stimulus to adjust for specific adaptations, allowing for increases in load and strength at an individual pace by catering the program to daily performance measures. A specific autoregulatory program, developed from DeLorme's progressive resistance exercise (PRE) method and outlined by Siff (46) is the autoregulating progressive resistance exercise (APRE) method. With APRE, loads are determined/modified in-workout based upon repetitions to failure performed at a specified RM (e.g. 10, 6, 3 RM) in an attempt to individualize training stimuli and maximize performance per cycle. Mann et al. 2010 compared this approach to a traditional linear periodization program in Division I football players, and found that the APRE method led to significantly greater improvement in 1RM bench press strength (APRE: 20.97 ± 23.16 lbs. vs. LP: -0.09 ± 11.15 lbs.) 1RM squat (APRE: 43.32 ± 44.74 lbs. vs. LP: 8.36 ± 34.85 lbs.) and 225-pound bench press repetitions performed (APRE: 3.17 ± 2.86 repetitions vs. LP: -0.09 ± 2.4 repetitions) (32).

To more accurately define daily exertion, both coaches and researchers have begun assigning resistance training loads using a rating of perceived exertion scale (RPE). RPE scales were originally designed for aerobic exercise exertion (4). Multiple RPE scales and methods have since been developed for intra-training feedback, both for aerobic and anaerobic exercise. These scales are validated relative to each other (5, 42), are associated with exercise intensity (26, 27), and blood lactate accumulation/fatigue (28, 39). Recent evidence indicates an athlete's ability to properly assess RPE improves with experience and training status (47), suggesting that exertion alone may not be appropriate. Instead, a combined scale of RPE and repetitions in reserve (RIR) may be a more appropriate measure of resistance training intensity. Reactive Training Systems have employed these scales in practice (49). Recently, Zourdos et al. (53) examined the scale at various intensities, recording average velocity of each repetition, and found a strong inverse relationship between average velocity and RPE at all percentages. The observed relationship suggests that using RPE to gauge RIR seems to be a practical and effective method to autoregulate intensity relative to %1 RM, and may serve as a potentially unifying measure for different aspects of autoregulation.

Some forms of autoregulation also test performance before every workout, with the results dictating the specific loads that athlete will use in the subsequent training session. Testing may include physiological measures (force production, barbell velocity, etc.) or subjective measures, such as energy level ratings, quality of sleep, or quality of diet (33). The goal of this pre-session performance testing is to determine athlete readiness, or the physical and mental state of being fully prepared to engage in physical activity. McNamara and Stearne 2010 compared nonlinear periodization and an autoregulatory progression (termed Flexible Nonlinear Periodization by the authors) in which training sessions were performed weekly at either 15RM, 12RM, and 10RM loads (33). While volume was matched between groups, the FNL group chose which weight range they performed based upon a pre-session 0-10 readiness/energy scale, in which 0 represented no energy and motivation to train, and 10 represented high energy and motivation. While no differences were found between groups in improvements in chest press or long jump performance, the FNL group improved significantly in the leg press relative to the NL group (FNL: 62 kg vs. NL: 16 kg), suggesting that autoregulating based on daily readiness may be as effective or even superior to NL for eliciting gains in strength.

To date, no studies have employed physiological or performance variables to determine readiness or assign training loads, however, strength coaches and practitioners have begun using velocity based training (VBT) as a more effective means of monitoring training than %1 RM alone. VBT measures barbell displacement and time, calculating velocity and power with a known external load (30, 31). A very strong relationship (r values of 0.95 or greater) has been shown between external load and concentric velocity (21). The mean concentric velocity at a corresponding %1 RM has been shown to remain consistent across all subjects regardless of maximal strength levels (21), and is highly predictive of relative load (16). Velocity is also related to measures of mechanical and metabolic fatigue, showing high correlations (r = 0.91 and greater) with decrements in countermovement jump height and the accumulation of blood lactate (15). Thus, velocity measures appear to be an important indicator of systemic performance and readiness, and can be used as a valuable prescription tool. Because of the load-velocity relationship, velocity performance at submaximal loads can be compared to established norms over time, in order to estimate 1 RM/maximal daily performance and readiness. Mean velocity has been suggested as a more appropriate measure for performance over the entire concentric movement phase, due to the large amount of time spent decelerating the bar (10, 31). However, peak velocity is often employed by practitioners for measuring Olympic lifting performance, due to the highly ballistic nature of the movement (30), and may be a more appropriate measure of daily readiness in an effort to more sensitively quantify maximum velocity performance ability.

Despite its growing prevalence in the field of strength and conditioning, the efficacy of various forms of autoregulatory training have not been compared. Specifically, research is needed to determine differences between methods incorporating subject input, in-session performance, and pre-session readiness, especially attempting to using physiological performance variables (e.g. peak velocity) to determine readiness. It is also necessary to determine the correlations between readiness and in-session performance, as readiness measures with predictive power for training performance are of particular importance (and those without correlation are relatively useless). Therefore, the purpose of this study was twofold: to attempt to determine if peak velocity is an appropriate and predictive measure of readiness and training session performance, and to compare the efficacy of autoregulatory progressive resistance exercise and a velocity-based progressive resistance exercise protocol for improvements in strength.

Experimental Approach to the Problem

The goal of the study was to compare the efficacy of autoregulatory progressive resistance exercise and velocity-based autoregulatory progressive resistance exercise for improvements in the barbell back squat and barbell bench press one repetition maximum. It was also necessary to determine the efficacy of autoregulation using peak velocity/readiness as a determination of daily loads relative to an autoregulatory protocol previously determined to be effective for improving 1RM strength. The primary dependent variables were back squat and bench press 1 RM. All data collection occurred between September and November of 2015. Subjects were randomly assigned to one of two groups: APRE (n=7), in which subjects progressed linearly from low load/high volume to high load/low volume and VAR (n=9), in which training loads were dictated by objective pre-session performance measures. Subjects reported to the laboratory for a familiarization session, 18 workout sessions (3 nonconsecutive days per week for 6 continuous weeks) and a post-testing session. Pre-testing sessions consisted of 1RM testing, and anthropometric assessments. At the start of each session, subjects completed a Likert readiness questionnaire to measure mental and physical readiness, as well as 2 sets of 3 repetitions of maximal effort barbell jump squats at ~20% 1RM and 2 sets of 3 repetitions of maximum effort speed bench press at ~20% 1RM, with peak concentric velocity recorded for all repetitions. The 6-week training program consisted of autoregulatory progressive resistance exercise (APRE or VAR). At the end of the training session, anthropometric measures were collected, and subjects were post-tested on 1RM strength in the barbell back squat and barbell bench press exercises.

Subjects

Eighteen recreationally trained males (VAR = 9, APRE = 9) volunteered for the investigation and were randomly assigned to either the VAR (n=9) or APRE (n=9) groups. All subjects had been actively weight training for at least 1 year prior to participation. Two subjects withdrew from the APRE group due to injury during the course of the training protocol. Demographic characteristics for each group are presented in Table 1. There were no significant differences between groups for age, body mass, or height ($p > 0.05$).

Table 1. Subject Characteristics

	APRE group (n = 7)	VAR group (n = 9)
Age (yr)	21.57 ± 2.87	22.78 ± 2.73
Body mass (kg)	84.06 ± 14.7	85.26 ± 15.7
Height (m)	1.76 ± 0.07	1.80 ± 0.049

Prior to the investigation subjects were informed of the experimental risks and details, and signed consent documents consistent with University of Kansas Human Subjects Committee - Lawrence guidelines. After consent was obtained, subjects completed additional health history questionnaires, and were cleared of all musculoskeletal injuries. All subjects completed workouts with at least 90% compliance (one missed training session or less).

