THE LONGITUDINAL RELATIONSHIP BETWEEN REPETITIONS IN RESERVE AND AVERAGE CONCENTRIC VELOCITY IN THE BACK SQUAT AND BENCH PRESS

by

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ABSTRACT

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This study examined the longitudinal relationship between repetitions in reserve (RIR) and average concentric velocity (ACV) in the back squat and bench press exercises. Fourteen resistance-trained men were randomized into two groups (4-6RIR or 1-3RIR) and completed a six-week program. The RIR/ACV slope was significantly greater ($p<0.001$) in the bench press ($0.027\pm0.001 m \cdot s^{-1}$) than squat ($0.020\pm0.001 m \cdot s^{-1}$), and was steeper in 1-3RIR than 4-6RIR ($p<0.001$). The RIR/ACV relationship varied from set-to-set ($p=0.001$); however, the largest difference in ACV at the same RIR from set-to-set was only 0.044 $m \cdot s^{-1}$; likely not practically meaningful. The RIR/ACV relationship changed over time ($p=0.004$); however, since training was not to failure, it is unclear if this longitudinal change was due to improved RIR accuracy or a true change in the RIR/ACV relationship. Therefore, the RIR/ACV relationship is exercise-specific and practically stable from set-to-set; however, future research is needed to determine the long-term stability of this relationship.

THE LONGITUDINAL RELATIONSHIP BETWEEN REPETITIONS IN RESERVE AND AVERAGE CONCENTRIC VELOCITY IN THE BACK SQUAT AND BENCH PRESS

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I: INTRODUCTION

Recent studies have reported wide ranges in repetitions performed at various percentages of one-repetition maximum (1RM) during resistance training sets. Specifically, ranges of 6-28 repetitions at 70% on the back squat (1) and 6-10 repetitions at 80% of 1RM on the Smith machine bench press (2) have been reported. Consequently, this interindividual variation in repetitions performed may cause percentage-based prescription (i.e., 3 sets of 10 at 70% of 1RM) to lead to individual differences in proximity to failure. Importantly, proximity to failure influences temporal recovery (3), potentially interfering with weekly volume and frequency.

Due to the interindividual variation in repetitions performed, autoregulation strategies such as repetitions in reserve (RIR) (4) and average concentric velocity (ACV) (5) have been used to control for proximity to failure. For example, the "RIR Stop" method (6) prescribes a specific load to be performed and for the set to be terminated at a pre-determined RIR (i.e., 3 sets of 100 kg and stop each set at 2 RIR). Similarly, velocity loss (7) terminates a set at a pre-determined percentage velocity decline from the fastest repetition in the set. For instance, an athlete could be prescribed 70% of 1RM and a 40% velocity loss, then if the fastest repetition in a set was 0.70 $m \cdot s^{-1}$, the set would be terminated at an ACV of ≤ 0.42 $m \cdot s^{-1}$.

Despite these autoregulatory techniques, limitations exist for both RIR and ACV as standalone strategies. Although, RIR inherently individualizes training prescription, it is also subjective. Various studies (8-11) have shown that athletes are not perfectly accurate when predicting intraset RIR, and resistance-trained individuals have still under-estimated RIR by 2.05 ± 1.73 repetitions when predicting 1 RIR during a set to failure at 70% of 1RM on the squat (11). Conversely, ACV is objective, but recent evidence (2) has shown large interindividual variation in proximity to failure at a given velocity loss percentage. Further, the velocity loss and RIR relationship is not stable across different percentages of 1RM or from set-to-set. For example, if the fastest repetition at 70% of 1RM on the squat is 0.70 $m \cdot s^{-1}$, a 40% velocity loss would terminate the set at ≤0.42 $m \cdot s^{-1}$. Conversely, if the fastest repetition decreases on the third set, velocity loss would terminate the set at a different proximity to failure than the first set.

To rectify the limitations of both RIR and velocity loss, an individualized RIR/ACV profile could be created. Moran-Navarro et al. (12) reported that the ACV values corresponding to a 2, 4, 6, and 8 RIR were similar at 65, 75, and 85% in the squat and bench press. Sanchez-Moreno et al. (2) reported similar ACV values during the last repetition of sets to failure on the Smith machine bench press at 50, 60, 70, 80, and 90% of 1RM. Furthermore, Hickmott (13) found stability of the RIR/ACV relationship from set-to-set. Therefore, an RIR/ACV profile can be created by performing a set to failure at a moderate intensity on a specific exercise, then cross-referencing the number of RIR with the ACV. For example, if 10 repetitions are completed during a bench press set and the eighth repetition velocity was 0.20 $m \cdot s^{-1}$; then, this individual could terminate sets at 0.20 $m \cdot s^{-1}$ to achieve a 2 RIR. Although RIR/ACV profiles rectify standalone RIR and velocity loss limitations, it is unknown if these profiles change over time in trained individuals. Iglesias-Soler et al. (14) observed a decrease in the slope of the load-velocity relationship after five weeks in untrained men; however, it seems less likely that RIR/ACV profiles would change over the course of a short-term training study in trained individuals.

Therefore, the purpose of this study was to examine the RIR/ACV relationship in the back squat and bench press in trained men. This study evaluated if the RIR/ACV relationship varied between exercises, from set-to-set, and over six weeks of training. We hypothesized that the RIR/ACV relationship would be exercise-specific, but would remain stable from set-to-set and from pre- to post-study.

