RELATIONSHIP BETWEEN VELOCITY AND REPETITIONS IN RESERVE IN THE BACK SQUAT, BENCH PRESS, AND DEADLIFT

by

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ABSTRACT

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This study examined the relationship between average concentric velocity (ACV) and repetitions in reserve (RIR) in the back squat, bench press, and deadlift. Fourteen resistance-trained men performed three experimental sessions (one for each exercise), which was comprised of 4 sets to failure at 80% of one-repetition maximum. The ACV was recorded on every repetition of every set and cross-referenced with RIR. The main findings of this study were that RIR was a significant predictor of ACV for all three exercises; the mean set ACV was significantly different between exercises ($p<0.001$); and the relationship between RIR and ACV was set-dependent ($p<0.001$). However, the within-exercise difference in ACV from set-to-set is unlikely to be practically significant as all of these ACV differences were below the threshold of 0.06 $m \cdot s^{-1}$, which is the smallest worthwhile change in ACV. Therefore, these results suggest that the RIR/ACV relationship is exercise-specific, and is stable from set-to-set.

RELATIONSHIP BETWEEN VELOCITY AND REPETITIONS

IN RESERVE IN THE BACK SQUAT, BENCH PRESS, AND DEADLFIT

LIST OF TABLES

LIST OF FIGURES

I: INTRODUCTION

Autoregulation within a resistance training program can be defined as the adjustment of acute training variables in order to individualize the programs stressors for optimal adaptations (1). One acute training variable that can be adjusted is training volume via autoregulating the number of repetitions per set. Recently, Cooke et al. demonstrated a high degree of inter-individual variability in repetitions performed at a given intensity (i.e. 70% of one-repetition maximum-1RM) on the squat (range: 6-26) (2). Therefore, if athletes are prescribed percentage-based programs (i.e. 4 sets of 10 repetitions at 70% of 1RM) some athletes may fail on a set, while others might not receive a sufficient stimulus. Importantly, training to failure has resulted in an elongated recovery period versus non-failure training (3); thus, autoregulating the number of repetitions per set and monitoring the proximity to failure can ensure the appropriate training stimulus.

Helms et al. (4) has used the repetitions in reserve (RIR) "RIR Stop" method to control for proximity to failure. To implement this method, 4 sets at 70% of 1RM could be prescribed and each set would be "stopped" when the athlete perceived there was 2 RIR (or another predetermined RIR) remaining in the set. The RIR stop method does theoretically control for proximity to failure; however, recent data reported that when trained lifters predicted 1, 3, and 5 RIR during a squat set of 70% of 1RM to failure their RIR predictions were 2.05 ± 1.73, 3.65 ± 2.46, and 5.15 ± 2.92 repetitions under the actual RIR; respectively (5). Therefore, the subjective nature of RIR stop does not seem to reliably control for proximity to failure.

In terms of objective training tools, percentage velocity loss (6) is the most common method used to control for RIR during a resistance training set. For example, a program may prescribe 4 sets at 70% of 1RM and stipulate that the athlete terminate each set following a 40% velocity loss from the set's fastest – typically first – repetition. However, from set-to-set it is unlikely that the same percentage velocity loss will have the same relationship with the number of RIR in that set. For example, if the first repetition velocity during a set of back squats is 0.55 $m{\cdot}s^{-1}$, a 40% velocity loss would terminate the set at a velocity ≤0.33 $m{\cdot}s^{-1}$. However, if the same load is used on a later set the first repetition velocity will likely be slower (i.e. 0.45 $m{\cdot}s^{-1}$) and a 40% velocity loss would terminate the set at a velocity of ≤0.27 $m{\cdot}s^{-1}$. One potential method to rectify this issue is to establish is the relationship between absolute average concentric velocity (ACV) values with the number of RIR, and terminate sets at a specific ACV value instead of percentage velocity loss. Indeed, Moran-Navarro et al. (7) established that there was no significant difference in the ACV values which corresponded to 2, 4, 6, and 8 RIR during one set to failure at 65, 75, and 85% of 1RM within both the back squat and bench press among trained men; suggesting that absolute ACV values can be effectively used to determine RIR. However, most resistance training programs incorporate multiple sets, and to our knowledge, no study has examined if RIR/ACV is stable from set-to-set nor has any study examined the nature of this relationship in the deadlift exercise. Further establishment of the RIR/ACV relationship can allow athletes to objectively perform resistance training sets to a specific RIR in an effort to control for proximity to failure and potentially mitigate unnecessary fatigue.

Therefore, the purpose of this study was to examine the RIR/ACV relationship in the back squat, bench press, and deadlift exercises in resistance-trained males. Further, this study examined if the RIR/ACV relationship varied between exercises and across sets during 4 sets to failure at 80% of 1RM. It was hypothesized that the RIR/ACV relationship would be significantly different between exercises; however, we hypothesized that the RIR/ACV relationship would be similar from set-to-set within each exercise.

II: REVIEW OF LITERATURE

Individualized and Integrated Resistance Training

The optimal resistance-training programming structure has been debated substantially in the past century (8). Specifically, numerous periodization theorists have advocated particular periodization models that have been developed from not only the scientific literature but their own intuition as well. However, the overarching foundation of all periodization models share common resistance-training principles; thus, they must not be perceived as mutually exclusive models. Therefore, it has been suggested that a wholistic model – integrating the beneficial components of each model – should be utilized in resistance-training programming (8).

Similarly, single methods have typically been applied to prescribe volume (4,6). Particularly, all present models of volume autoregulation have failed to interrelate the various methods available. However, it may be suggested that the same concept that has been recommended for periodization, also be proposed for volume autoregulation. In other words, it may be appropriate to integrate percentage velocity loss and absolute velocity values with the RIR-based RPE scale in order to achieve the intended proximity from failure; consequently, optimizing the magnitude of stimulus towards the targeted training adaptation.

Finally, recent evidence has indicated that the responses to training stimuli are considerably different between individuals; thus, individualization in resistance-training programming is paramount to ensure chronic physiological adaptations persist (9).

Nonetheless, the majority of training protocols fail to align with the unique responses of each individual (8,9). Therefore, employing universal modalities inclusive for all individuals lacks individualization, resulting in suboptimal adaptations. As a result, it may be argued that strategies emerging exclusively for each individual ascertains individualization, resulting in optimal adaptations (8,9). Overall, the requirement for individualization in resistance training is a fundamental topic that must be further investigated, uncovered, and explained.

Percentage-Based Training

Percentage-based training (PBT) prescribes load as a %1RM and is presumably the most generic load prescription model (10). Although PBT is employed extensively, countless limitations of PBT are apparent. An unmistakable limitation of PBT is that it is based on a single 1RM testing session; thus, if subject performance is abnormal and/or if investigator administration is performed incorrectly, the training stimulus applied may be irrelevant to the desired outcome (5). Additionally, completing a 1RM test is a time-consuming process that creates considerable stress and generates substantial fatigue (11). Furthermore, 1RM may change immensely in a short period of time and may fluctuate significantly on a session-to-session basis (10).

Finally, the number of repetitions that can be performed at given intensities is highly inter-individually variable depending on training history, genetics, and anthropometrics (2,12). For example, a 2019 study conducted by Cooke and colleagues investigated the number of repetitions that could be performed by 58 resistance-trained males and females at 70%1RM in the squat. Their data indicated that the mean repetitions performed was 14 with a standard deviation of ± 4. Surprisingly, the difference between the maximum and minimum number of repetitions performed was 20; ranging from 6 – 26. Therefore, prescribing identical percentages of 1RM for different individuals lacks standardization of effort between individuals. Ultimately, it is clear that solely utilizing PBT to prescribe load possesses numerous limitations; most notably its inability to standardize inter-individual level of effort.

RPE-Based Training

Due to the limitations of the scale produced by Hackett et al. (2012), Zourdos and colleagues (2016) developed a single resistance training-specific RPE scale measuring RIR (13,14). Importantly, a scale of this nature was initially developed by world-renowned powerlifting athlete and coach, Mike Tuchscherer and published in "The Reactive Training Systems Manual" (15). However, Zourdos and colleagues (2016) were the first to present this scale within the body of scientific literature (14).

The novel RIR-based RPE scale developed by Zourdos and colleagues (2016) offers numerous advantages to individualize training load. An athlete's status is everchanging due to numerous physiological and psychological factors affecting daily readiness and performance, including sleep, nutrition, and stress (1). Furthermore, large individual differences in progression and recovery from training are evident (1).

Helms et al. (2016) argue that using %1RM or RM to provide intensity are established from a single previous testing session that may not be reflective of their present capabilities (1). To provide an example, if an athlete performs atypically during testing, the results will not be indicative of their typical performances (1). Consequently, this may lead to inappropriate load prescriptions in the ensuing training cycle (1). For example, novice trainees exhibit sessional fluctuations in 1RM (16). In contrast, if an athlete's performance during testing is a valid measure of their present capabilities, this may still lead to inappropriate load prescriptions during training sessions when readiness and performance are abnormal. To provide an example, 1RM may be declined during periods of overreaching (17).