Procedures

All procedures were performed in the Department of Health, Sport, and Exercise Sciences Applied Physiology Lab or Jayhawk Sport Performance Lab. Each subject performed a familiarization session, 18 workout sessions (3 times per week for 6 weeks), and a post-testing session. All sessions were monitored by CSCS and First Aid/CPR certified researchers.

Familiarization

At the initial familiarization meeting subjects were debriefed regarding the study. Anthropometric data was taken (age, height, weight), subjects were familiarized with the resistance training equipment and exercises used during the study, and were tested for one repetition maximum (1 RM) in the barbell parallel back squat and bench press exercises. Testing procedures were performed according to previously established protocols (Champaign, IL: Human Kinetics)(34). Squat 1 RM was required to reach parallel depth, determined by descending to the point of the hip joint/anterior superior iliac spine (ASIS) was even with the knee joint, and returning to a standing position. During the bench press, subjects were instructed to touch the bar to the chest, keep their glutes in contact with the bench, and to begin and end at full elbow extension. Prior to the one repetition maximum protocol, subjects completed a Likert readiness questionnaire to measure mental and physical readiness (see Figure 1). Subjects then performed 2 sets of 3 repetitions of maximal effort barbell jump squats at ~20% 1RM and 2 sets of 3 repetitions of maximum effort speed bench press at ~20% 1RM, with peak concentric velocity recorded for all repetitions. Velocity data was collected using the EliteForm system (Lincoln, NE), a rack-mounted, video capture system used to detect and track barbell velocity and power. EliteForm has been validated for velocity and power data collection relative to a ceiling–mounted linear position transducer (Unimeasure, Corvallis, OR) (14).

Likert readiness questionnaire

Prior to every training session, subjects completed a standard visual analog scale of 100 mm in length, similar to those developed by Nosaka et al. 2002 and described by others (18, 36). Similar modified scales have been validated relative to the CSAI-2, a questionnaire frequently utilized in sports psychology research to determine mental state or performance anxiety (25, 35).

As the participant marked the line left to right, corresponding readiness tags ranging from 0 (No readiness) to 10 (maximal readiness) indicated the physical and mental readiness of the subject. Subjects were instructed to place a vertical mark on the horizontal visual analog scale and circle a number on the categorical scale. Marks did not have to be made at one of the whole numbers already listed (for example, answers such as 6.5/10 were acceptable). The Likert scale questionnaire is shown in Figure 1:

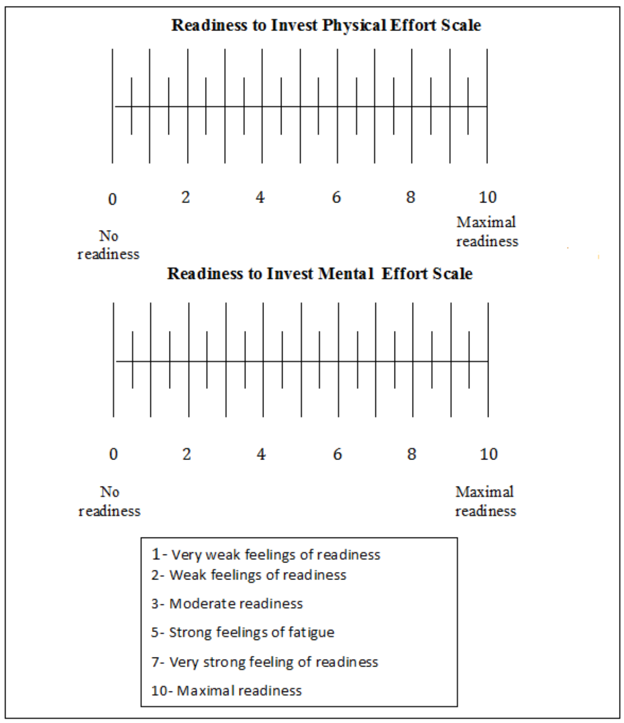

Figure 1. Likert readiness questionnaire

Autoregulating Progressive Resistance Exercise and Velocity-based Autoregulating Resistance Exercise Protocols

Subjects were randomly assigned to one of two groups: velocity-based autoregulatory progressive resistance exercise (VAR, n=9), or autoregulatory progressive resistance exercise (APRE, n =7). Participants exercised three days per week. Each training session took approximately 60-75 minutes, and occurred at the same time of day per subject. Prior to each training session subjects used a Likert readiness questionnaire to measure mental and physical readiness (see Figure 1). Subjects then performed 2 sets of 3 repetitions of barbell jump squats and 2 sets of 3 repetitions of speed bench press ~20% 1 RM, with peak concentric velocity recorded for all repetitions. These results were compared to the previously generated velocity performance in order to determine physiological readiness and load selection for the VAR group. If the subject registered a 3% or greater velocity than the average of the previous three training sessions' performance, it was presumed that readiness was high, ability to perform was high, and heavier loads were used. If the subject registered velocities 3% or more below the average of the previous three training sessions, it was presumed that readiness was low, fatigue was high, ability to perform was diminished, and lighter loads/higher volume were prescribed for that day. Three percent was selected as the criteria for a significant change in velocity based on previous pilot data from our lab.

For both groups, autoregulatory progressive resistance exercise was implemented for the bench press and back squat exercises. Over the 6-week training period, three different autoregulatory protocols were used: 10RM, 6RM, and 3RM. The APRE group performed 2 weeks of each method, progressing linearly from high to low volume (i.e. 10 to 6 to 3). The pre-session velocity performance dictated VARs load and volume. No attempt was made to match volume between groups. Table 2 outlines the autoregulatory progressive resistance exercise protocols for each repetition range. 4 sets are performed per exercise, with two warm up sets at 50% and 75% RM, respectively, followed by two sets at 100% RM performed to technical failure. Table 3 describes the adjustments in load made for set 4 determined by set 3 performances. Set 4 performance was used to determine the initial resistance used for set 3 in the following RM training session.

Table 2. APRE Protocols

3RM Strength/Power	6RM Strength/Hypertrophy	10RM Hypertrophy
50% 3RM for 6 repetitions	50% 6RM for 10 repetitions	50% 10RM for 12 repetitions
75% 3RM for 3 repetitions	75% 6RM for 6 repetitions	75% 19RM for 10 repetitions
100% 3RM to failure*	100% 6RM to failure*	100% 10RM to failure*
Adjusted load to failure**	Adjusted load to failure**	Adjusted load to failure**

*set three reps determine load to be used in set four
**determine load by cross referencing set three reps with Table 3

Table 3. APRE Adjustment Guidelines

3RM Protocol		6RM Protocol		10RM Protocol	
Set 3 repetitions	Set 4 load adjustment (lbs.)	Set 3 repetitions	Set 4 load adjustment (lbs.)	Set 3 repetitions	Set 4 load adjustment (lbs.)
0	-5 to -10	0-2	-5 to -10	0-3	-5 to -10
1	0 to -5	3-4	0 to -5	4-7	0 to -5
2-4	No change	5-7	No change	8-12	No change
5-7	+5 to +10	8-12	+5 to +10	13-17	+5 to +10
8+	+10 to +15	13+	+10 to +15	17+	+10 to +15