II: REVIEW OF LITERATURE

Introduction

Resistance training produces adaptations to skeletal muscle, including hypertrophy and strength (15). Specifically, these two variables are dependent upon intensity. Many researchers have manipulated exercise intensity to predict outcomes in strength, hypertrophy, or both, primarily through the utility of 1RM. Certain mechanisms within the body that involve neural, metabolic and mechanical factors dictate muscular adaptations that occur with the onset of exercise (16). Neural adaptations account for a large majority of early exercise-induced increases in strength (17), whereas increases in the cross-sectional area of trained muscles are primarily derived from the increase in muscle fiber size (18). Further improvements in strength and size as an lifter becomes more trained requires the manipulation of training variables, such as intensity and volume (sets x repetitions).

There is evidence in support of both resistance training in close proximity to failure, as well as resistance training further from failure. Proximity to failure has been considered an indicator of effort employed during resistance training (9). Drinkwater et al. defined training to failure as the inability to move a specific load beyond a critical joint angle (i.e., sticking point) (19). Izquierdo et al. further defined this terminology as the incapacity to complete a repetition in a full range of motion due to fatigue (20). It has been suggested that repetition failure is highly essential in resistance training (9,19,21); however, others have suggested that performing resistance training to failure is unnecessary to elicit significant responses to skeletal muscle (20,22-23). Moreover, the accumulation of metabolites when training to failure could induce anabolic signaling (24), and additional metabolic and mechanical stress that accumulate during resistance training could become exacerbated when training to failure (20). Gonzalez-Badillo et al. found that training to failure resulted in higher cardiovascular and biochemical stress, greater fatigue and slower rates of neuromuscular recovery (23). Further, Izquierdo et al. suggests that by not training to failure, metabolic and mechanical stress that occur when training to failure reduces, resulting in greater rates of recovery (20). Additionally, Belcher et al. observed indirect markers of muscle damage in well-trained men performing 4 sets of 80% 1RM to failure in the back squat, bench press, and deadlift (25). Based on the results, the authors suggest management of training volume per session so that recovery can occur within a reasonable time frame in order to optimize long-term adaptations in well-trained lifters (25). Thus, the research question of whether or not untrained or trained individuals should train in close proximity or far proximity to failure must be reviewed.

Proximity to Failure in Untrained Individuals

Some researchers have observed the effects of resistance training to failure compared to training not to failure in untrained individuals (22, 26-29). Sampson and Groeller compared two groups of untrained males: one group trained to failure and the second group did not train to failure, but volume was equated. These researchers found that skeletal muscle adaptations occurred in the absence of training to failure, suggesting that training to failure is unnecessary in eliciting similar responses in untrained individuals (22). Similarly, Martorelli and colleagues conducted a 10-week study with untrained young females, split into three groups. The first group performed 3 sets to failure, the second group performed 4 sets of 7 repetitions not to failure with equated volume, and the third group performed 3 sets of 7 repetitions not to failure in the bilateral bicep curl (27). Hypertrophy and strength improved in all three groups, yet, hypertrophy was significantly greater in group the that trained to failure and the group that did not train to failure but trained with equated volume to the failure group. These results suggest that although training to failure provoked gains in strength and hypertrophy, training not to failure with equated volume also achieved these same gains. Both (22, 27) agreed that training to failure is unnecessary to elicit substantial improvements in hypertrophy and strength outcomes.

Additional researchers have considered the effects of low-intensity vs. high-intensity resistance training to volitional interruption, muscle failure (29), or both (28) in untrained individuals. Nobrega et al. defined volitional interruption as the moment when the individual voluntarily interrupts the exercise prior to reaching muscle failure (28). Nobrega et al. compared low-intensity to high-intensity resistance training to volitional interruption or muscle failure (28). When training to volitional interruption, improvements in strength and hypertrophy were similar in both low- and high-intensity groups when compared to training to muscle failure in both low- and high intensity groups (28). These results provide evidence in support of the concept that training to failure could be superfluous, and training to volitional interruption at either a low- or high-intensity could be just as effective as training to failure. Additionally, Lasevicius et al. compared low-load to high-load resistance training with and without achieving muscle failure on muscle strength and hypertrophy for eight weeks (29). When training with low loads, training with a high level of effort was of greater importance than total training volume in order to improve mass. Also, when training with high loads, training to failure is not needed to elicit additional benefits (29). This additionally provides sound evidence against training to failure in order to elicit greater responses in strength and hypertrophy in untrained individuals. Based on the previous literature, training to failure may not be necessary to stimulate major adaptations to strength and hypertrophy in untrained men. Conversely, being that these studies only included untrained individuals, it must also be considered that neural adaptations to resistance training make up for a large majority of gains in muscle strength and hypertrophy early on (17). Therefore, when observing untrained individuals in resistance training protocols comparing sets to failure or not to failure, it seems obvious to suggest either protocol would enhance gains in muscle strength and hypertrophy; yet, having untrained individuals train to failure may not be the safest or most accurate assessment to determine true gains in muscle strength and hypertrophy.

Training to Failure in Trained Individuals

Other researchers have also considered if training to failure is necessary to better improve performance outcomes among trained individuals (3, 6, 11, 23, 30-32). Specifically, Pareja-Blanco and colleagues randomly allocated trained males with at least 1.5-4 years training experience into one of two groups that differed in repetition velocity loss allowed in each set: 20% (VL20) or 40% (VL40) (3). Participants completed the smith machine back squat for 8 weeks, twice per week, with an average intensity of 75% 1RM. The researchers derived the first repetition's mean velocity of a given set to determine the velocity loss to be allowed based upon which group they were in. On average, VL20 performed further away from failure, and VL40 reached muscle failure in 56.3% of total training sets throughout the study (3). The results suggested that training at a higher magnitude of velocity loss (VL40) resulted in a greater degree of muscle hypertrophy, however, VL40 also performed more total repetitions and thus, performed more work than VL20. Further, VL20 improved squat strength similarly to VL40, suggesting that training closer to failure (VL40) is not necessarily needed to elicit gains in strength. Although greater hypertrophy was expressed when closer to failure (VL40), more total repetitions were performed, suggesting that more hypertrophy is more likely to occur when performing a greater amount of total repetitions, or simply more total work. However, when taking neuromuscular fatigue into consideration, training closer to failure has been observed as inappropriate. Gonzalez-Badillo et al. analyzed the time course of recovery following two protocols differing in level of effort. Both groups performed three sets at 80% 1RM in the back squat and bench press, however, number of repetitions differed between groups (5). Authors suggested that when performing a protocol that is further from failure, faster velocities can be performed, neuromuscular performance is less impaired, faster recovery is achieved, and hormonal response, heart rate variability and muscle damage are experienced to a lesser degree than when training to failure (5).