Various textbooks supply tables demonstrating repetitions allowed at varying intensities as a guideline for load prescription. Nonetheless, the number of repetitions performed at given intensities varies in different athletes. Overall, the RIR-based RPE scale is innovative in its ability to address individualization, manage fatigue, and optimize performance. Importantly, this novel scale has greater validity in resistance training than the conventional RPE scales.

In a very recent investigation, Zourdos and colleagues (2019) demonstrated that two factors affect the accuracy of intraset RIR using the RIR-based RPE scale: proximity to failure and total repetitions performed (5). The methodology in this study involved having well-trained subjects complete a validated 1RM squat assessment, followed by a 10-minute rest period. Next, a 70%1RM set to volitional failure on the squat was performed, in which opaque trash bags covered the weight discs, serving the purpose of blinding the subjects to the absolute and relative load on the barbell. Employing the RIR-based RPE scale, subjects verbally stated when they perceived that they were at a 5 RPE (5 RIR), 7 RPE (3 RIR), and 9 RPE (1 RIR) throughout the 70%1RM AMRAP set (5). There were vast differences in the number of repetitions that individuals could perform at 70%1RM, with the minimum number of repetitions registered being 9 and the maximum number of repetitions registered being 26 (5).

For each of the three intraset RPE ratings, the RIR difference (RIRDIFF) was calculated via the following formula: RIRDIFF = actual repetitions – predicted repetitions. A higher RPE rating was associated with a lower RIRDIFF, as evidence by a significant condition effect ($p < 0.001$) [21]. In particular, at the called 9, 7, and 5 RPE the RIRDIFF was 2.05 ± 1.73, 3.65 ± 2.46, and 5.15 ± 2.92, respectively. Furthermore, at the called 9 RPE, the closest RIRDIFF was 0, occurring 4 times, and the furthest RIRDIFF was 6, occurring 1 time. Moreover, at the called 7 RPE, the closest RIRDIFF was 0, occurring 1 time, and the furthest RIRDIFF was 7, occurring 5 times. Lastly, at the called 5 RPE, the closest RIRDIFF was 0, occurring 1 time, and the furthest RIRDIFF was 11, occurring 1 time. In other words, there are large discrepancies between individuals in their ability to accurately gauge RPE, suggesting that RPE may be beneficial for certain individuals to use, but disadvantageous for others. At the called 9 RPE, there was a significant and inverse relationship between chronological age and RIRDIFF, which provides evidence to support that older individuals may be more accurate at gauging RPE when closer to failure.

In summary, these findings demonstrate that intraset RIR-based RPE rating is more accurate closer to failure and when fewer total repetitions are performed in a set; thus, intraset RIR-based RPE rating is less accurate further from failure and when more total repetitions are performed in a set. Therefore, this data provides implications that when prescribing training load using the RIR-based RPE scale the intensity should be high (≥ 80%1RM), proximity to failure should be moderate to high (≤ 3 RIR) and the total repetitions performed should be moderate to low. To account for this limitation, Zourdos et al. (2019) suggest providing an RPE range for training loads, and chronically tracking the relationship between load, RPE, and repetitions performed to enhance the efficacy of practically applying RIR-based RPE prescription.

Helms and colleagues (2016) adapted a chart relating %1RM, repetitions performed, and RIR-based RPE from the data of the experienced squatters in the study conducted by Zourdos et al. (2016) (1, 14). Specifically, the mean scores from the 90 and 100%1RM single repetition sets, and the 8- repetition set at 70%1RM were used to develop this chart. The remaining %1RM values were interpolated and extrapolated from this data. Importantly, athletes and coaches must recognize that inter-individual variability in the relationship among these three variables is evident; thus, individual athletes must adapt individual tables.

Although this table serves as a means to conceptually understand the relationship between %1RM, repetitions performed, and RIR-based RPE, the authors address several prominent limitations. The most obvious limitation is that this chart was developed from 15 subjects with a training age of 5.2 ± 3.5 years. In other words, the sample size was very small and the training age was highly dispersed. Furthermore, only 3 different percentages of 1RM were used to generate the entire chart; therefore, it may be argued that a greater number of percentages of 1RM may reflect more accurate values. In addition, the barbell back squat was used as the sole exercise to develop this chart; thus, charts unique to each exercise, such as the bench press and the deadlift must be established. Moreover, this chart is based exclusively on mean values; however, each individual is unique in the number of repetitions that they can complete with a given load (2, 12).Notably, Helms et al. (2016) recognize these limitations and advise that this chart simply provide a conceptual framework for athletes to individualize based on their own abilities.

The purpose of the study conducted by Helms and colleagues (2018) was to examine how incorporating RPE as a method of volume autoregulation affected total volume completed in the three powerlifts among twelve nationally qualified powerlifters (4). Twelve nationally-qualified NZPF powerlifters (male = 9; female = 3; age = 26.3 ± 6.8 years) trained on three non-consecutive days per week for 3 consecutive weeks, whilst performing the squat and bench press during each training session and the deadlift solely during the final two sessions of each week. The microcycle undulation order involved hypertrophy-, power-, and strength-centric training sessions comprising of 8 repetitions at 8 RPE, 2 repetitions at 8 RPE, and 3 repetitions at 9 RPE respectively.

During each training session, subjects self-selected their load for the first top working set (TS1) in an effort for the prescribed repetitions to comply with the target RPE. A second top working set (TS2) was performed if the subject failed to reach the target RPE on TS1. Specifically, a 2% load correction increase for TS2 per 0.5 RPE below the target RPE on TS1 was implemented. TS2 was not completed, if the RPE target was either reached or exceeded on TS1. Upon completion of the top set(s), back-off sets were performed in accordance with the RPE stop load reduction provided. However, if the RPE target was not obtained during the top sets, a 2% load correction per 0.5 RPE off from the target RPE was used to calculate the hypothetical load that should have been prescribed for the top set in order to hit the target RPE. Similarly, a 4% reduction in load for each repetition failed on a top set in addition to the load correction was used to calculate the hypothetical load. The three different RPE stops utilized for the back-off sets were a 2, 4, and 6% load reduction from the top set. A single RPE stop was used for each week; however, six permutations of the weekly order of RPE stops existed. Therefore, the weekly order of RPE stops was counterbalanced to acknowledge the order effect. Back-off sets were performed until one: the RPE recorded for a back-off set was equal to or greater than the target RPE, or two: eight total back-off sets were reached. It is important to note that RPE stops were originally developed by Mike Tuchscherer in "The Reactive Training Systems Manual" and were initially termed fatigue percents (14).

The weekly total relative volume (product of sets x repetitions x %1RM) performed on all three lifts combined (sum of squat + bench press + deadlift) increased linearly as RPE stop percentage increased ($p < 0.001$; 2% = 74.6 ± 22.3; 4% = 88.4 ± 23.8; 6% = 114.4 ± 33.4) [22]. Furthermore, weekly total relative volume for all lifts was 53.4%, 29.3%, and 18.6% higher for 6 versus 2%, 6 versus 4%, and 4 versus 2% RPE stop percentages. This evidence supports that volume is positively related to RPE stop percentage; however, the magnitude of volume increase is not linearly related to RPE stop percentage. Interestingly, weekly bench press volume on all three training sessions combined (hypertrophy + power + strength) was significantly greater as the RPE stop load reduction increased (2% > 4% > 6%; $p \leq 0.05$). Contrastingly, weekly combined squat volume was only significantly higher in the 6% compared to the 2% load reduction. Lastly, weekly combined deadlift volume was significantly higher in the 6 versus 4% load reduction and 6 versus 2% load reduction. These findings may be attributed to the similar biomechanical demands of the back squat and deadlift requiring similar musculature and impeding recovery. Additionally, a noteworthy limitation of this study was that the power session attributed to the greatest number of times that the capped back-off set limit was obtained; therefore, generating unnecessary excessive volume during a training type session in which the primary goal is recovery.

This method of autoregulating training volume using RPE stop percentages can be practically applied within a periodized program. More specifically, volume-focused mesocycles should use lower RPE targets and higher RPE stops to maximize morphological adaptations. Conversely, intensity-focused mesocycles should use higher RPE targets and lower RPE stops to optimize neurological adaptations. Furthermore, the authors of this paper argue that RPE stop percentages should be specific to the training session type. As a result, they suggest that hypertrophy, power, and strength sessions should utilize RPE stop percentages of approximately 4 – 6%, 0 – 2%, and 2 – 4% respectively. Nonetheless, further research is warranted to compare a training program with autoregulated volume to that with a fixed volume prescription.

Velocity-Based Training

In order to examine the relationship between RPE and ACV for the squat, bench press, and deadlift, Helms et al. (2017) conducted a study in which fifteen nationally-qualified male and female powerlifters performed a 1RM for each of the 3 powerlifts in competition order (18). The International Powerlifting Federation (IPF) technical rules provided the standard for approved lifting equipment and for a successful 1RM lift.