Training Protocol

Subjects trained three times per week (either Monday-Wednesday-Friday or Tuesday-Thursday-Saturday), with the three sessions performed in consistent order on a weekly basis. Subjects performed the autoregulation protocol on Day 1 and Day 2 for back squat and bench press, but did not perform sets to failure for the bench press exercise on Day 3. Accessory exercises (Romanian deadlift, step ups, reverse hyperextensions, barbell row, barbell overhead press, dumbbell row, front squat, bench press, lunges, and lat pulldown) involved 3 sets of 12 repetitions for the 10RM protocol, 4 sets of 8 repetitions for the 6RM protocol, and 4 sets of 5 repetitions for the 3RM protocol. Determination of proper loads for accessory exercises was done using a 10 point RPE/RIR combined scale (see Table 5). Weights were selected to correspond to an 8 RPE/2 RIR load, with weight added in subsequent sets whenever possible while maintaining the appropriate RPE response. After 6 weeks of training in this manner, subjects were re-tested on 1 RM performance in the back squat and bench press. Table 4 outlines the weekly training protocol:

Table 4. Weekly training schedule

Day 1	APRE Sets x reps	APRE Sets x reps	APRE Sets x reps
Back Squat	3RM	6RM	10RM
RDL	4 x 5	4 x 8	3 x 12
DB Step Ups	4 x 5 each	4 x 8 each	3 x 12 each
Reverse Hypers	4 x 5	4 x 8	3 x 12
Day 2			
Bench Press	3RM	6RM	10RM
BB Row	4 x 5	4 x 8	3 x 12
BB Overhead Press	4 x 5	4 x 8	3 x 12
DB Row	4 x 5 each	4 x 8 each	3 x 12 each
Day 3			
Front Squat	4 x 5	4 x 8	3 x 12
Bench Press	4 x 5	4 x 8	3 x 12
DB Lunges	4 x 5 each	4 x 8 each	3 x 12
Lat Pulldown/Pullups	4 x 5	4 x 8	3 x 12 each

Table 5. Resistance Exercise-Specific Rating of Perceived Exertion (RPE)

Rating	Description of Perceived Exertion
10	Maximum Effort
9.5	No further repetitions but could increase load
9	1 repetition remaining
8.5	1-2 repetitions remaining
8	2 repetitions remaining
7.5	2-3 repetitions remaining
7	3 repetitions remaining
5-6	4-6 repetitions remaining
3-4	Light effort
1-2	Little to no effort

Statistical Analysis

All data are reported as mean ± standard deviation (SD). Two 2x2 (group x time) mixed model analysis of variance (ANOVA) was used to determine significant differences in back squat and bench press 1RM improvement between groups. Two 2x20 (group x time/training session) mixed model ANOVA was used to determine significant differences in readiness measures between groups over the course of training. Two 2x18 (group x time/training session) mixed model ANOVA was used to determine significant differences in volume load between groups over the course of training. A 2x6 (group x time) mixed model ANOVAs were used to determine significant differences in volume load between groups on Day 1 (back squat to failure) and Day 2 (bench press to failure) between groups. Post hoc analysis used pairwise comparisons with a Bonferroni correction. Volume load was calculated for every training session for each subject by summing the repetitions performed times the load lifted (kg) for each set. Independent samples t-tests were used to determine differences in subject characteristics and baseline strength before training. Pearson product moment correlations were used to determine relationships between readiness variables, and to determine relationships between readiness variables and individual session performance in the back squat and bench press. Session performance was examined in two ways: by determining the predicted 1RM based on the number of repetitions performed for sets 3 and 4 for the back squat and bench press, and by the number of repetitions performed in sets 3 and 4 relative to the number of repetitions expected to be performed. Predicted 1RMs were calculated using the Epley equation (1RM = (load x reps x 0.033) + load) (2). Correlations were calculated using the difference between the pre-session expected 1RM and the observed 1RM (for example, if a subject's predicted 3RM was 200 pounds, the expected 1RM would correspond to (200 x 3 x 0.033) + 200, or approximately 219.8 pounds. If a subject performed 5 repetitions, they essentially "outperformed" the expected 3RM and 1RM, with a new predicted max of 233 pounds. This difference would be recorded as the observed 1RM less the predicted 1RM, or 13.2 pounds). The number of repetitions performed was defined as the difference in number of repetitions performed relative to expected repetitions (for example, if a 10RM protocol was employed and the subject performed 7 repetitions, this difference would be recorded as -3). These in-session factors were calculated in an effort to quantify how much better or worse subjects performed in given training sessions relative to expected performance in a consistent manner across 10RM, 6RM, and 3RM protocols, and if the training stimulus was "appropriate" given current physiological state. Cohen's d effect sizes were calculated for the improvement (change scores) for back squat and bench press. Cohen's *d* effect sizes were defined per the following criteria: small; $d = 0.2$, moderate; $d = 0.5$, and large; $d = 0.8$ (6). Analysis was conducted using SPSS V.23 (Chicago, IL). Statistical significance was set at $p \leq 0.05$.

Chapter 4: Results

Back Squat and Bench Press Strength Improvement Performance

There was a significant improvement in back squat 1RM and bench press 1RM over the course of the study for both groups ($F = 56.062$, $p < 0.001$, and $F = 34.607$, $p < 0.001$, respectively). There was no significant difference in initial strength levels between the two groups for squat (APRE: 127.33 ± 24.41 kg vs. VAR: 133.31 ± 40.64 kg, $t = 0.342$ [df = 14], $p = 0.737$) or bench press: (APRE: 99.1425 ± 27.89 kg vs. VAR: 96.26 ± 26.33 kg, $t = -0.212$ [df = 14], $p = 0.835$).

Pre and post-training changes in absolute bench press and squat strength were compared between the APRE and VAR groups. No interaction between pre/post-testing and time (time x group) was found for the back squat (APRE: 13.284 ± 5.307 kg vs. VAR: 15.624 ± 9.032 kg, F=

.367 [df = 14], p = 0.554) or for the bench press (APRE: 11.016 ± 7.341 kg vs. VAR: 7.56 ± 5.319 kg, F= 1.198 [df = 14], p = 0.292). Pre and post-training 1 RM values for the back squat and bench press are shown in Figures 1A and 1B, respectively. A moderate effect size was observed for improvements in back squat (ES = 0.488) and a small to moderate effect size was observed for improvements in bench press (ES = 0.331). Each subject improved at least 2.27 kg in both the bench press and squat over the course of the 6 weeks, with increases as high as 27.27 kg in the back squat and 24.94 kg in the bench press