Additionally, Karsten et al. compared the impact of two high-volume set configuration workouts on performance outcomes in 18 recreationally-trained men (15). Authors deemed these men as recreationally trained by having a 2-3 weekly training frequency for over a minimum of 2 and a maximum of 5 years. The protocol consisted of a 6-week design, with two differing high-volume set configuration workouts per week. The repetitions to failure workout comprised of 4 sets of 10 repetitions per exercise with a 2-minute rest between sets, while the workout performed not to failure comprised of 8 sets of 5 repetitions per exercise with a 1-minute rest. Favorable outcomes were observed in the repetition to failure group for body composition and strength gains, however, upper-body power and anterior deltoid thickness were observed in the group who did not to train to failure. Authors also suggested that strength gains were relatively similar between groups, however, hypertrophic gains were more prevalent in the group who did not train to failure (15). This was the first study to compare weekly equalized volume, intensity, and frequency using two differing configurations. This is highly beneficial for strength and conditioning coaches or experts who work with athletes to consider for athletes who require more upper-body power, or those who already have an adequate training, as recovery could be exacerbated if training to failure is implemented. Furthermore, Carroll et al. compared the physiological responses of skeletal muscle to training at a relative intensity (not training to failure) or training using repetition maximum (training to muscular failure) in well-trained males (30). The sample comprised of 15 well-trained men, who have resistance trained at least 3 times weekly for approximately 7.7 ± 4.4 years. These individuals underwent the protocol for 10 weeks, three times weekly. Adaptations to whole muscle size, fiber size and greater accretion of key myofibrillar proteins favored training at a relative intensity rather than using repetition maximum. Additionally, there was no difference in volume load between groups. Authors suggested that superior fatigue management in the relative intensity group, as well as consistent training to failure in the repetition maximum group leading to a reduced ability to adapt, both contributed to these results (30). This further provides evidence in support of not training to failure in well-trained men when taking into consideration hypertrophic gains in particular.

RIR-based RPE scale

Rating of perceived exertion (RPE) scales have been shown to be highly effective in measuring performance among both aerobic and resistance exercise; however, the original RPE scale, created by Borg in 1970, was initially created to gauge exertion based upon physiological responses to the body (32). Because this scale was not entirely cohesive with resistance training, researchers compared a version of this RPE scale to one based upon RIR to better represent repetitions to failure to properly gauge muscular failure during resistance training (33). This RIR-based RPE scale was originally created by Reactive Training Systems in 2008 (34). Hackett et al. had 17 experienced male lifters complete 5 sets of 10 repetitions in the back squat and bench press (33). Participants then provided the researchers with their current RIR values before continuing to failure. These authors concluded that when muscular failure was achieved, maximal RPE values were not recorded, suggesting RIR as the more appropriate measure of intensity for resistance exercise than traditional RPE scales (33). Consequently, Zourdos and colleagues investigated the RIR-based RPE scale among experienced and novice lifters in the back squat exercise, while additionally including velocity measures (4). The sample size consisted of 29 males and females with either 2 or more years of lifting experience or less than one year of lifting experience, all of which completed the back squat exercise. Participants performed a 1RM test, then performed single repetitions at 60%, 75% and 90% 1RM, followed by one set of 8 repetitions at 70% 1RM before giving their RPE for that given set. The results from this study confirmed that the accuracy of self-reported RPE is greater among experienced lifters when compared to novice lifters (4), and that the inverse relationship between RIR and ACV is highly prevalent, displaying slower average velocity and higher RPE at 1RM in experienced lifters over novice lifters (4). Therefore, experienced lifters are more likely to provide more accurate RIR readings when compared to novice lifters.

The RIR-based RPE scale has also been observed to be more effective than a predetermined %1RM in order to prescribe load (6). Helms et al. investigated the differences between RPE and %1RM load assignment in resistance-trained men. Over the course of 8 weeks, researchers found that both loading types were indeed effective, however, RPE-based loading displayed a small 1RM strength advantage in a majority of individuals (6). Additionally, Cooke et al. observed a variety of repetitions that 58 participants could perform at 70% 1RM in the back squat, which varied from 6-26 repetitions (1). This highlights the variability that fluctuates among lifters at a given %1RM, which provides further evidence in support of the RIR-based RPE scale over the sole utility of %1RM to prescribe loads when working with trained individuals. Also, the use of this scale provides assistance to autoregulate training based upon daily readiness (35). Thus, load can be autoregulated more efficiently on a given week with the utility of the RIR-based RPE.

The RIR-based RPE has the ability to measure how close a lifter is to failure without necessarily reaching failure. Zourdos et al. suggested this scale to be used in lieu of %1RM to prescribe training load (11). Further, trained individuals are more likely to accurately gauge RIR when performing a given set (4). It has also been observed that accuracy of RIR improves set by set (8, 36-37); and when approaching failure, RIR accuracy has been better predicted than when further away from failure (36, 38). Although recent evidence has displayed favor towards training to failure in order for lifters to accurately prescribe load thereafter, training in close proximity to failure or to failure can come with a host of negative outcomes as previously explained. Sampson and Groeller expressed training to failure as, "not necessarily required to elicit significant changes in skeletal muscle structure or function" (22), suggesting that training further away from failure could also elicit improvements in strength and hypertrophy if provided with enough stimulus. Further evidence is needed to consider the accuracy of RIR-based RPE in well-trained lifters over time. Moreover, the utility of an additional metric, such as ACV, which has been observed alongside the RIR-based RPE scale acutely, could potentially be helpful to more accurately determine true RIR long-term in well-trained men.