During the 1RM testing protocol, both RPE and ACV were recorded on all sets at ≥ 80%1RM. For each lift, subjects performed 8, 3, and 2 repetitions at 50, 60, and 70% of estimated 1RM respectively, followed by single repetitions at 80 and 90% of estimated 1RM. Afterwards, subjects performed strategic attempts in order to accurately determine their 1RM. If a subject reported a 10 RPE following a set, the load used for that set was recorded as their 1RM. On the other hand, if a subject failed a lift, they were allowed one re-attempt with that same load. Still, if a subject failed a lift on the re-attempt, no further attempts were allowed, and the load used for the last successful attempt was recorded as their 1RM. Upon completion of the 1RM protocol, the %1RM for all prior sets of one-repetition were calculated.

For the squat, bench press, and deadlift the RPE rating and ACV ($m \cdot s^{-1}$) at 1RM were 9.6 ± 0.5 and 0.23 ± 0.05, 9.7 ± 0.4 and 0.10 ± 0.04, and 9.6 ± 0.5 and 0.14 ± 0.05 respectively. The RPE ratings between the 3 powerlifts were not significantly different from one another; however, the ACVs for the 3 powerlifts were significantly different from one another. The data revealed strong inverse relationships between RPE and ACV (squat: $r = -0.87$, $p < 0.001$; bench press: $r = -0.79$, $p < 0.001$; deadlift: $r = -0.82$, $p < 0.001$). Furthermore, there were very strong relationships between RPE and actual %1RM in both the squat and deadlift ($r = 0.91$, $p < 0.001$) and a strong relationship in the bench press ($r = 0.88$, $p < 0.001$). Moreover, there were very strong relationships between ACV and actual %1RM in the squat ($r = - 0.91$, $p < 0.001$), bench press ($r = -0.90$, $p < 0.001$), and deadlift ($r = -0.92$, $p < 0.001$).

Conclusively, these findings suggest that all three modalities – RPE, ACV, and %1RM – may be used in conjunction to accurately predict and perform a 1RM assessment, in addition to prescribe, monitor, and adjust training load within a periodized model. All three methods of load prescription and volume autoregulation have advantages and limitations as has been addressed and discussed in explicit detail throughout this review of literature.

Innovatively, Helms and colleagues (2017) adapted individual regression equations for the squat, bench press, and deadlift that predict 1RM from ACV at ≥ 80%1RM. To illustrate, the regression equation for the squat, bench press, and deadlift are y = -0.449x + 1.096, y = -0.600x + 1.051, and y = -0.600x + 1.076 respectively. In the regression equation, the x-value represents the ACV in $m \cdot s^{-1}$ at ≥ 80%1RM and the y-value represents the predicted %1RM as a decimal. Therefore, to achieve the actual 1RM, simply divide the predicted %1RM as a decimal provided from the y-value by the load used in kilograms. Most importantly, the 90% CL for each of the three regression equations constitutes in a ± 5% for the predicted %1RM; thus, diminishing its accuracy and efficacy of being practically applied to predict 1RM. As a result, Helms et al. (2017) suggest that individualized load-velocity profiles should be developed if one is to use ACV exclusively as a stand-alone modality to prescribe training loads and predict 1RM.

The primary purpose of the study conducted by Rodriguez-Rossell and colleagues (2019) was to determine the relationship between repetitions completed and velocity loss from four varying percentages of 1RM (60, 70, 80, and 90) performed to failure in the squat and bench press (19). Their findings demonstrated a strong relationship between the number of repetitions completed and velocity loss. However, the number of repetitions performed at each intensity was highly inter-individually variable; thus, suggesting that velocity loss must be individualized in order to standardize for inter-individual level of effort. Nevertheless, a strong relationship between the magnitude of velocity loss and percentage of repetitions performed was evident in both the squat ($R^2 = 0.93$) and the bench press ($R^2 = 0.97$), independent of the individual differences in repetitions performed. Interestingly, acute neuromuscular fatigue was not dependent on the number of repetitions performed, but rather on the amount of velocity loss within a set to concentric failure. Consequently, resistance training volume should be prescribed using specific velocity loss thresholds rather than pre-determined number of repetitions in order to ensure that the appropriate degree of effort and desired stimulus is exhibited during each set in accordance with the overarching training goal.

Weakley and colleagues (2019) implemented a counterbalanced crossover design in order to investigate the kinetic and kinematic data of velocity loss thresholds during a squat in order to examine neuromuscular fatigue and hypertrophic outcomes (20). Specifically, for set 1 loads were systematically selected until a load was achieved that corresponded to an initial repetition ACV of 0.70 ± 0.01 m· s^{-1}. Alternatively, for sets 2 – 5 the initial repetition ACV was required to be 0.70 ± 0.06 m· s^{-1}. Finally, sets were terminated when a 10%, 20%, and 30% velocity loss from the first repetition within the set was obtained. Unsurprisingly, MCV was highest in the 10% velocity loss group, followed by the 20%, and 30% velocity loss groups with small individual differences evident. In addition, repetitions performed was highest in the 30% velocity loss group, followed by the 20%, and 10% velocity loss groups with very large individual differences evident. Practically, these results support that larger velocity loss thresholds elicit greater training volumes; thus, increasing overall hypertrophy. Conversely, smaller velocity loss thresholds favor hypertrophy of type II fibers; therefore, promoting strength and power. Conclusively, coaches and athletes can apply velocity loss thresholds in order to prescribe load and achieve the desired training adaptations.

The primary purpose of the study conducted by Moran-Navarro and colleagues (2019) was to determine the reliability of the absolute velocities associated with a 2, 4, 6, and 8 RIR in the squat, bench press, shoulder press, and prone bench pull at 65, 75, and 85% of 1RM (7). Interestingly, the absolute velocities at each RIR were highly reliable (CV: 4.4 – 8.0%) independent of the percentage of 1RM used. Surprisingly, these absolute velocities demonstrated no significant differences between the three groups. Based on this data it may be suggested that incorporating absolute velocity cutoffs is a reliable and accurate tool to precisely determine the proximity from failure.

Parejo-Blanco et al. (2017) developed a method employing velocity loss to autoregulate volume and proximity to failure within a set (6). In this study, subjects had a resistance training experience of 1.5 to 4 years and a 1RM squat of 1.41 ± 0.19 times body mass. Additionally, the training intervention encompassed a progressive periodized model for the squat and involved two weekly training sessions on Monday and Thursday for eight consecutive weeks. Two groups performed the identical training intervention differing solely in the percentage velocity loss employed: 20% (VL20) and 40% (VL40). Specifically, a set was stopped when the prescribed percent velocity loss from the initial repetition was surpassed following a repetition. Moreover, an explicit mean propulsive velocity (MPV) within 0.03 $m \cdot s^{-1}$ corresponding to an estimated percentage of 1RM was utilized to prescribe training load.

Over the course of the study, the average MPV was significantly faster ($p < 0.001$) in VL20 (0.69 ± 0.02 $m \cdot s^{-1}$) in comparison to VL40 (0.58 ± 0.03 $m \cdot s^{-1}$). On the other hand, the number of repetitions performed was significantly greater ($p < 0.001$) by approximately 40% in VL40 (310.5 ± 42.0) compared to VL20 (1.85.9 ± 22.2). Muscle failure was obtained in 56.3% of the total sets for VL40, and significantly more work ($p < 0.001$) by approximately 36% was completed by VL40 (200.6 ± 47.1 kJ) versus VL20

(127.5 ± 15.2 kJ). Furthermore, VL20 increased 1RM squat strength and countermovement jump height by 18.0% and 9.5% respectively, whereas VL40 increased the same measures by only 13.4% and 3.5% respectively. Lastly, both groups increased total cross-sectional area (CSA) of the quadriceps femoris; however, CSA of the vastus lateralis (VL) and vastus intermedius (VI) hypertrophied solely in VL40.

The evidence from this investigation supports the findings from several previous studies that training to failure is not inherently superior to submaximal training for improvements in strength and hypertrophy. Interestingly, a significant decrease in type IIX muscle fiber type was evident in VL40, but not VL20. This remodeling in muscle fiber type from fast- to slow-twitch may be due to the maximal rate of force development (RFD) decreasing with increasing repetitions in a set taken to failure. Importantly, this transition in phenotypic fiber type may have adverse effects for those striving to maximize strength, power, and explosiveness in their sport. Thus, it may be concluded that in order to optimize strength training at higher velocities and higher forces may be more advantageous than training at slower velocities performed to failure.

III: METHODS

Subjects

Fourteen resistance trained men between 18–40 years old were recruited for this study. For inclusion, subjects must: 1) have performed the back squat, bench press, and deadlift at least 1 time per week for the past 2 years as determined via a training history questionnaire, 2) have a minimum 1RM squat, bench press, and deadlift 1.5, 1.25, and 1.5 times body mass; respectively, and 3) be free of injury/illness that would contraindicate participation (high blood pressure, diabetes, etc.) as determined via a health history questionnaire. Subjects were instructed to refrain from any additional exercise and to continue their normal nutritional intake for the duration of the study. Lastly, this study was approved by Florida Atlantic University's Institutional Review Board and all subjects were required to sign an informed consent prior to participation.