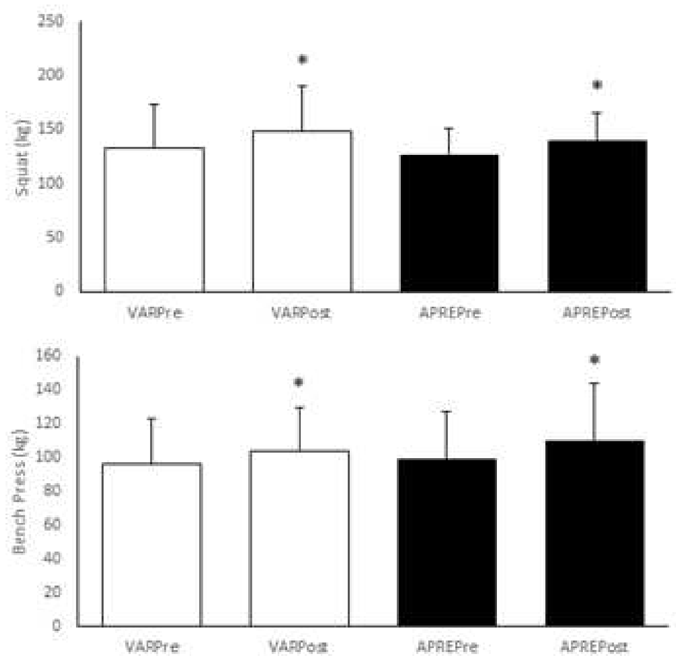

Figure 2. Change in A) squat and B) bench press 1 RM performance

Readiness Measure Correlations

Table 6 lists the correlations between the various readiness measures, both by group and for all subjects. Across all subjects, a significant relationship was found between barbell jump squat peak velocity and speed bench press peak velocity, speed bench velocity and mental readiness, speech bench velocity and physical readiness, and mental and physical readiness. No relationship was found between jump squat velocity and Likert-scale readiness. For the VAR group, a significant relationship was found between barbell jump squat peak velocity and speed bench peak velocity, barbell jump squat peak velocity and mental readiness, barbell jump squat velocity and physical readiness, and between mental and physical readiness. For the APRE group, a significant positive relationship was found between barbell jump squat and speed bench velocity, and mental and physical readiness. A significant negative relationship was observed between barbell jump squat velocity and mental and physical readiness. No significance was found between speed bench velocity and mental or physical readiness.

Table 6. Correlations between pre-session Readiness variables

	VAR	**df = 173**	**APRE**	**df = 130**	**Total**	**df = 305**
Variables	**r**	**p**	**r**	**p**	**r**	**p**
Jump Squat & Speed Bench	0.265	<0.001*	0.473	<0.001*	0.430	<0.001*
Jump Squat & Mental	0.274	<0.001*	-0.265	0.002*	0.081	0.149
Jump Squat & Physical	0.262	<0.001*	-0.301	<0.001*	0.053	0.347
Speed Bench & Mental	0.367	<0.001*	-0.003	0.976	0.214	<0.001*
Speed Bench & Physical	0.419	<0.001*	0.043	0.626	0.236	<0.001*
Mental & Physical	0.846	<0.001*	0.825	<0.001*	0.837	0.000*

* Correlation is significant at $p \leq 0.05$

Table 7 lists the correlations between readiness variables and in-session performance for back squat and bench press. Only the readiness measures recorded on Day 1 for back squat, and Day 2 for bench press (in which the APRE protocols were employed and sets 3 and 4 were taken to failure) were used in order to compare specific daily performance. 1RMPred refers to the predicted 1RM based on the number of repetitions performed to failure for sets 3 and 4, calculated using the Epley equation (1RM = (load x reps x 0.033) + load). Correlations were calculated using the difference between the pre-session expected 1RM and the observed 1RM.

Set 3 reps and set 4 reps refer to the difference in number of repetitions performed relative to expected repetitions.

Table 7. Correlations between pre-session Readiness and in-session performance

Back Squat	**VAR**	**df = 53**	**APRE**	**df = 40**	**Total**	**df = 94**
Variables – Day 1	**r**	**p**	**r**	**P**	**r**	**p**
Jump Squat & 1RMPred3	0.114	0.413	0.214	0.180	0.131	0.206
Jump Squat & 1RMPred4	0.038	0.784	0.017	0.915	0.041	0.691
Jump Squat & Set 3 reps	0.111	0.425	0.106	0.510	0.085	0.414
Jump Squat & Set 4 reps	0.087	0.532	0.142	0.376	0.119	0.250
Physical & 1RMPred3	0.199	0.149	0.072	0.656	0.164	0.112
Physical & 1RMPred4	0.357	0.008*	-0.016	0.921	0.259	0.011*
Physical & Set 3 reps	0.116	0.402	0.098	0.542	0.116	0.265
Physical & Set 4 reps	0.374	0.005*	-0.106	0.509	0.236	0.021*
Mental & 1RMPred3	0.135	0.332	0.070	0.662	0.116	0.263
Mental & 1RMPred4	0.348	0.010*	0.104	0.518	0.281	0.006*
Mental & Set 3 reps	0.072	0.604	0.140	0.382	0.096	0.355
Mental & Set 4 reps	0.361	0.007*	0.061	0.703	0.271	0.008*
Bench Press	**VAR**	**df = 53**	**APRE**	**df = 41**	**Total**	**df = 92**
Variables – Day 2	**r**	**p**	**r**	**p**	**r**	**p**
Speed Bench & 1RMPred3	0.270	0.048*	-0.028	0.858	0.006	0.951
Speed Bench & 1RMPred4	0.045	0.748	0.277	0.076	0.100	0.339
Speed Bench & Set 3 reps	0.248	0.071	-0.188	0.233	-0.059	0.574
Speed Bench & Set 4 reps	0.096	0.489	0.354	0.021*	0.181	0.082
Physical & 1RMPred3	0.196	0.156	0.338	0.028*	0.235	0.023*
Physical & 1RMPred4	0.049	0.723	-0.005	0.974	0.041	0.699
Physical & Set 3 reps	0.145	0.296	0.325	0.036*	0.197	0.058
Physical & Set 4 reps	0.178	0.197	-0.051	0.746	0.097	0.354
Mental & 1RMPred3	0.163	0.240	0.439	0.004*	0.245	0.018*
Mental & 1RMPred4	0.240	0.080	0.004	0.980	0.144	0.169
Mental & Set 3 reps	0.128	0.358	0.478	0.001*	0.231	0.026*
Mental & Set 4 reps	0.378	0.005*	-0.071	0.656	0.197	0.354

* Correlation is significant at $p \leq 0.05$

For back squat performance, across all subjects a significant correlation was found between physical readiness and set 4 predicted 1RM, physical readiness and set 4 repetitions performed, mental readiness and set 4 predicted 1RM, and mental readiness and set 4 repetitions performed. For the VAR group, a significant correlation was found between physical readiness and set 4 predicted 1RM, physical readiness and set 4 repetitions performed, mental readiness and set 4 predicted 1RM, and mental readiness and set 4 repetitions performed. No significant relationships were found for the APRE group, and no significant relationships were found between jump squat peak velocity and session performance.

For bench press performance, across all subjects a significant correlation was found between physical readiness and set 3 predicted 1RM, mental readiness and set 3 predicted 1RM, and mental readiness and set 3 repetitions performed. For the VAR group, a significant relationship was found between speed bench peak velocity and set 3 predicted 1RM, and mental readiness and set 4 repetitions performed. For the APRE group, a significant relationship was observed between speed bench peak velocity and set 4 repetitions performed, physical readiness and set 3 predicted 1RM, physical readiness and set 3 repetitions performed, mental readiness and set 3 predicted 1RM, and mental readiness and set 3 repetitions performed.

Peak Velocity Performance between groups

There was no interaction observed between groups relative to training session for jump squat peak velocity performance (ANOVA: $F = 0.771$, $p = 0.740$), nor was there a main effect for group ($F = 3.492$, $p = 0.089$) or training session ($F = 1.201$, $p = 0.259$). There was no significant change in average barbell jump squat peak velocity over the course of the study, nor was there a difference between groups. The VAR group exhibited consistently higher average jump squat peak velocity performance, but the effect was nonsignificant. Average peak velocity by group is represented in Figure 2.