RIR/ACV Relationship

As previously stated, an inverse relationship between ACV and RIR has been demonstrated and is highly prevalent among experienced lifters (4). Additionally, these lifters tend to lift at slower velocities than novice lifters (4). Thus, Helms et al. observed the relationship between ACV and RIR in the back squat, bench press, and deadlift (39). In this study, 15 powerlifters worked up to a 1RM for each lift while ACV was recorded for all sets performed at 80% 1RM and higher, up to 1RM. RPE at 1RM for the back squat, bench press, and deadlift was 9.5 ± 0.5, 9.7 ± 0.4, and 9.6 ± 0.5, respectively; and ACV at 1RM was 0.23 ± 0.05, 0.10 ± 0.04, and 0.14 ± 0.05 m/s^{-1}, respectively (39). The ACV at 1RM of the back squat observed by Helms et al. was similar to the ACV in the experienced lifters observed by Zourdos et al. (4, 39). Based upon the evidence, experienced lifters are more likely to gauge RIR-based RPE more accurately than untrained or novice lifters. Although this information is extremely useful, it is not yet understood how the RIR/ACV relationship would differ at submaximal intensities lower than 80% 1RM, and how that relationship could potentially become more accurate over time.

Moran-Navarro et al. also observed the relationship between ACV and RIR among novice, well-trained, and highly-trained men (12). Load-velocity relationships were established by the individual determination of 1RM for the bench press, full squat, prone bench pull, and shoulder press. These relationships were utilized to determine loads for each participant during their one set to failure at 65, 75, and 85% 1RM during each exercise. The primary goal was to determine if repetition velocity could be used to monitor or prescribe level of effort for a given exercise, and the authors found that regardless of the load, absolute velocities associated with a certain level of effort (RIR) could be reliably used (12), providing additional support for the utilization of both RIR and ACV in order to more accurately prescribe or monitor load.

Conclusion

In conclusion, researchers have compared training in proximity to failure in a multitude of differing ways. These variables include individuals with varying training ages, variability among intensities or periodization techniques, as well as the inclusion of metrics such as ACV, which can be used alongside the RIR-based RPE scale and %1RM, to accurately detect intensity while also autoregulating training based upon daily readiness. Although training to failure has been shown to elicit strength and hypertrophy gains in both untrained and trained individuals, it has been deemed unnecessary among many researchers, as training to failure elicits longer recovery time, induced anabolic signaling, and additional stress, as observed in markers of muscle damage. This suggests the need for a combination of metrics to determine how far from failure one can train to elicit gains in strength and hypertrophy. The well-established ACV/RIR relationship is inversely proportional, and is accurate in trained lifters. Also, RIR accuracy tends to improve over the course of a given set. However, longitudinal outcomes of this relationship have yet to be examined. Therefore, purpose of this study is to observe the longitudinal outcomes of the ACV/RIR relationship when training close to or further away from failure, and how the accuracy of this relationship could vary over time. By utilizing 1RM values at the beginning of a training protocol and observing the %1RM load lifted during the beginning and the end of a longitudinal study at specific submaximal loads based upon RIR ranges, one would consider that the load lifted would increase over time, thereby utilizing RIR, ACV and %1RM values, and thus improving muscle hypertrophy and strength in the long term.

III: METHODS

Participants

14 resistance-trained men between 18-40 years old were recruited for this study. For inclusion, subjects must: 1) have performed the back squat and bench press at least 1 time per week for the past 2 years as determined via a training history questionnaire, 2) have a minimum 1RM squat and bench press of 1.5 and 1.25 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. Only males were included in this study since the menstrual cycle has been shown to effect exercise performance, thus occurrence of menses around pre- and post-testing days could affect outcomes. Subjects were instructed to refrain from any additional exercise and to continue their normal nutritional intake for the duration of the study. This study was completed in Florida Atlantic University's Muscle Physiology Laboratory. 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. Subject characteristics for the 4-6 and 1-3 RIR groups can be seen in Table 1.

Table 1: Subject Characteristics

Variable	*4-6 RIR (n=7)*	*1-3 RIR (n=7)*	*Combined (n=14)*
Height (cm)	177.01 ± 5.42	174.53 ± 6.16	175.77 ± 5.72
Body Mass (kg)	82.06 ± 14.19	78.24 ± 12.77	80.15 ± 13.12
Relative Squat Strength (1RM/BM)	1.71 ± 0.34	1.74 ± 0.13	1.72 ± 0.25
Relative Bench Press Strength (1RM/BM)	1.25 ± 0.15	1.30 ± 0.08	1.27 ± 0.12

Data are Mean ± standard deviation. 1RM = One-repetition maximum. BM = Body Mass. RIR = Repetitions in Reserve.

Experimental Design

The purpose of this study was to observe the longitudinal relationship between repetitions in reserve (RIR) and average concentric velocity (ACV) among two groups of resistance-trained men. A secondary purpose of this study was to examine if this relationship would remain stable or fluctuate over time due to increases in strength. The two groups varied based on proximity to failure, which was measured via the RIR-based rating of perceived exertion (RPE) scale (RIR-based RPE scale) in order to efficiently gauge level of effort (Figure 1). The two groups trained the back squat and bench press to a 4-6 RIR or 1-3 RIR on non-consecutive days (i.e. Monday, Wednesday and Friday). Thus, participants in the 4-6 RIR group were required to work within a range where 4-6 repetitions could be completed after the cessation of the set, and participants in the 1-3 RIR group were required to work within a range where 1-3 repetitions could be completed after the cessation of the set. Further, ACV was recorded for each repetition completed throughout the entire study.