Experimental Design

The primary aim of this study was to examine the relationship between both percentage velocity loss and absolute velocity values with proximity to failure over the course of 4 sets to failure at 80% of 1RM in the squat, bench press, and deadlift. A secondary aim of this study was to establish a table for normative values for the 1st set to failure, relating the number of repetitions performed, absolute velocity, percentage velocity loss, and RIR at 80% of 1RM in the squat, bench press, and deadlift.

Subjects reported to the laboratory 8 times over 3.5 weeks to complete the study. On day 1 of week 1, subjects completed a health history questionnaire and physical activity questionnaire, had anthropometrics assessed, and performed 1RM testing for the squat, bench press, and deadlift in accordance with previously validated procedures by Zourdos et al. (14). Day 2 of week 1 was performed 48 hours later, and consisted of a light training session on all three exercises (3 sets of 5 repetitions at 70% of 1RM) to serve as a bridge to the following week. The first experimental session, day 1 of week 2, was performed 72 hours later and involved 4 sets to volitional failure at 80% of 1RM for either the squat or deadlift. Next, 96 hours later, the same light training session as week 1 was performed on day 2 of week 2. Week 3 and 4 were identical to week 2; however, the bench press was performed during week 3, and the order of the squat and deadlift were counterbalanced between weeks 2 and 4. Five-minute rest periods were allotted between each set during the experimental sessions and average concentric velocity (ACV: $m \cdot s^{-1}$) was recorded for each repetition of every set. A timeline of events can be seen in Table 1.

Table 1. Timeline of Events

	Day 1 (Mon.)	**Day 2 (Tues.)**	**Day 3 (Wed.)**	**Day 4 (Thurs.)**	**Day 5 (Fri.)**
Week 1			• HHQ • PAQ • APT • 1RM Testing		• LTS
Week 2	• ES (SQ or DL)				• LTS
Week 3	• ES (BP)				• LTS
Week 4	• ES (SQ or DL)				• LTS

Health History Questionnaire (HHQ), Physical Activity Questionnaire (PAQ), Anthropometric Testing (APT), One-Repetition Maximum (1RM), Light Training Session (LTS), Experimental Session (ES, 4 sets to failure at 80% of one-repetition maximum), Squat (SQ), Bench Press (BP), Deadlift (DL).

Exercise Procedures

One-Repetition Maximum (1RM) Testing. All 1RM tests were conducted in accordance with previously validated procedures (14). The order of 1RM testing was the squat, bench press, and deadlift which is consistent with the order as performed in the International Powerlifting Federation (21), and all lifts were required to meet the movement criteria set forth by the International Powerlifting Federation. The only lifting equipment allowed was a belt, squat shoes, knee sleeves, and wrist wraps, and if worn during 1RM testing, then the same equipment was required to be worn in all sessions.

To begin 1RM testing, all participants were required to perform a standardized 5-minute bodyweight dynamic warm-up prior to 1RM testing. Next, subjects began the squat-specific warm-up by performing 8 repetitions with the empty barbell followed by 5, 3, 2, and 1 repetition at 25, 50, 75, and 85% of their estimated 1RM, respectively. Then, load was incrementally increased appropriately for 1RM attempts, and a rest period of 5–7 minutes was administered between each attempt. To aid in attempt selection, ACV and rating of perceived exertion (RPE) via the repetitions in reserve (RIR)-based RPE scale was collected on each 1RM attempt. A 1RM attempt was considered valid if one of the following conditions were met: 1) subject reports a '10' on the RPE/RIR scale and the investigator determines a subsequent attempt with increased weight cannot be successfully or safely completed, 2) subject reports a '9.5' on the RPE scale and misses the subsequent attempt with a load increase of 2.5 kg or less, 3) Subject reports a '9' or lower on the RPE scale and fails the subsequent attempt with a load increase of 5kg or less. All successive increases in load following the 90% of 1RM performance were required to be less than or equal to the previous attempts increase in load. Finally, Eleiko barbells and lifting discs (Chicago, Illinois, USA) that have been calibrated to the nearest 0.25 kg were used.

Experimental Sessions. During the experimental session, which was day 1 of weeks 2–4 (Table 1), subjects performed 4 sets to volitional failure with 80% of 1RM on one of either the squat, bench press, or deadlift. All experimental sessions began with a standardized 5-minute bodyweight dynamic warm-up; then, subjects performed an exercise-specific warm-up of 5 repetitions at 20% of 1RM and 3 repetitions at 50% of 1RM. Subsequently, the 4 sets to volitional failure at 80% of 1RM were performed with 5 minutes of rest between sets.

Light Training Sessions. A light training session was performed for the squat, bench press, and deadlift on day 2 of weeks 1, 2, 3 and 4 in order to prevent detraining and enhance recovery (Table 1). This light training session included 3 sets of 5 repetitions at 70% of 1RM with 5 minutes of rest between sets.

Measurements and Assessments

Body-Fat Percentage. Body-fat percentage was estimated via skinfold measurements collected on the right side of the body from three sites (chest, abdomen, and thigh) and determined in accordance with the formula from Jackson and Pollock (1978). The average of two measurements for each site was recorded. If sites varied by greater than 2 mm, a 3rd measurement was acquired; then, the two measurements within 2 mm of each other was averaged. All skinfold measurements were conducted by the same investigator.

Percentage Loss and Absolute Values of Average Concentric Velocity (ACV). On every repetition of each set, ACV ($m \cdot s^{-1}$) was recorded using the Open Barbell System Version 3 (OBS). The OBS, a linear position transducer, has been validated for ACV measurement against a 3D motion capture (22). The OBS contains a velocity sensor with a display unit that attaches to the barbell, just inside of the 'sleeve' via a cord with a Velcro strap. The OBS was placed so that a perpendicular angle was achieved between the cord and the ground during each lift. From the fastest (typically first) repetition, velocity loss at each RIR was calculated.

Repetitions in Reserve-Based Rating of Perceived Exertion (RIR-Based RPE). The repetition at which each velocity loss occurs at was cross-referenced with RIR-based RPE and, absolute ACV values were established for each repetition and cross-referenced with RIR-based RPE. Specifically, this study reported the RIR which corresponds to each velocity loss percentage and each absolute velocity value was determined upon completion of each set. To accomplish this, the final successful repetition completed prior to volitional failure was considered a 0 RIR (10 RPE) and each previous repetition was considered 1 RIR higher. For example, if a subject successfully completed 8 repetitions and failed on the 9th repetition, the 8th repetition was considered a 0 RIR, while the 7th repetition was considered 1 RIR, and the 6th repetition was considered 2 RIR, etc. For example, if an absolute ACV value of 0.40, 0.35, and 0.30 $m \cdot s^{-1}$ occurred on the 6th, 7th, and 8th repetition, then 0.40, 0.35, and 0.30 $m \cdot s^{-1}$ was considered a 2, 1, and 0 RIR, respectively.

Statistical Analyses

Data were analyzed using a general linear mixed model with random intercepts; models were constructed using PROC MIXED (SAS Software version 9.4, Cary, NC, USA). Subject was identified as a random effect; fixed effects included exercise (back squat, bench press, or deadlift), set (1-4), RIR (continuous), and all 2-way and 3-way interactions between them. Repeated measures among sets were modeled using a compound symmetry covariance structure. Statistically significant interactions were followed by hypothesis tests comparing simple effects or simple slopes as appropriate, using the Bonferroni method to account for multiplicity. Statistical significance was assessed based on an *a priori* significance level of $\alpha = 0.05$.

IV. RESULTS

3-Way Interaction

One subject did not perform both the third and fourth sets of the deadlift, and another participant completed only the bench press; thus, these missing sets were excluded from the analysis. The 3-way interaction (exercise × set × RIR) in the original model was not statistically significant ($p = 0.840$); as a result, a reduced model was fit with the 3-way interaction term removed.

Exercise × Set Interaction

A significant 2-way interaction ($p=0.027$) was observed between exercise and set, indicating that the effect of set number on ACV varied among exercises. Post-hoc tests revealed that for every set, bench press ACV was significantly lower than deadlift ACV ($p<0.001$), and deadlift ACV was significantly lower than squat ACV ($p<0.001$). Within exercise, lower adjusted mean ACV values were observed during sets 1-3 of the bench press compared to set 4 of the bench press ($p<0.05$). For squat, the adjusted mean ACV for set 1 was slower than for sets 2, 3, and 4 ($p<0.05$), while the adjusted mean ACV for deadlift was significantly slower for sets 1 and 2 compared to set 4 ($p<0.05$). As such, ACV generally tended to increase from the first to the fourth set within each exercise. For each exercise, the adjusted least square mean ACV value for each set is presented in Table 2.