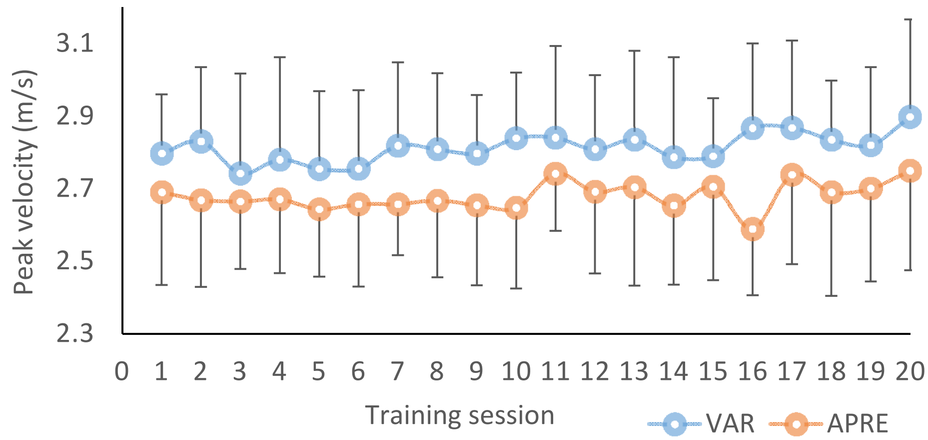

Figure 3. Average jump squat peak velocity by group

There was an interaction observed between training session and group for peak speed bench press velocity (ANOVA: F = 1.857, p = 0.023). The VAR group showed a significant improvement in speed bench press peak velocity, while this was not observed in the APRE group. Figure 3. Illustrates this divergence in performance:

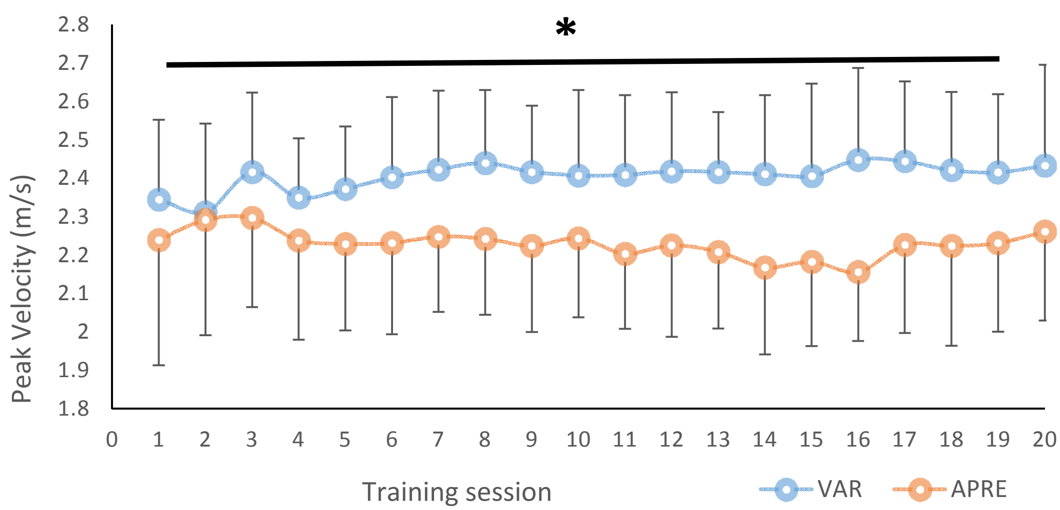

Figure 4. Average speed bench press peak velocity by group
* Indicates significant time effect in VAR only

Volume Load performance between groups

Table 8 details the average volume load (kg) performed during each training session by group, as well as the standard deviation and coefficient of variation. Coefficient of variation was calculated as the ratio of the standard deviation relative to the mean volume load for each training session, expressed as a percentage. Values are expressed as mean ± (SD):

Table 8. Volume load by group and training session

		VAR			APRE		
Week	**Day**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
	1	6041.5	(2698.8)	44.6%	7024.9	(1205.3)	17.2%
1	2	5322.2	(2320.9)	43.6%	6856.1	(1787.8)	26.1%
	3	6020.1	(2488.2)	41.3%	6503.2	(882.3)	13.6%
	1	7260.3	(2695.1)	37.1%	7886.4	(1582.2)	20.1%
2	2	5823.1	(1955.0)	33.6%	7728.0	(2310.7)	29.9%
	3	6493.5	(2433.7)	37.5%	7277.6	(1582.4)	21.7%
	1	7637.1	(1659.9)	21.7%	7639.9	(1328.2)	17.4%
3	2	6839.7	(2080.7)	30.4%	7424.1	(1987.5)	26.8%
	3	6706.7	(1368.9)	20.4%	7648.9	(1566.1)	20.5%
	1	8423.0	(2937.1)	34.9%	8835.3	(1341.5)	15.2%
4	2	7525.2	(1979.9)	26.3%	7703.4	(1754.6)	22.8%
	3	7710.6	(2474.4)	32.1%	8180.3	(1471.9)	18.0%
	1	9998.7	(2336.5)	23.4%	6102.0	(629.5)	10.3%
5	2	7435.7	(1094.2)	14.7%	5594.5	(1277.7)	22.8%
	3	6704.8	(1706.0)	25.4%	5784.5	(1135.9)	19.6%
	1	9195.4	(3044.1)	33.1%	6582.7	(693.6)	10.5%
6	2	7994.4	(1807.7)	22.6%	5561.7	(1325.0)	23.8%
	3	8032.7	(2304.2)	28.7%	5508.4	(980.3)	17.8%
Total		7284.3	(2424.4)	33.3%	7008.1	(1656.8)	23.64%

There was a statistically significant interaction between training session and training group (ANOVA: $F = 7.544$, $p < 0.001$), and a main effect for training session ($F = 6.001$, $p < 0.001$). There was no main effect for group ($F = 0.037$, $p = 0.851$). The results indicate that although there was no significant difference in total volume load performed between groups, there was a significant change in average volume load by training session over the course of the study. Specifically, the APRE group completed significantly less average volume load by the end of training, and the VAR group completed significantly more average volume load by the end of training. Post hoc pairwise comparisons for APRE indicated a significant difference between training sessions 1 and 10 (week 4 day 1), most likely a result of the subject's adaptation to heavier training loads (week 4 was the second week of the 6RM protocol for APRE). There was also a significant difference in average volume load between session 12 (week 4 day 3), and session 14 (week 5 day 2) and between session 12 and session 17 (week 6 day 2). This is most likely due to the 3RM protocol employed in weeks 5 and 6 and subsequently lower volume load totals, particularly for the upper-body training sessions (day 2). VAR post hoc comparisons indicated a significant difference in volume load between the first two weeks and last two weeks of training for nearly every training session, supporting the significant increase in average volume load over the course of training and large variation between subjects. Coefficients of variation by training session day ranged from 10.3-29.9% for the APRE group, and 14.7-44.6% for the VAR group, with greater overall volume load variation in the VAR group (33.3% vs. 23.64%). In regards to Day 1 (back squat and associated accessory exercises) volume load, a significant interaction was found between training session and group (ANOVA: $F = 8.688$, $p < 0.001$), as well as a main effect for training session ($F = 4.537$, $p = 0.001$). There was no main effect for group ($F = 0.731$, $p = 0.408$), meaning there was no significant difference between groups for the average volume load, however the APRE group performed significantly less back squat volume load as training progressed, and the VAR group performed significantly more back squat volume load as training progressed. Post hoc comparisons indicated a significant difference in back squat volume load between the first three weeks and last three weeks for both VAR and APRE. A similar effect was observed in regards to Day 2 (bench press to failure and associated accessories), with a significant interaction between group and training session day (ANOVA: $F = 23.853$, $p < 0.001$), a main effect for time ($F = 8.279$, $p < 0.001$), but not for group ($F = 0.000$, $p = 0.989$), and progressively greater volume performed by the VAR group. Post hoc analysis indicated a significant difference in bench press volume load between the first 4 weeks and last 2 weeks of training for both APRE and VAR.