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

Figure 1: *Repetitions in Reserve-Based Rating of Perceived Exertion Scale*

Reprinted, with permission from Zourdos et al., 2016.

Throughout a 6-week span, participants followed a daily undulating periodized program design similarly designed to that of Klemp et al. (40), which concluded that volume-equated high- and low-repetition daily undulating programming strategies produce similar hypertrophy and strength adaptations (40). Exercise selection, rest periods and prescribed sets and repetitions were identical among both groups. Both groups trained three times per week on non-consecutive days, performing repetitions in a descending order each week. The program design is explained below (Tables 2-3).

Table 2: 4-6 RIR Training Group

4-6 RIR Group Week	Day 1 Protocol	Day 2 Protocol	Day 3 Protocol
1	3 sets x 10 reps @ 4-6 RIR	3 sets x 8 reps @ 4-6 RIR	4 sets x 6 reps @ 4-6 RIR
2	3 sets x 10 reps @ 4-6 RIR	3 sets x 8 reps @ 4-6 RIR	4 sets x 6 reps @ 4-6 RIR
3	3 sets x 9 reps @ 4-6 RIR	3 sets x 7 reps @ 4-6 RIR	4 sets x 5 reps @ 4-6 RIR
4	3 sets x 9 reps @ 4-6 RIR	3 sets x 7 reps @ 4-6 RIR	4 sets x 5 reps @ 4-6 RIR
5	3 sets x 8 reps @ 4-6 RIR	3 sets x 6 reps @ 4-6 RIR	4 sets x 4 reps @ 4-6 RIR
6	3 sets x 8 reps @ 4-6 RIR	3 sets x 6 reps @ 4-6 RIR	4 sets x 4 reps @ 4-6 RIR

RIR= Repetitions in Reserve. Reps= Repetitions. 4-6 RIR = Subjects were instructed to select a load that elicited an RIR within the listed range at the prescribed repetition range.

Table 3: 1-3 RIR Training Group

1-3 RIR Group Week	Day 1 Protocol	Day 2 Protocol	Day 3 Protocol
1	3 sets x 10 reps @ 1-3 RIR	3 sets x 8 reps @ 1-3 RIR	4 sets x 6 reps @ 1-3 RIR
2	3 sets x 10 reps @ 1-3 RIR	3 sets x 8 reps @ 1-3 RIR	4 sets x 6 reps @1-3 RIR
3	3 sets x 9 reps @1-3 RIR	3 sets x 7 reps @ 1-3 RIR	4 sets x 5 reps @1-3 RIR
4	3 sets x 9 reps @ 1-3 RIR	3 sets x 7 reps @ 1-3 RIR	4 sets x 5 reps @ 1-3 RIR
5	3 sets x 8 reps @ 1-3 RIR	3 sets x 6 reps @ 1-3 RIR	4 sets x 4 reps @ 1-3 RIR
6	3 sets x 8 reps @ 1-3 RIR	3 sets x 6 reps @ 1-3 RIR	4 sets x 4 reps @ 1-3 RIR

RIR = Repetitions in Reserve. Reps= Repetitions. 1-3 RIR = Subjects were instructed to select a load that elicited an RIR within the listed range at the prescribed repetition range.

All measurements were conducted by the principal investigator or graduate assistants working within the Muscle Physiology Laboratory and Exercise Biochemistry Laboratory (i.e., the principal investigator was not always present). Subjects reported to the training laboratory a total of 25 days over the course of 7 weeks, which included pre-study 1RM testing for both the squat and bench press. Forty-eight to 72 hours following pre-study testing, subjects began an introductory training week which consisted of three training sessions on non-consecutive days with reduced volume to prepare for the main training program. The week after introductory training, subjects then began the main training program as outlined in Tables 2-3. During pre-testing, subjects also completed a medical history form, physical activity questionnaire, signed an informed consent document, and had their blood collected. The medical history form and physical activity questionnaire are included within the submission.

Exercise Procedures

Back Squat and Bench Press Technique: Both the back squat and bench press were performed in accordance with International Powerlifting Federation standards (41). For the back squat, subjects were asked to stand straight with the hips and knees locked, and the barbell was placed across the upper back/shoulders, respectively. Upon the investigators command of "squat" subjects were asked to descend by bending the knees until the hip joint was below the top of the knee. Then subjects returned to the starting position upon their own volition. Subjects waited until a rack command was issued to re-rack the barbell. For the bench press, subjects were instructed to lay supine on a weight bench, while maintaining five points of contact (head, butt, and shoulders in contact with the bench, both feet in flat on the floor throughout the movement), respectively. Subjects removed the barbell from the rack and held it with arms extended in a stable position. Investigators issued a start command upon which subjects lowered the barbell until it contacted the chest and was then pressed upwards until the arms were once again fully extended. Subjects waited until a rack command was issued to re-rack the barbell.

One Repetition Maximum (1RM) Testing: The order of 1RM testing began with the back squat and was followed by the bench press. 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. All participants performed a standardized 10-minute warm-up prior to 1RM testing. Participants then completed a 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, in accordance with previously validated procedures by Zourdos et al. (4). Load was then incrementally increased appropriately for 1RM attempts, and a rest period of 5-7 minutes was administered between each attempt. To aid in attempt selection, RIR-based RPE and ACV were collected on each 1RM attempt. To determine if a 1RM attempt was valid, one of the following conditions must have been met: 1) subject reported a ‘0’ on the RPE/RIR scale and the investigator determined a subsequent attempt with increased weight would not be successfully or safely completed, 2) subject reports a ‘0.5’ on the RPE/RIR scale and missed the subsequent attempt with a load increase of 2.5kg or less, 3) subject reported a ‘1’ or higher on the RPE/RIR scale and failed 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.