Table 2: Individual Set ACV

Exercise	Set	ACV ± SE ($m \cdot s^{-1}$) (95% CI)
Squat	1	0.430 ± 0.015 (0.402-0.459)^
	2	0.446 ± 0.015 (0.417-0.475)
	3	0.450 ± 0.015 (0.421-0.479)
	4	0.450 ± 0.015 (0.420-0.479)
	All Sets	0.444 ± 0.015 (0.415-0.473)
Bench Press	1	0.280 ± 0.015 (0.250-0.310)*#@
	2	0.276 ± 0.015 (0.246-0.306)*#@
	3	0.286 ± 0.015 (0.256-0.316)*#@
	4	0.307 ± 0.016 (0.276-0.337)*#
	All Sets	0.287 ± 0.015 (0.257-0.317)*#
Deadlift	1	0.386 ± 0.015 (0.356-0.415)*!
	2	0.387 ± 0.015 (0.358-0.417)*!
	3	0.399 ± 0.015 (0.368-0.429)*
	4	0.408 ± 0.016 (0.378-0.439)*
	All Sets	0.395 ± 0.015 (0.365-0.425)*

*Data are Mean ± Standard Error (95% Confidence Interval). @Significantly lower than set 4 of bench press ($p<0.05$). ^Significantly lower than sets 2, 3, and 4 of squat ($p<0.05$). !Significantly lower than set 4 of deadlift ($p<0.05$). *Significantly lower than corresponding squat set ($p<0.001$). #Significantly lower than corresponding deadlift set ($p<0.001$).*

RIR × Exercise Interaction

The RIR × Exercise interaction was statistically significant ($p<0.001$); thus, the relationship between RIR and ACV varied among exercises. Post hoc analyses revealed that the simple slope for RIR was significantly greater than 0 within each individual lift (all $p<0.001$). Furthermore, the simple slope for RIR in the bench press (0.031 $m \cdot s^{-1}$) was significantly greater ($p<0.001$) than that of the squat (0.025 ms), which was significantly greater ($p<0.001$) than the RIR simple slope for the deadlift (0.015). The RIR, estimated ACV, 95% ACV confidence intervals, and associated percentage velocity loss for each exercise can be seen in Table 3.

Table 3: Estimated ACV, and Velocity Loss at Each RIR

	SQUAT		**BENCH PRESS**		**DEADLIFT**	
RIR	**Estimated ACV ± SE ($m \cdot s^{-1}$) (95% CI)**	**% Velocity Loss**	**Estimated ACV ± SE ($m \cdot s^{-1}$) (95% CI)**	**% Velocity Loss**	**Estimated ACV ± SE ($m \cdot s^{-1}$) (95% CI)**	**% Velocity Loss**
0	0.347 ± 0.015 (0.317-0.377)	51.94	0.166 ± 0.015 (0.135-0.197)	73.86	0.337 ± 0.015 (0.307-0.368)	39.82
1	0.372 ± 0.015 (0.342-0.402)	48.48	0.197 ± 0.015 (0.167-0.228)	68.98	0.352 ± 0.015 (0.322-0.383)	37.14
2	0.407 ± 0.014 (0.367-0.427)	43.63	0.229 ± 0.015 (0.198-0.259)	63.94	0.367 ± 0.015 (0.337-0.398)	34.46
3	0.422 ± 0.014 (0.392-0.451)	41.55	0.260 ± 0.015 (0.229-0.290)	59.06	0.382 ± 0.015 (0.352-0.412)	31.79
4	0.447 ± 0.014 (0.417-0.476)	38.09	0.291 ± 0.015 (0.261-0.321)	54.17	0.397 ± 0.015 (0.366-0.427)	29.11
5	0.472 ± 0.014 (0.442-0.502)	34.63	0.322 ± 0.015 (0.292-0.353)	49.29	0.412 ± 0.015 (0.381-0.442)	26.43
6	0.497 ± 0.015 (0.467-0.527)	31.16	0.354 ± 0.015 (0.323-0.384)	44.25	0.427 ± 0.015 (0.396-0.457)	23.75

7	0.522 ± 0.015 (0.492-0.552)	27.70	0.385 ± 0.015 (0.354-0.416)	39.37	0.441 ± 0.015 (0.410-0.472)	21.25
8	0.547 ± 0.015 (0.517-0.577)	24.24	0.416 ± 0.016 (0.384-0.448)	34.49	0.456 ± 0.015 (0.425-0.487)	18.57
9	0.572 ± 0.015 (0.541-0.603)	20.78	0.447 ± 0.016 (0.415-0.479)	29.61	0.471 ± 0.015 (0.440-0.502)	15.89
10	0.597 ± 0.015 (0.566-0.628)	17.31	0.479 ± 0.016 (0.446-0.511)	24.57	0.479 ± 0.016 (0.446-0.511)	14.46
11	0.622 ± 0.016 (0.590-0.653)	13.85	0.510 ± 0.016 (0.477-0.543)	19.69	0.501 ± 0.016 (0.468-0.533)	10.54
12	0.647 ± 0.016 (0.615-0.679)	10.39	0.541 ± 0.017 (0.507-0.575)	14.80	0.516 ± 0.016 (0.483-0.548)	7.86
13	0.672 ± 0.016 (0.639-0.705)	6.93	0.572 ± 0.017 (0.538-0.607)	9.92	0.530 ± 0.017 (0.497-0.564)	5.36
14	0.697 ± 0.017 (0.664-0.730)	3.46	0.604 ± 0.018 (0.568-0.639)	4.88	0.545 ± 0.017 (0.511-0.579)	2.68
15	0.722 ± 0.017 (0.688-0.756)	0.00	0.635 ± 0.018 (0.598-0.671)	0.00	0.560 ± 0.017 (0.525-0.595)	0.00

Data are Mean ± Standard Error (95% Confidence Interval). ACV = Average Concentric Velocity. RIR = Repetitions in Reserve.

RIR × Set Interaction

The RIR × Set interaction was statistically significant ($p<0.001$), indicating that the relationship between RIR and ACV varied among sets. Post hoc analyses revealed that the simple slope for RIR was significantly greater than 0 within each individual set (all $p<0.001$), averaged across all three exercises. The simple slope for RIR in set 1 was significantly lower ($p<0.001$) than both sets 2 and 4. The adjusted p-value revealed no difference between the RIR simple slope in set 1 versus set 3 ($p=0.191$) and no other pairwise differences were observed (all $p>0.05$). Figure 1 displays the relationship between RIR and ACV for each individual set within each exercise.

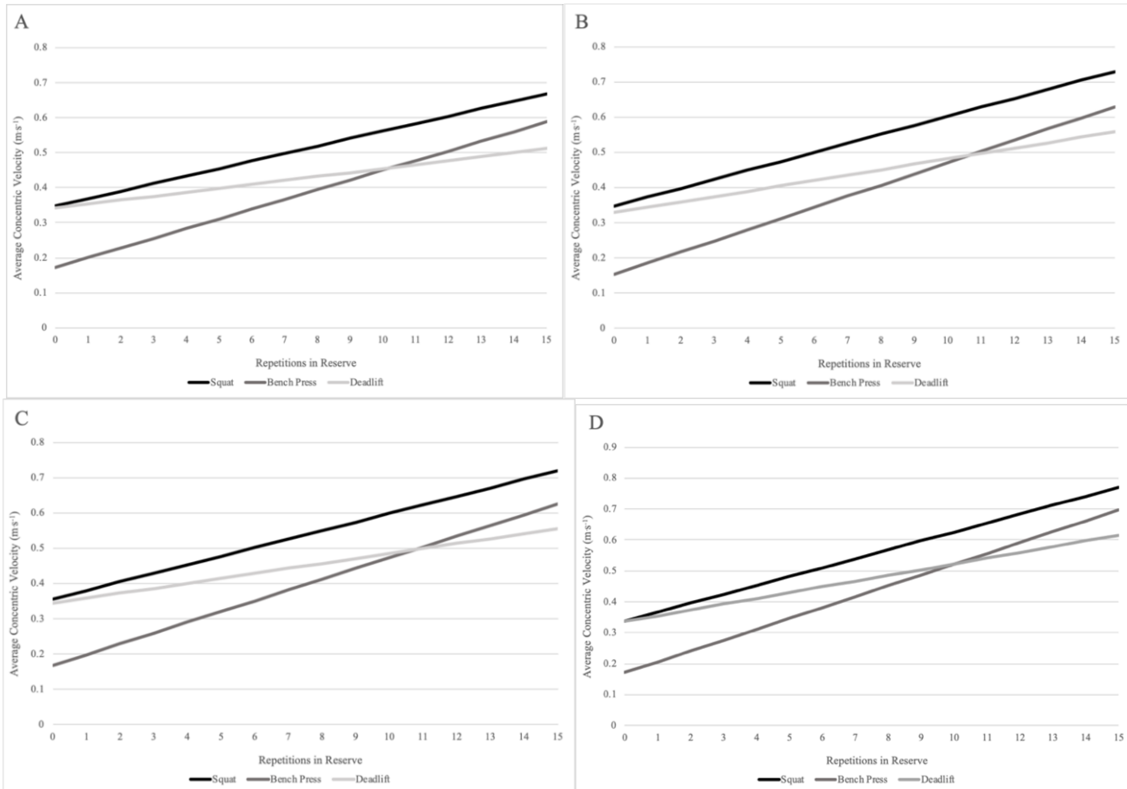

Figure 1ABCD. *The relationship between repetitions in reserve and average concentric velocity during sets 1 (A), 2 (B), 3 (C), and 4 (D) during the squat, bench press, and deadlift.*

V. DISCUSSION

To our knowledge, this is the first study to examine the change in the RIR/ACV relationship over multiple sets in the squat, bench press, and deadlift. The main findings of this study were: 1) RIR was a significant predictor of ACV for all three exercises, 2) The mean set ACV was significantly different between exercises, indicating that exercise-specific velocity profiles should be established, and 3) The relationship between RIR and ACV was set-dependent; however, the magnitude of within-exercise difference in ACV from set-to-set is unlikely to be practically meaningful as it falls below the threshold of 0.06 $m \cdot s^{-1}$ (23), which has been previously established as the smallest worthwhile change in ACV. Therefore, our hypotheses that RIR and ACV would be significantly related, and that this relationship would be exercise-dependent, were supported. Our hypothesis that the RIR/ACV relationship would remain similar from set-to-set was not supported according to the statistical significance threshold.