Chapter 5: Discussion

Improvements in 1RM strength in squat and bench press

To our knowledge, this is the first study to compare autoregulatory training dictated by objective pre-session performance measures with previously established autoregulatory protocols. Both groups demonstrated improved 1RMs over the course of training. No significant differences were observed between groups in 1RM changes, suggesting that both programs were equally effective in improving 1RM strength during a 6-week training cycle.

Although both training models significantly improved strength, the total volume load performed by the two groups was markedly different. VAR performed progressively greater total volume load over the last two weeks of training, while APRE performed progressively less total volume load during the last two weeks of training, regardless of training day (i.e. Day 1 vs Day 2 vs Day 3). VAR also exhibited a greater coefficient of variation, both overall and across nearly every training day, suggesting greater variance in daily volume load totals between VAR subjects relative to APRE, understandable given the highly flexible nature of the load/volume prescription for the VAR group. No effort was made to match for total volume performed between groups or subjects, so while the APRE group transitioned linearly from 10RM protocols with high volume to 3RM protocols with lower volume/high loads, the VAR group was not subject to any high load taper in the last two weeks, and instead assigned loads based solely off of pre-session peak velocity performance. This may in part explain the (nonsignificant) differences in strength improvements between the two groups (VAR showed greater improvement in the barbell back squat 1RM, while APRE showed a greater improvement in barbell bench press 1RM). Lower body strength improvements in 1RM may be possible training at higher volumes than the upper body, which may require/be more sensitive to greater loads (and subsequent neurological adaptations) for improvements in max strength (37, 52).

The lack of difference in improvement may, in part, be partly explained by the heterogeneity of subject training status and baseline strength levels. While there were no significant differences between groups, training status ranged from 1-8 years, with baseline back squat 1 RMs ranging from 83.9 kg to 210.9 kg (in multiple cases relative to over twice bodyweight), and baseline bench press 1RMs ranging from 74.8 kg to 156.5 kg. Autoregulation has been suggested to be more appropriate and effective in highly trained populations (32). Properly adjusting session training loads via RPE depends heavily on realistically assessing readiness and fatigue. The ability to assess self-readiness takes time to learn and subsequently improves with training status (47). Training multiple sets to failure multiple times per week is extremely fatiguing, and requires a great deal of technical efficiency. Previous research has suggested that training to failure may not be as effective for gains in strength in lesser trained populations (38), and while there was no significant difference in improvement between subjects with lower and higher levels of baseline strength, these differential results are obscured by several outliers, both extreme responders to the program and several subjects who encountered load-dependent technique issues during the course of the study (it should be noted that outliers occurred in recreationally trained and highly trained subjects. 2x2 ANOVA for improvements in 1RM for back squat and bench press with outliers omitted still showed no significant interaction and decreased effect sizes). It was necessary to correct these dysfunctions during training in order to prevent injury, and while every subject improved in both back squat and bench press, this could have diminished the potential maximization of strength gains during the post-training 1RM testing. Many subjects failed to reach their best predicted 1RM result (via repetitions to failure in-session) during post-testing in either bench press or back squat, particularly those subjects with a lower training status who did not have as much experience exercising under heavy loads (45). Indeed, only one subject was able to outperform in-session predicted 1RMs, and most of the highest predicted 1RMs came from the 10RM protocol. This highlights the fact that maximum strength is a skill, and as with any skills it takes time to accustom the neuromuscular system to produce force under high loads (2, 40, 45). As such, autoregulation in which sets to failure occur in every training session and volume that could greatly vary prior to testing (i.e. the VAR group), may not be an ideal protocol for tapering to a true max test such as a powerlifting meet (40). Regardless, both programs were effective in producing significant increases in strength over the course of six weeks. Autoregulation appears to be an important tool for strength coaches and practitioners seeking to quickly improve strength in trained populations.

Readiness measures

Small but significant correlations were observed between a number of readiness measures. The relationships between the subjective measures of readiness and peak velocity suggests that they may associate with some aspects of physical performance, and may have predictive power for acute resistance training performance. Mental and physical readiness did correlate with measures of in-session performance for both back squat and bench press in both groups. However, no relationships were seen between mental and physical readiness and back squat in-session performance in the APRE group. This may have been due in part to the negative relationship observed between jump squat peak velocity and mental ($r = -0.265$, $p = 0.002$) and physical ($r = -0.301$, $p < 0.001$) readiness in the APRE group. Subject bias, unfamiliarity with the Likert-scale responses used, and the lack of change in average peak jump squat velocity over the course of the study may explain this negative relationship. Subjects may also have struggled to determine the difference between mental and physical readiness, as the very strong correlation between them indicates that subjects may have had trouble distinguishing between the two. How physically ready a subject feels is in itself a mental measure, and when reported via survey there may not be a distinct difference between mental and physical readiness. A single scale representative of overall readiness, as outlined in McNamara et al. 2010, may be a more appropriate subjective measure (33).

The significant relationship between upper and lower body performance as measured via speed bench press and squat jump may suggest that peak velocity can be used as an approximation of overall physiological state, and that readiness may be largely affected by central mechanisms. This relationship may be best supported by comparing the variance of squat jump performance over the course of the study. Average jump squat peak velocity performance remained relatively stable for both groups, suggesting minimal learning effect on lower body velocity production, thus making it suitable for subjects with low training status. The only significant increase in squat jump peak velocity occurred prior to the post-training 1RM. We speculate this increase may have been the result of increased motivation. Squat jump performance may accurately predict an increase in motivation or central drive, suggesting that central mechanisms may have a greater effect than anything else for improving readiness and performance (1, 3, 50).

While there was a significant relationship between speed bench press and mental and physical readiness overall and in the VAR group, this relationship was not observed in the APRE group. Furthermore, a significant improvement in speed bench press peak velocity performance was observed in the VAR group over the course of the study, but not the APRE group. This surprising phenomena may be explained by a number of factors. First, the speed bench press technique, in which subjects were instructed to explode the bar maximally during the concentric portion of the lift, may be an inappropriate tool with which to measure peak velocity, and an open kinetic chain exercise such as a bench press throw may have been more appropriate relative to using jump squat for the lower body. Despite the subjects' best intentions, as much as 40% of the concentric bar path of a bench press has been shown to involve deceleration, and with a minimum velocity threshold of approximately 0.15 meters per second (the typical velocity of a 1RM bench press in an untrained subject, or the minimum velocity at which a repetition can be completed), the bench press is not a ballistic exercise (22, 30, 31). However, the speed bench technique may actually have been the more sensitive measure of readiness, as the divergence in speed bench performance may have been a reflection of the lower volume loads and heavier absolute loads used by the APRE group over the course of the study. This may also have indicated a specificity of neurological adaptation to the higher loads and an increase in technical proficiency of the bench press (and not ballistic speed bench/bench throw) movement, suggesting that the upper body measure (perhaps in some part due to the afferent feedback of the bar being in the hands) may be a more sensitive measure of readiness that is more indicative of central mechanisms (1).