Training Protocol: Forty-eight hours following 1RM testing, the introductory week began. During the introductory week, a lowered volume resistance training protocol was performed on non-consecutive days (i.e. Monday, Wednesday, Friday). Following the introductory week, a daily undulating periodized program was executed throughout the course of 6 weeks (Tables 2-3). In weeks 1 and 2, a repetition pattern of 10, 8 and 6 was followed on Monday, Wednesday and Friday, respectively. In weeks 3 and 4, the pattern decreased to 9, 7 and 5 repetitions. In weeks 5 and 6, the pattern decreased, again, to 8, 6 and 4 repetitions (Tables 2-3). Level of effort was gauged by the RIR-based RPE scale so that both groups were able to maintain their targeted range of level of effort (e.g., 4-6 RIR, 1-3 RIR) based upon their 1RM testing values for the back squat and bench press. All training sessions began with a standardized 10-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.

Instrumentation

Velocity Assessment: The Open Barbell System (OBS), a linear position transducer that calculates velocity, has been validated for ACV measurement against a 3D motion capture (42). The OBS has a string with a Velcro, which attaches to the barbell and to a velocity calculator. This provides measures of average and peak velocity ($m \cdot s^{-1}$) throughout the lift. The values recorded by the OBS were displayed on the display unit and were manually recorded by the investigator.

Rating of Perceived Exertion (RPE): The RIR-based RPE scale created by Zourdos et al. (4) was utilized after each set completed to ensure each subject remained within the given RIR range (Figure 1). The specific ranges of sets, repetitions and RIR ranges for each week of the training protocol are displayed in Tables 2 and 3. If a participant completed all assigned sets and, at the prescribed load, they were able to autoregulate successive loads. If either group under or over-performed the desired rep-range, a standardized modification was implemented based upon Table 4 (35). Further, RIR and ACV values established for each given repetition were cross-referenced for analysis.

Table 4: Load change protocol for 4-6 and 1-3 RIR Groups

Actual RIR	Assigned RIR range: 4-6	Assigned RIR range: 1-3
9	Increase load by 12%	Increase load by 24%
8	Increase load by 8%	Increase load by 20%
7	Increase load by 4%	Increase load by 16%
6	**Participant choice**	Increase load by 12%
5	**Participant choice**	Increase load by 8%
4	**Participant choice**	Increase load by 4%
3	Decrease load by 4%	**Participant choice**
2.5	Decrease load by 6%	**Participant choice**
2	Decrease load by 8%	**Participant choice**
1.5	Decrease load by 10%	**Participant choice**
1	Decrease load by 12%	**Participant choice**
0.5	Decrease load by 14%	Decrease load by 2%
0	Decrease load by 16%	Decrease load by 4%

RIR = Repetitions in Reserve. Protocol from Helms et al. 2018.

Statistical Analysis

Data were analyzed using a series of random intercept linear mixed models with subject identified as a random effect. Fixed effects included exercise (back squat and bench press), set (1-3), RIR (continuous), groups (4-6 RIR and 1-3 RIR), and time (pre to post).

Each model contained 2-3 fixed effects and all 2-way and 3-way interaction terms in order to answer the pertinent research questions at hand. Correlated data from subsequent sets for a given exercise within each testing visit were modeled using compound symmetry covariance structures. Statistically significant interactions were followed by hypothesis tests comparing simple effects or simple slopes as appropriate, using the Bonferroni method to account for multiplicity. Models were constructed using PROC MIXED (SAS Software version 9.4, Cary, NC, USA) with a statistical significance threshold of $\alpha = 0.05$.

IV: RESULTS

RIR × Exercise Interaction

The RIR × Exercise interaction was statistically significant ($p<0.001$); thus, the relationship between RIR and ACV varied between the squat and bench press. Post hoc analyses showed that the simple slope for RIR was greater than 0 for both exercises ($p<0.001$) and the slope for RIR in the bench press (0.027 ± 0.001 $m{\cdot}s^{-1}$) was significantly greater than the slope for the squat (0.020 ± 0.001 $m{\cdot}s^{-1}$). Further, ACV was significantly faster in the squat than in the bench press ($p<0.001$). Table 5 displays the RIR, estimated ACV, and associated percentage velocity loss for each exercise.

Table 5: Estimated ACV, and Velocity Loss at Each RIR

	SQUAT*		**BENCH PRESS**	
RIR	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**	**% Velocity Loss**	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**	**% Velocity Loss**
0	0.409 ± 0.013 (0.382-0.485)	38.87	0.208 ± 0.013 (0.182-0.235)	62.53
1	0.428 ± 0.013 (0.402-0.455)	35.88	0.236 ± 0.013 (0.210-0.262)	57.72
2	0.448 ± 0.012 (0.422-0.474)	32.89	0.263 ± 0.012 (0.237-0.289)	52.91
3	0.468 ± 0.012 (0.443-0.494)	29.90	0.291 ± 0.012 (0.265-0.316)	48.10
4	0.488 ± 0.012 (0.462-0.514)	26.91	0.318 ± 0.012 (0.293-0.354)	43.29

*Data are Mean ± Standard Error (95% Confidence Interval). ACV = Average Concentric Velocity. RIR = Repetitions in Reserve. *Squat ACV significantly faster than bench press ACV (p<0.001).*

RIR × Set Interaction

There was a significant RIR × Set interaction (p=0.0010), indicating that the RIR and ACV relationship varied from set-to-set with both the squat and bench press combined. Post hoc analysis revealed similar slopes between sets 1 (0.021 ± 0.001 $m{\cdot}s^{-1}$) and 2 (0.022 ± 0.001 $m{\cdot}s^{-1}$), and a greater slope in set 3 (0.024 ± 0.001 $m{\cdot}s^{-1}$) versus both set 1 (p=0.010) and set 2 (0=0.026), indicating slower ACV in set 3. Although the slopes differed in set 3 compared to sets 1 and 2, the largest magnitude of difference in ACVs at the same RIR from set-to-set was only 0.044 $m{\cdot}s^{-1}$ (set 1 vs. set 3 at 0 RIR) (Table 6), and visual representation (Figure 2) shows a similar pattern between sets.