Although our data reports both a significant RIR × Set interaction, indicating that the relationship between ACV and RIR varied between sets, it is likely that this difference is not practically meaningful. For example, across all three exercises the ACV at 1 RIR during set 1 was 0.307 ± 0.011 $m \cdot s^{-1}$ versus 0.309 ± 0.012 $m \cdot s^{-1}$ at 1 RIR during set 4, which is only a difference of 0.002 $m \cdot s^{-1}$. In fact, the largest difference of ACV between sets within an individual exercise was only 0.05 $m \cdot s^{-1}$, which is below the previously established smallest worthwhile change for ACV of 0.06 $m \cdot s^{-1}$ (23). Further, a visual inspection of Figure 1 reveals a similar trend for the RIR/ACV relationship from set-to-set. Therefore, it does not seem that the number of RIR was related to a different ACV from set-to-set.

Practically, establishing that the number of RIR at a specific ACV is practically stable from set-to-set allows resistance training programming to terminate a set at a specific ACV to control for the number of RIR during a set. It is important to monitor RIR during resistance training as multiple studies (3,24) have established that training to failure on the free-weight barbell exercises can lead to diminished performance and increased indirect markers of muscle damage for 24-48 hours longer compared to volume-equated non-failure training. Consequently, an elongated recovery period can negatively impact weekly training volume and frequency. Previously, Moran-Navarrao et al. (7) established that the ACV/RIR relationship at 2, 4, 6, and 8 RIR in the barbell back squat and bench press was not different during one set to failure at 65, 75, and 85% of 1RM in a sample of well-trained men. For Example, Moran Navarro et al. (7) reported that ACVs of 0.40 ± 0.03, 0.41 ± 0.02, and 0.38 ± 0.03 $m{\cdot}s^{-1}$ corresponded with 2 RIR at 65, 75, and 85% of 1RM in the squat; respectively. Our study adds novelty to these previous findings by reporting the stability of the RIR/ACV relationship over multiple sets and by inclusion of the deadlift exercise. Additionally, the present study reported a similar RIR/ACV relationship as Moran-Navarro et al. (7) as all ACVs that corresponded to the same RIR were within 0.06 $m{\cdot}s^{-1}$ between studies.

The concept of prescribing resistance training to control for RIR is not new. Originally, Helms et al. (4), introduced the RPE or “RIR Stop” method, which has been used in two ways: 1) program a fixed number of repetitions at given load (i.e. 8 repetitions at 70% of 1RM) and have athletes perform as many sets as possible until a set reaches a predetermined RIR (i.e. 2 RIR) in an effort to individualize training volume or 2) prescribe a specific load (i.e. 80% of 1RM) and instruct an athlete to perform as many repetitions as possible until they reach the predetermined RIR. While this method is quite practical and inherently individualized, the RIR rating is subjective and well-trained lifters have been observed to predict RIR with an error of 2.05 ± 1.73 and 5.15 ± 2.92 repetitions when attempting to predict 1 and 5 RIR in the back squat (5). Further, it has also been shown that RIR ratings become more accurate as the number of repetitions per set decreases (5). The findings of the present study, which observed the stability of the RIR/ACV relationship from set-to-set along with Moran-Navarro et al. (7) demonstrating the ACV at a specific RIR was similar between high repetitions sets (65% of 1RM) and low repetition sets (85% of 1RM) seemingly rectifies the limitations of the RIR stop method.

Although terminating a set at a predetermined ACV is effective to quantify RIR, percentage velocity loss is currently the most popular adaptation of using velocity to control for RIR (6). Percentage velocity loss, stipulates that an athlete terminate a set following a specific percentage of velocity decline (i.e. 10, 20, 30, or 40%) from the fastest repetition (i.e. usually the first repetition) in a set. The present study retroactively calculated percentage velocity loss for each exercise (Table 3) and unsurprisingly, similar to absolute ACV, the percentage velocity loss which corresponded to a specific RIR was considerably different between exercises; suggesting that velocity loss percentages should be exercise-specific. Indeed, Rodriguez-Rosell et al. (19) reported that a greater velocity loss could be achieved throughout the total duration of a set in the Smith machine bench press versus the Smith machine squat. In agreement, we observed a significantly greater ($p<0.001$) simple slope for the ACV/RIR relationship in the bench press (0.031 $m \cdot s^{-1}$) versus the squat (0.025 $m \cdot s^{-1}$), and a ~22% greater velocity loss in the bench press at 0 RIR (bench press: 73.86%; squat: 51.94%). Additionally, the present study reports only a 39.82% velocity loss at 0 RIR in the deadlift; further indicating the need for exercise-specific velocity prescription. Additionally, it has been well-established that the load-velocity profile among a variety of exercises is exercise-dependent (25).

Significant limitations exist when using velocity loss to control for proximity to failure in a group-setting or when using a multiple set training prescription. For example, if an athlete is instructed to terminate a bench press set following a 40% velocity loss, that set would be terminated at 0.42 $m \cdot s^{-1}$ if the fastest repetition in the set was 0.70 $m \cdot s^{-1}$. However, a 40% velocity loss would terminate a set at 0.36 m/s if the fastest repetition in the set was 0.60 $m \cdot s^{-1}$, which would likely result in a different proximity to failure. Further, using the same percentage velocity loss across multiple sets is likely to lead to different proximities to failure. To illustrate, if the fastest repetition during the first squat set at 70% of 1RM is 0.70 $m \cdot s^{-1}$, but the fastest repetition on the 4th set is 0.58 $m \cdot s^{-1}$, then a 40% velocity loss on the first set would equal 0.42 $m \cdot s^{-1}$ and would equate to 3 RIR, while on the fourth set the 40% velocity loss would equal 0.35 and correspond to 0 RIR. Indeed, Pareja-Blanco et al. (6), reported that when using a 40% velocity loss prescription for 3-4 sets of squats per training session at 70-85% of 1RM over 8 weeks, trained athletes reached muscular failure on 56.3% of the sets, the majority of which occurred in the later sets after successfully completing the first set. Importantly, even when the ACV on the first repetition of a set changes the RIR/ACV relationship remains the same; thus, terminating a set at an absolute ACV could rectify the limitations of percentage velocity loss.

The current study is not without limitations. First, this study only utilized well-trained young men and only used the free-weight back squat, bench press, and deadlift; thus, the RIR/ACV relationships presented should not be extrapolated to other sample populations or to other exercises. Additionally, only 80% of 1RM was used in this study. While previous data have shown similar RIR/ACV relationships at different intensities, this finding should be verified on a variety of exercises.

In summary, the present study demonstrates that the change in RIR during sets of the back squat, bench press, and deadlift is a significant predictor of ACV. Further, to our knowledge, this study is the first to report that the RIR/ACV relationship is practically stable from set-to-set in the free-weight barbell exercises, which provides a framework for athletes to use absolute velocity values to terminate a set in lieu of the RIR stop method or the commonly used percentage velocity loss to control for RIR during resistance training.

Practically, if the desired proximity to failure is 3 RIR during a resistance training session, then using the present data, 4 sets on the back squat could be programmed with the stipulation to terminate each set when the ACV reaches ≤0.42 $m \cdot s^{-1}$. Further, since the smallest worthwhile change in ACV is 0.06 $m \cdot s^{-1}$, then the coach or athlete could use their discretion to terminate a set within a range of 0.37-0.47 $m \cdot s^{-1}$. Further, this absolute velocity stop method can be individualized by an athlete performing a set to failure at a moderate percentage of 1RM (i.e. 70%) to create their own RIR/ACV profile. Finally, since ACV is reliable from session-to-session (23), the RIR/ACV relationship is reliable across various percentages of 1RM (7), and the present study has demonstrated the practical stable RIR/ACV across sets the proposed individualization protocol should have widespread utility.