While peak velocity was used in this study to determine readiness, as it was hypothesized that peak velocity may more accurately approximate maximum daily performance ability, it may be too sensitive a measure to predict session performance, due to the myriad of variables that impact velocity and force production. Neither jump squat nor speed bench press peak velocity performance were effective in identifying in-session performance of back squat or bench press sets to failure, with the lone exceptions being a weak correlation between speed bench and predicted 1RM for set 3 in the VAR group, and a weak correlation between speed bench and the number of repetitions performed in set 4 for the APRE group. This suggests that the proper measurement of velocity is highly context and exercise-dependent, and should be carefully selected based upon the goals of the measurement. Regardless of peak or mean measurement, using velocity to monitor readiness on a daily basis may not be necessary or appropriate except for elite athletes. There are simply too many other variables that influence results that the subjects in this study may not have been trained enough for significant change to override measurement noise. This is also the first known study to attempt to use velocity as a measure of readiness, or to attempt to determine a significant difference for daily peak velocity performance. As such, the determination that a 3% change in peak velocity performance relative to a weekly average was significant enough to warrant a change in VAR group training volume load was based off of pilot data conducted within our lab. This was determined using a small sample size and was, for all intents and purposes, an arbitrary construct or starting point to examine velocity based autoregulation. Based on calculations of coefficients of variation and smallest worthwhile change, this 3% selection may have been an inappropriate representation of significance, with perhaps a 1.5-2% variance being more appropriate for most subjects. It should be noted that average peak velocity and variation fluctuated greatly between individual subjects. This may help further explain the lack of a significant relationship between peak velocity measures and in-session performance, as an improper determination of readiness and physiological state may have led to further inappropriate training loads being assigned as well, impacting maximum performance. Strength coaches attempting to determine significant changes in velocity may be better off determining significance on an individual athlete basis.

Velocity is essential to sport performance; however, it may be inappropriate for evaluating readiness on a day to day basis. Velocity based measures may be better suited for tracking long term changes. Establishing an athlete-specific load velocity profile, and *autoregulating* training via velocity, rather than load, to elicit sport-specific performance improvement, and monitoring velocity to control *fatigue* rather than establish readiness, may be more appropriate. More research is needed to determine the best practical application of these relationships, especially regarding which factors to measure, what type of change over time can be considered significant, and their relative predictive power for subsequent training performance.

Practical Applications

For short training cycles intended to increase maximal strength gains (e.g. off-season mesocycles), autoregulatory training overload has been shown to be an effective training program (32). While autoregulation has been shown to be effective in untrained and moderately trained populations, it may be more appropriate for highly trained athletes who possess greater levels of technical proficiency and innate understanding of readiness status. Further research is needed to determine the most predictive measures of athlete readiness, however using frequent, non-fatiguing pre-session tests may be effective for strength coaches to approximate the myriad variables that create an athlete's physiological state. While determining training based on changes in daily peak velocity performance may be too sensitive a measure to be significant in all but elite populations, tracking changes over time in these variables could serve as a useful tool to monitor fatigue or prevent injury (via more appropriate volume loads), as well as more accurately improving maximum performance capability during peaking phases of training. Further research is warranted to greater understand the differential approaches to autoregulation that currently exist, particularly regarding the applications of pre-session performance/readiness, in-session performance, and subjective vs. objective factors.

APPENDIX

A. Informed Consent
B. Medical History Form

A)

STUDY00002878

IRB #

Adult Informed Consent Statement: A Comparative Study of Strength Improvements in Autoregulatory Exercise Programs

INTRODUCTION

The Department of Health, Sport, and Exercise Sciences at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY

The purpose of the study is to compare the efficacy of different types of autoregulatory training for improvements in strength in the barbell back squat and barbell bench press between subjects performing autoregulatory progressive resistance exercise and velocity-based autoregulatory progressive resistance exercise over the course of a 6-week training interval.

PROCEDURES

You will be asked to partake in 20 sessions total, including one familiarization session, 18 training sessions (three times per week for six weeks), and one final testing session. Each session should take approximately 1 hour. During the familiarization session you will fill out a health history questionnaire, anthropometric measures (height, weight, etc.) will be taken, and a one repetition maximum (1RM) will be established for the barbell back squat and barbell bench press. Subjects will also receive an Academic Stress Calendar, to record periods of high academic stress over the course of the study. Prior to the 1RM protocol subjects will perform 3 maximum effort vertical jumps on a force plate, as well as 2 sets of 3 repetitions of jump squats and 2 sets of 3 repetitions of speed bench press at 20%1RM, with peak concentric velocity recorded for all repetitions. Velocity data will be collected using either a Tendo unit (Trencin, Slovak Republic), a tether-based dynamometer that attaches to the end of a barbell, or using the EliteForm system (Lincoln, NE), a rack-mounted, video capture system used to detect and track barbell velocity and power

Subjects will train three times per week for six weeks. Prior to each training session subjects will use a Likert questionnaire to assess readiness, and once per week (on Day 3) subjects will also fill out a Sleep Quality Questionnaire. Subjects will then perform 3 maximum effort vertical jumps on a force plate, 2 sets of 3 repetitions of jump squats and 2 sets of 3 repetitions of speed bench press at 20%1RM, with peak concentric velocity recorded for all repetitions. These results will be compared to the previously generated velocity performance in order to determine physiological readiness. Day 1 will include back squats, Romanian deadlifts, step ups, and reverse hyperextensions. Day 2 will include bench press, barbell row, barbell overhead press, and dumbbell row. Day 3 will include front squat, bench press, lunges, and lat pulldown or pullups.

The number of repetitions and weights used for each exercise will be determined on a daily basis. For the back squat and bench press exercises, an autoregulatory protocol at 10RM (~75% 1RM), 6RM (~85% 1RM), or 3RM (~90% 1RM) will be employed, depending on pre-session performance. The protocols consist of 2 warm up sets at 50% and 75% XRM, respectively, and 2 sets to failure at ~100% XRM. Accessory exercise sets and reps will vary, depending on the autoregulatory protocol employed: 3 sets of 12 repetitions for 10RM, 4 sets of 8 repetitions for 6RM, and 4 sets of 5 repetitions for 3 RM. Weights used will be determined via a Rating of Perceived Exertion 1-10 scale. Subjects will select a load corresponding to an 8 RPE, or a weight at which approximately 2 more repetitions could be performed each set. On the final set, 10 pounds will be added, and you will attempt to complete all repetitions. If all reps are successfully completed, this 8 RPE + 10-pound load will be the starting weight for the subsequent session.

At the end of the six-week training protocol, you will be retested in the back squat and bench press 1 repetition maximum.

RISKS

As with all types of physical activity, the resistance training protocols in this study carry a low risk of injury or harm to the musculoskeletal system. A medical history record will also be required prior to participation, which will include personal and private information.

BENEFITS

Individual subjects can expect improvements in a number of physiological variables (primarily strength and power production) and improved performance in exercises such as Back Squat and Bench Press. Subjects will also receive feedback on proper technique, safety, and programming methods, which will aid subjects in continuing to improve even after the completion of the study. This study could also lead to significant insight regarding optimum training techniques, which could have particular benefit for athletes and special populations.