Table 6: Squat and Bench Press Combined ACV Across all Sets

	SET 1		SET 2		SET 3*#	
RIR	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**	**% Velocity Loss**	**Estimated ACV ± SE ($m{\cdot}s^{-1}$)**	**% Velocity Loss**	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**	**% Velocity Loss**
0	0.338 ± 0.012 (0.313-0.363)	43.94	0.314 ± 0.012 (0.289-0.339)	47.58	0.294 ± 0.012 (0.269-0.319)	54.08
1	0.359 ± 0.012 (0.334-0.384)	40.56	0.336 ± 0.012 (0.312-0.361)	43.92	0.318 ± 0.012 (0.294-0.343)	49.92
2	0.380 ± 0.012 (0.356-0.405)	37.18	0.358 ± 0.011 (0.334-0.383)	40.26	0.343 ± 0.011 (0.318-0.367)	45.76
3	0.402 ± 0.011 (0.377-0.426)	33.80	0.380 ± 0.011 (0.356-0.405)	36.60	0.367 ± 0.011 (0.343-0.391)	41.60
4	0.423 ± 0.011 (0.399-0.447)	30.42	0.403 ± 0.011 (0.378-0.427)	32.94	0.391 ± 0.011 (0.367-0.413)	37.44

*Data are Mean ± Standard Error (95% Confidence Interval). ACV = Average Concentric Velocity. RIR = Repetitions in Reserve. *RIR/ACV slope significantly steeper in set 3 vs. set 1 (p=0.010). #RIR/ACV slope significantly steeper in set 3 vs. set 2 (p=0.026).*

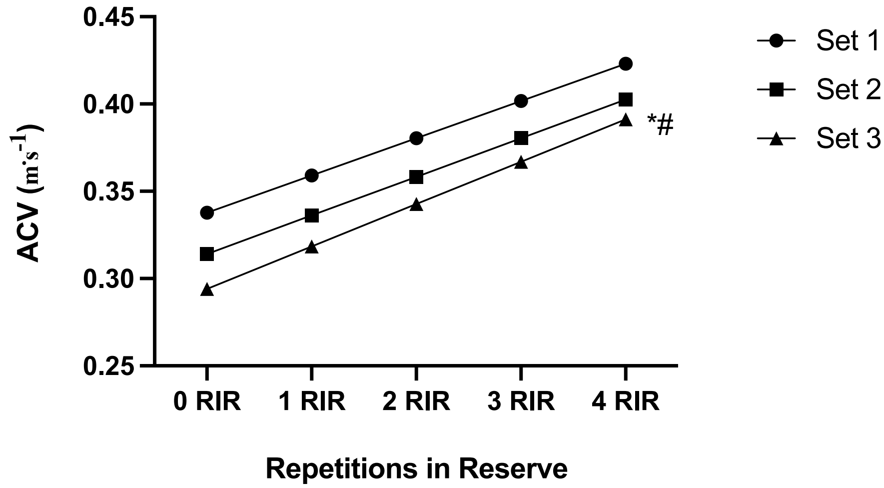

Figure 2. *The relationship between RIR and ACV during all sets for the squat and bench press combined. The Repetitions in reserve × Set Interaction was statistically significant (p=0.0010)*

RIR × Group Interaction

Across all sets and sessions there was a significant RIR × Group interaction with the slope being significantly greater ($p<0.001$) in the 4-6 RIR group (0.020 ± 0.001 $m{\cdot}s^{-1}$) than in 1-3 RIR (0.027 ± 0.001 $m{\cdot}s^{-1}$). These findings indicate that as subject trained closer to failure, a steeper slope explained the RIR/ACV relationship. For example, at 0 RIR, the estimated ACV in the 4-6 RIR group was 0.074 $m{\cdot}s^{-1}$ faster than the ACV in the 1-3 RIR group. Figure 3 displays the RIR/ACV relationship in each group over all sets analyzed.

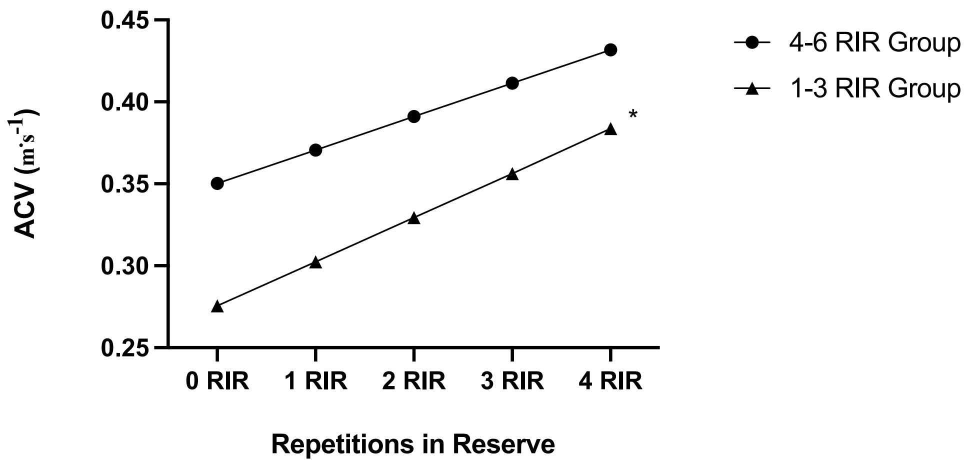

Figure 3. *The relationship between RIR and ACV during all set for the squat and bench press combined in both the 4-6 RIR and 1-3 RIR groups. *The Repetitions in reserve × Group Interaction was statistically significant (p<0.001)*