APPENDICES

APPENDIX A: APPROVAL LETTER

FAU FLORIDA ATLANTIC UNIVERSITY

Institutional Review Board
Division of Research
777 Glades Rd.
Boca Raton, FL 33431
Tel: 561.297.1383
fau.edu/research/researchint

Michael Whitehurst, Ed.D., Chair

DATE:	January 24, 2018
TO:	Michael Zourdos, Ph.D.
FROM:	Florida Atlantic University Health Sciences IRB
IRBNET ID #:	1162153-2
PROTOCOL TITLE:	[1162153-2] Time Course of Muscle Damage and Intra-Set Repetitions in Reserved Based Rate of Perceived Exertion Accuracy in the Squat, Bench Press, and Deadlift
PROJECT TYPE:	*New Project*
ACTION:	APPROVED
APPROVAL DATE:	January 24, 2018
EXPIRATION DATE:	January 24, 2019
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *B4*

Thank you for your submission of Response/Follow-Up materials for this research study. The Florida Atlantic University Health Sciences IRB has APPROVED your *New Project.* This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

- This study is approved for a maximum of ***40*** participants.
- It is important that you use the approved, stamped consent documents or procedures included with this letter.
    - Protocol (stamped)
    - Consent Form (stamped)
    - Medical History Form (stamped)
    - Physical Activity Questionnaire (stamped)
- ****Please note that any revision to previously approved materials or procedures, including modifications to numbers of subjects, must be approved by the IRB before it is initiated.** Please use the amendment form to request IRB approval of a proposed revision.
- All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All regulatory and sponsor reporting requirements should also be followed, if applicable.
- Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.
- Please note that all research records must be retained for a minimum of three years.

- **This approval is valid for one year.** A Continuing Review form will be required prior to the expiration date if this project will continue beyond one year.

If you have any questions or comments about this correspondence, please contact Danae Montgomery at:

Institutional Review Board
Research Integrity/Division of Research
Florida Atlantic University
Boca Raton, FL 33431
Phone: 561.297.1383
researchintegrity@fau.edu

* Please include your protocol number and title in all correspondence with this office.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within our records.

APPENDIX B: INFORMED CONSENT

ADULT CONSENT FORM

Consent Form Version & Date: Version 2.0: January 23rd, 2018.

1) **Title of Research Study:** Time Course of Muscle Damage and Intra-Set Repetitions in Reserved Based Rate of Perceived Exertion Accuracy in the Squat, Bench Press, and Deadlift

2) **Investigator(s):** Michael C. Zourdos, Ph.D., CSCS, Daniel J. Belcher, B.A., CSCS, Colby A. Sousa, B.S., CSCS, Joseph P. Carzoli, B.S., CSCS.

3) **Purpose:** The purpose of this research study is to assess muscle damage and intra-set RPE accuracy in the squat, bench press and deadlift

4) **Procedures:** If you choose to participate in this study you will be required to complete the following assessments among 17 laboratory visits over 3.5 weeks:

- Refrain from all exercise for at least 48 hours prior to day one and will abstain from any additional exercise or excessive physical activity throughout the duration of the study
- Refrain from the use of any nutritional supplements, recovery modalities (foam rolling, massage, etc.), and any unnecessary over-the-counter medications throughout the duration of the study
- One repetition maximum (1RM) strength in the squat, bench press, and deadlift
- Four sets to volitional failure with 80% 1RM in the squat, bench press, and deadlift one time each on separate weeks
- Three sets of five repetitions with 70% 1RM in the squat, bench press, and deadlift on four separate occasions
- Two single repetitions with 70% 1RM in the squat, bench press, and deadlift six total times for each exercise over three weeks
- Body composition by skinfold caliper (chest, abdomen, thigh)
- Verbally call out at "6" when you believe you can only perform four more repetitions and a "9" when you believe you can only perform one more repetition during each of the four volitional sets to failure
- Joint range of motion assessments at the knee and elbow six times each week over three weeks
- Delayed onset muscle soreness assessments through mild palpations of the quadriceps, hamstrings, and chest via an algometer six times for each site over three separate weeks
- Measurements of both arm and leg swelling with a tape measurer six times for each site over three separate weeks
- Six blood collections each week consisting of two 10 ml samples (20 ml total) each draw for analyses of creatine kinase and lactate dehydrogenase from a prominent vein on the front area of the arm.
- Fast (no food or drink except for water) for at least two hours prior to all blood collections

All measurements will be conducted by the principal investigator or graduate assistants working within the Muscle Physiology Laboratory (i.e. the principal investigator will not always be present). For the first visit, you will be required to complete an informed consent form, training history questionnaire, and medical history form followed by anthropometric (height, body mass, upper arm length, forearm length, and total arm length) and body composition (skinfolds; chest, abdomen, thigh) measurements.

FAU Institutional Review Board

1162153-2	
Approved On:	January 24, 2018
Expires On:	January 24, 2019

Afterwards, you will complete a standardized five-minute dynamic warm-up routine designed to increase the body's core temperature and prepare the muscles for exercises that will be performed. Following the warm-up, you will complete a squat-specific warmup (20% projected 1RM x 5, 50% x 3, 60% x 1, 70% x 1, 80% x 1, % x 1). Next, one-repetition maximum (1RM) testing for the squat will begin. All 1RM tests will be administered with accordance to the National Strength and Conditioning Association (NSCA) guidelines, and all exercises will be performed to the rules set by the United States of America Powerlifting (USAPL). After determining the 1RM in the squat, a five-minute rest period will precede a bench-specific warmup (same protocol described for squat-specific warmup), followed by a 1RM test for the bench press. Upon determination of 1RM in the bench press, a five-minute rest period will precede a deadlift-specific warmup (same protocol described for squat-specific warmup), followed by a 1RM test for the deadlift. All 1RM attempts will be separated by 3- to 5-minute rest periods. Next, 48 hours following 1RM testing, you will perform a light training session for each lift (3 sets of 5 repetitions at 70% of 1RM). There will be five minutes of rest between sets during the light training session.

The following three weeks will be conducted in the following manner for each the squat, bench press, and deadlift being performed on separate weeks in a randomized order. On day one of week two (72 hours after the week one light training session) you will perform four sets to volitional failure at 80% of 1RM on one of the three exercises. Additionally, immediately prior to and following the four sets to failure, along with 24, 48, 72, and 96 hours later, indirect markers of muscle damage, and performance fatigue will be assessed.

These indirect markers of muscle damage will consist of the following: elbow and knee joint ROM, upper leg and upper arm swelling, quadriceps, hamstring, and chest delayed onset muscle soreness (DOMS), and blood will be collected for serum creatine kinase (CK) and lactate dehydrogenase (LDH). Following the exercise specific warm-up and prior to performance of the four failure sets, performance fatigue will be measured by changes in average concentric velocity during two, single repetitions with 70% of that week's tested exercise immediately prior to and after the damaging protocol and again at 24, 48, 72, and 96 hours post-training. For clarity, blood will be collected at each time point in which the indirect markers are assessed. A trained technician will perform all blood sampling by inserting a 21-gauge butterfly needle into a superficial vein of the upper arm. At each blood draw two tablespoons of blood will be collected into specific collection tubes for subsequent analysis. After blood samples are collected serum will be stored in a -80 degree Celsius freezer for further analysis. Further, you will be asked to fast for two hours prior to each blood draw. Specifically, this means you will not eat or drink anything for the two hours prior to a blood draw, except for water.

During each set to volitional failure, you will be asked to verbally provide the rating of perceived exertion (RPE) values of "6" and "9" when you feel they are occurring during the four sets to volitional failure and again following each lifting set during each session. Further, during each set of every session the Open Barbell System (Squats and Science, Brooklyn, NY) linear position transducer will record average concentric velocity, peak concentric velocity, peak concentric power, and average eccentric velocity.

Following the assessments of damage and fatigue markers at 96 hours post-training, you will then perform a light training session on the two exercises which were not used in that week's damaging bout to avoid detraining on those exercises. Then, you will have 72 of rest before returning to the laboratory for week three. Weeks three and four will serve exactly as week two except the damaging bout will be performed with a different exercise.

Participant Initials ________

For the squat, you will stand straight with your hips and knees locked, and the barbell placed across your upper back/shoulders. You will then descend with the bending of the knees until the top of your leg at the hip joint is below the top of your knee. Then you will return to your starting position upon your own volition.

For the bench press, you will lay chest up on a flat bench with a barbell in your closed hands. You will then descend with the bending of the elbows until the bar touches your chest in a controlled manner. Then you will return to your starting position upon your own volition. During the multiple repetition sets, you must refrain from bouncing the weight off of your chest at the bottom of each repetition.

For the deadlift, you will lift the barbell from the floor using a conventional deadlifting technique. You will lift the barbell in a vertical plane until your knees and hips are locked, and your shoulders are pulled back. You will then return the barbell to the floor in a controlled manner. During the multiple repetition sets, you must keep your hands gripped on the barbell at all times and the weight cannot bounce of off the floor between repetitions. A timeline of all procedures can be seen in Table 1 below.

Finally, participation in this study will in no way affect your grade in any course.

5) <u>Risks:</u>

Anytime you engage in exercise there are some inherent risks including: muscle strains, soreness, or joint aches. Since you will perform resistance exercise, the muscle soreness caused by muscle damage may be experienced for up to 96 hours.

If muscle soreness does occur, the investigators will assure that you can meet the movement standards before proceeding with data collection; however, risk of injury is always present during resistance exercise.

If an injury does occur you will notify the principal investigator if present, if not you will notify a graduate research assistant whom will immediately notify the principal investigator. The principal investigator will then stay in consistent contact with you in regards to your well-being. If serious injury or an emergency situation occurs during training, the investigators will immediately contact student health services if you are a student and if you are not a student the investigators will call your primary care physician or 911 if necessary.