PAYMENT TO PARTICIPANTS

Subject will not receive financial compensation for participation in this study.

PARTICIPANT CONFIDENTIALITY

Your name or private information will not be associated in any publication or presentation with the information collected about you or with the research findings from this study. Instead, the researcher(s) will use a subject number rather than your name. Your identifiable information will not be shared unless (a) it is required by law or university policy, or (b) you give written permission.

Permission granted on this date to use and disclose your information remains in effect for three years following completion of data collection. By signing this form you give permission for the use and disclosure of your information for purposes of this study during this allotted time."

Some data may be collected using the EliteForm system (Lincoln, NE), a rack-mounted, video capture system used to detect and track barbell velocity and power, located in Robinson 207. EliteForm uses an electronic data collection system called StrengthPlanner, which records training session data (sets, repetitions, load, etc.). All data collected on StrengthPlanner will be done using subject numbers only (see 6.7), with no directly identifying subject information. EliteForm stores this data in an online database, which is encrypted with standards consistent with online ecommerce, in order to ensure data protection and subject confidentiality. The data is only accessible via an administrative password.
The EliteForm unit uses video capture as a method to detect barbell velocity and power, in which subject faces are easily recognizable. However, the video recordings themselves are only necessary for velocity and power data, and will not be used or viewed in any way during the course of the study. Videos are only recorded on the local EliteForm machine in the Strength Lab, are not sent to EliteForm's cloud database, and are only accessible by the primary investigator. Videos will be deleted daily, and will not be viewed or transcribed in any way, in order to protect and maintain subject confidentiality. These recordings are required in order to participate in the study. Consent to being recorded is required in order to participate in this study.

INSTITUTIONAL DISCLAIMER STATEMENT

In the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of a state employee acting within the scope of his/her employment.

REFUSAL TO SIGN CONSENT AND AUTHORIZATION

You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose further information collected about you, in writing, at any time, by sending your written request to: Alexander Bryce, 1301 Sunnyside Avenue, Robinson Center, University of Kansas, Lawrence KS, 66045.

Subjects may be withdrawn without their consent if it is determined that the subject cannot perform the training sessions safely for any reason, or should not continue in the study without serious risks of injury or harm.

If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use and disclose information that was gathered before they received your cancellation, as described above.

QUESTIONS ABOUT PARTICIPATION

Questions about procedures should be directed to the researcher(s) listed at the end of this consent form.

PARTICIPANT CERTIFICATION:

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or (785) 864-7385, write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7568, or email irb@ku.edu.

I agree to take part in this study as a research participant. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

______________________________ ____________________
Type/Print Participant's Name Date

____
Participant's Signature

Subjects will be video recorded during all familiarization and training sessions. By initialing below, I hereby give consent for my videograph to be taken during the course of this study.

______________________________ ____________________
Subject Initials Date

Researcher Contact Information

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B)

PRE-EXERCISE TESTING
HEALTH & EXERCISE STATUS
QUESTIONNAIRE

THE UNIVERSITY OF KANSAS

Name ____ Date______________

Home Address____

Phone Number ______________________ Email _______________________

Birthday (mm/dd/yy)____/_____/_____

Person to contact in case of emergency____

Emergency Contact Phone ____________________

Personal Physician __________________________ Physician's Phone______________

Gender________ Age ______(yrs) Pre: Height ____(ft)_____(in) Weight______(lbs.)
Post: Height ____(ft)_____(in) Weight______(lbs.)

Does the above weight indicate: a gain____ a loss____ no change____ in the past year?
If a change, how many pounds?__________(lbs.)

A. JOINT-MUSCLE STATUS (✓Check areas where you currently have problems)

Joint Areas
( ) Wrists
( ) Elbows
( ) Shoulders
( ) Upper Spine & Neck
( ) Lower Spine
( ) Hips
( ) Knees
( ) Ankles
( ) Feet
( ) Other______________________

Muscle Areas
( ) Arms
( ) Shoulders
( ) Chest
( ) Upper Back & Neck
( ) Abdominal Regions
( ) Lower Back
( ) Buttocks
( ) Thighs
( ) Lower Leg
( ) Feet
( ) Other____________________

B. HEALTH STATUS (✓Check if you currently have any of the following conditions)

( ) High Blood Pressure
( ) Heart Disease or Dysfunction
( ) Acute Infection
( ) Diabetes or Blood Sugar Level Abnormality

( ) Peripheral Circulatory Disorder
( ) Lung Disease or Dysfunction
( ) Arthritis or Gout
( ) Edema
( ) Epilepsy
( ) Multiply Sclerosis
( ) High Blood Cholesterol or Triglyceride Levels
( ) Allergic reactions to rubbing alcohol
( ) Anemia
( ) Hernias
( ) Thyroid Dysfunction
( ) Pancreas Dysfunction
( ) Liver Dysfunction
( ) Kidney Dysfunction
( ) Phenylketonuria (PKU)
( ) Loss of Consciousness

* *NOTE: If any of these conditions are checked, then a physician's health clearance will required.*

C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination________________________________

Physical problems noted at that time____

Has a physician ever made any recommendations relative to limiting your level of physical exertion? __________YES ___________NO

If YES, what limitations were recommended?______________________________________

____

D. FEMALE REPRODUCTIVE HISTORY

If you are male, skip to Section E.

Did you begin menses within the past year? __________YES __________NO

Have you had consistent menstrual periods for the last 3 months?
YES__________ NO__________

Date of onset of last menstrual period____

Have you used a hormonal contraceptive within the last 3 months?
YES___________ NO___________

E. CURRENT MEDICATION USAGE (List the drug name, the condition being managed, and the length of time used)

MEDICATION	CONDITION	LENGTH OF USAGE

F. **PHYSICAL PERCEPTIONS** (Indicate any unusual sensations or perceptions. ✓Check if you have recently experienced any of the following during or soon after *physical activity* (PA); or during *sedentary periods* (SED))

PA	SED		PA	SED	
( )	( )	Chest Pain	( )	( )	Nausea
( )	( )	Heart Palpitations	( )	( )	Light Headedness
( )	( )	Unusually Rapid Breathing	( )	( )	Loss of Consciousness
( )	( )	Overheating	( )	( )	Loss of Balance
( )	( )	Muscle Cramping	( )	( )	Loss of Coordination
( )	( )	Muscle Pain	( )	( )	Extreme Weakness
( )	( )	Joint Pain	( )	( )	Numbness
( )	( )	Other________________________	( )	( )	Mental Confusion

G. **FAMILY HISTORY** (✓Check if any of your blood relatives . . . parents, brothers, sisters, aunts, uncles, and/or grandparents . . . have or had any of the following)

( ) Heart Disease
( ) Heart Attacks or Strokes (prior to age 50)
( ) Elevated Blood Cholesterol or Triglyceride Levels
( ) High Blood Pressure
( ) Diabetes
( ) Sudden Death (other than accidental)

H. **EXERCISE STATUS**

Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

What is your fastest 5 km time? ______________

What is your fasted 10 km time? _____________

What is your fasted mile time? _______________

What is your fasted times at other distances not listed? ____________________________________

Do you regularly lift weights? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

What is your back squat 1 repetition maximum (RM)? _____________

What is your deadlift 1 RM? ____________

What is your power clean 1 RM? ____________

What are your other 1 RMs that are not listed? ____

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

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