Additionally, there are possible minor risks anytime there is a collection of blood or bodily fluids. These risks include: infections, fainting, inflammation near the skin, collection site soreness and bruising, and unintended needle sticks. To minimize the possibility of these events, all blood collections will be performed by a trained phlebotomist. The collection site will be sterilized with an alcohol swab prior to collection and a new single use sterile needle and collection tube will be used for each collection and opened in front of you. Additionally, new sterile latex gloves will be used for each collection as well and applied in front of you. Any collection site soreness or bruising that may occur should subside within 48-72 hours.

Finally, there is a risk of breach of confidentiality, however, to minimize this risk a code number will be assigned to you and only Dr. Michael Zourdos, Ph.D., CSCS will keep a record with your name and code number, in a locked file drawer. The computer with the recorded data will be password protected so there will be no access to electronic data. All data (hard copy and computer) will be destroyed in 10 years.

Participant Initials ________

6) Benefits:

The potential benefits to you are:

- Free measurements of body composition and 1RM testing
- Access to calibrated training equipment that is approved by and used within the International Powerlifting Federation (IPF) competitive events

7) Compensation for Injury:

If you are injured or get sick as a result of the study procedures, you should obtain medical treatment and then notify the study Principal Investigator. Payment for this medical treatment is not available from the study researchers. You, or any available health insurance you have, will be billed for this treatment. Your health insurance company may not pay for treatment of injuries as a result of your participation in this study. Also, no funds are available to pay any wages you may lose if you are harmed by this study.

Further, if an injury or illness does occur in the laboratory during the study the investigators will cease study participation and contact student health services immediately.

8) Data Collection & Storage:

Potentially identifiable information about you will consist of a medical history questionnaire and research data sheets. Data are being collected only for research purposes. All personal identifying information will be kept in password-protected files and a code number will be used for identification purposes. Data records will be kept in a locked file cabinet in an office within the department of Exercise Science and Health Promotion. Although results of this research may be presented at meetings or in publications, identifiable personal information pertaining to participants will not be disclosed unless required by law.

9) Contact Information:

- If you have questions about the study, you should call or email the investigator(s), Michael C. Zourdos, at (561)-297-1317 or mzourdos@fau.edu.

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1162153-2	
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Expires On:	January 24, 2019

- If you have questions or concerns about your rights as a research participant, contact the Florida Atlantic University Division of Research, Research Integrity Office at (561) 297-1383 or send an email to researchintegrity@fau.edu.

10) Consent Statement:

*I have read or had read to me the information describing this study. All my questions have been answered to my satisfaction. I am 18 years of age or older and freely consent to participate. I understand that I am free to withdraw from the study at any time without penalty. I have received a copy of this consent form.

Printed Name of Participant: ____

Signature of Participant: ________________________________ Date: _______________

Printed Name of Investigator: ______________________________________

Signature of Investigator: ________________________________ Date: _______________

Participant Initials _______

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APPENDIX C: HEALTH HISTORY QUESTIONNAIRE

Florida Atlantic University

Medical History Form

Demographics:
Name: ______________________________ Sport: __________ Pos.: ______________
Date: __________ Age: ______________ Birth Date: ___/___/___

Family History:
Has anyone in your immediate family had any of the following: Please circle yes or no.

Heart Disease	Yes	No	Diabetes	Yes	No
High Blood Pressure	Yes	No	Cancer	Yes	No
Stroke	Yes	No	Tuberculosis	Yes	No
Sudden Death (before 50)	Yes	No	Asthma	Yes	No
Epilepsy	Yes	No	Gout	Yes	No
Migraine Headaches	Yes	No	Marfan's Syndrome	Yes	No
Eating Disorder	Yes	No	Sickle Cell	Yes	No

Personal History:

1. Have you ever been hospitalized? Yes No
   Have you ever had surgery? Yes No
   Are you presently under a doctor's care? Yes No
   Please explain and give dates for all "Yes" answers: ________________________________
   ____
   ____

2. Please list any medications you are currently taking and for what conditions. ______________
   ____

3. Please list any known allergies. ____
   ____

4. Have you ever had a head injury / concussion? Yes No
   Have you ever been knocked out or unconscious? Yes No
   Have you ever had a seizure, "fit", or epilepsy? Yes No
   Have you ever had a stinger, burner, or pinched nerve? Yes No
   Do you have recurring headaches or migraines? Yes No
   Pleas explain and give dates of "Yes" answers: ____________________________________
   ____
   ____
   ____

5. Have you ever had the chicken pox? Yes No
   If yes, at what age? _________

6. Have you ever had the mumps or measles? Yes No

7. Do you have a history of asthma? Yes No

8. Are you missing an eye, kidney, lung, or testicle? Yes No

9. Do you have any problems with your eyes or vision? Yes No

10. Have you ever had any other medical problems (mononucleosis, diabetes, anemia)? Yes No

11. Have you ever taken any supplements for improved performance? Yes No

12. Are you presently taking any supplements for diet or performance? (creatine, protein, etc.)? Yes No
    If Yes then what substance? __________________________

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1162153-2	
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1

13. What is the lowest weight you have been at in the last year _____, highest _____? What is your ideal weight _______?

14. Do you have any trouble breathing or do you cough during or after practice? Yes No

15. Have you ever had heat cramps, heat illness, or muscle cramps? Yes No

16. Do you have any skin problems (itching, rashes, acne)? Yes No

Explain all "Yes" answers for questions 5 – 16: ____
____
____
____
____
____

17. Have you ever passed out during or after exercise?	Yes	No
Have you ever been dizzy during or after exercise?	Yes	No
Have you ever had chest pain during or after exercise?	Yes	No
Have you ever had high blood pressure?	Yes	No
Have you ever been told you have a heart murmur?	Yes	No
Have you ever had racing of you heart or a skipped heart beat?	Yes	No
Has anyone in your family died of heart problems or a sudden death before the age of 50?	Yes	No
Have you ever had high cholesterol	Yes	No
Have you ever had an EKG or echocardiogram?	Yes	No

Explain all "Yes" answers for question 17: ____
____
____
____
____

18. Have you ever sprained / strained, dislocated, fractured, or had repeated swelling or other injury of any bones or joints? Explain any "Yes" answers.

Head/Neck	Yes	No	________________
Shoulder	Yes	No	________________
Elbow & arm	Yes	No	________________
Wrist, hand & fingers	Yes	No	________________
Back	Yes	No	________________
Hip / Thigh	Yes	No	________________
Knee	Yes	No	________________
Shin/Calf	Yes	No	________________
Ankle, foot, toes	Yes	No	________________

19. What is the average number of hours you sleep per night? ________________

20. What time do you usually go to sleep at night? And, what time do you usually wake-up in the morning? ________________

21. What time did you go to sleep last night and what time did you wake up this morning? ________________

Would you like to speak further to the principal investigator regarding any topics or concerns? (i.e., nutrition, supplements, drugs, heart problems, weight loss/gain, sexual diseases, concussions, etc.,)? Yes No

If yes then what topic? ____

Please sign:

I hereby state that, to the best of my knowledge, my answers to the above questions are correct.

____

Athlete's Signature Date Signed

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2

APPENDIX D: PHYSICAL ACTIVITY QUESTIONNAIRE

Appendix A: Physical Activity Questionnaire

Think about all the exercise training in which you engage. Use that information to appropriately answer the following questions.

1. Have you competed before in strength competitions? If so, how often?

Yes or No If so, _______________ times/year

a. If yes to #1: How long have you been training for strength competitions?

_______________ years.

b. If yes to #1: When you compete, which sport do you compete in (Powerlifting, Strongman, or Bodybuilding)?

Event:______________________________________

2. Are you currently engaged in a structured resistance-training program? If so, how long?

Yes or No If so, _______________ years

3. How many hours of resistance training do you perform on average each week?

_______________ hours/week

4. How many times do you resistance train per week? Please indicate if you do more than once a day.

_______________ days/weekAverage_______________ times/day

5. How many times per week do you perform the following exercises?

a. Barbell back squat: ________ times/week

b. Barbell bench press: ________ times/week

c. Barbell deadlift:_________ times/week

6. How many years of experience do you have with following exercises? What is your estimated 1RM?

a. Barbell back squat: ___________ years; 1RM___________pounds

b. Barbell bench press: __________ years; 1RM__________pounds

c. Barbell deadlift:____________ years; 1RM__________pounds

7. Please describe your average resistance training intensity based on your self-estimated maximum load.

______________ % your maximum

8. Do you incorporate any aerobic training? If so, how many times per week?

Yes or No If so, ______________ times/week

9. Please describe your average aerobic training intensity on a scale below (as close as possible):

1 2 3 4 5 6 7 8 9 10

Very Light Light Moderate Intense Very Intense

10. Please best describe your occupation or daily activities other than your exercise training.

11. Do you have any coaching by a certified professional in general resistance training?

12. How often do you use the Repetitions in Reserve-Based Rating of Perceived Exertion Scale in your resistance training? Please circle one.

I Have Never Used It

I Have Used It A Few Times

I Use It Sometimes

I Use It Frequently

I Use It All The Time

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