Longitudinal Interactions for All Sets

There was a significant (p=0.004) 3-way interaction (RIR × Group × Time). There were then significant RIR × Time effects for both the 4-6 (p=0.040) and 1-3 RIR (p=0.047) groups indicating the RIR/ACV relationship did significantly change over time. Specifically, across the squat and bench press combined, the slope changed in the 4-6 and 1-3 RIR groups. Additionally, the two-way interaction for RIR × Group was significant (p<0.001), with a steeper slope and slower ACV in the 1-3 RIR group. Figure 4 displays the RIR/ACV relationship from 0-4 RIR in both groups during all pre-study sets vs. all post-study sets in the squat and bench press combined. The largest difference in ACV from pre- to post-study at the same RIR was 0.07 $m \cdot s^{-1}$ in the 4-6 RIR group at a 0 RIR, and 0.064 $m \cdot s^{-1}$ at a 4 RIR in the 1-3 RIR group (Table 7).

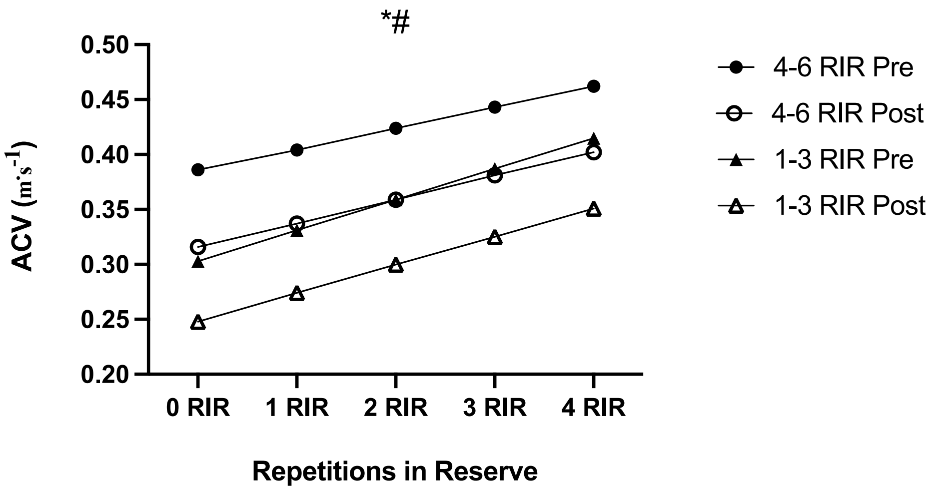

Figure 4. *The relationship between RIR and ACV during all sets at both pre- and post-study in both groups for the squat and bench press combined. *The RIR × Time Interaction was significant (p<0.05) for each group. #The RIR × Group Interaction was statistically significant (p<0.001)*

Table 7: Estimated ACV for the Squat and Bench Press Combined from Pre-to Post-Study

	Pre-Study 4-6 RIR	Post-Study 4-6 RIR*	Pre-Study 1-3 RIR	Post-Study 1-3 RIR*
RIR	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**	**Estimated ACV ± SE ($m{\cdot}s^{-1}$) (95% CI)**
0	0.386 ± 0.022 (0.343-0.429)	0.316 ± 0.021 (0.273-0.358)	0.303 ± 0.019 (0.262-0.344)	0.248 ± 0.019 (0.207-0.289)
1	0.405 ± 0.021 (0.363-0.447)	0.337 ± 0.021 (0.295-0.379)	0.331 ± 0.019 (0.291-0.372)	0.274 ± 0.019 (0.233-0.314)
2	0.424 ± 0.021 (0.382-0.466)	0.359 ± 0.021 (0.317-0.400)	0.359 ± 0.019 (0.319-0.399)	0.300 ± 0.019 (0.259-0.340)
3	0.443 ± 0.021 (0.402-0.485)	0.381 ± 0.021 (0.339-0.422)	0.387 ± 0.019 (0.347-0.427)	0.325 ± 0.019 (0.285-0.365)
4	0.462 ± 0.021 (0.421-0.504)	0.402 ± 0.021 (0.361-0.443)	0.415 ± 0.019 (0.375-0.455)	0.351 ± 0.019 (0.311-0.391)

*Data are Mean ± Standard Error. ACV = Average Concentric Velocity. RIR = Repetitions in Reserve. *The RIR x Time interaction was significant for both the 4-6 (p=0.040) and 1-3 RIR (p=0.047) groups*

V: DISCUSSION

To our knowledge, this is the first study to examine a change in the RIR/ACV relationship in a longitudinal study in the free-weight back squat and bench press in trained men. The main findings of this study were 1) RIR was a significant predictor of ACV for both exercises, 2) the RIR/ACV was exercise-specific, 3) the RIR/ACV relationship changed over time and from set-to-set, and 4) the RIR/ACV relationship differed between groups, with a steeper slope in the 1-3 RIR group. Although the RIR/ACV relationship differed from set-to-set and over time, it's unlikely these differences were practically meaningful. For example, the largest magnitude of difference in ACV at the same RIR between sets was only 0.044 $m{\cdot}s^{-1}$, which falls below the smallest worthwhile change threshold of 0.06 $m{\cdot}s^{-1}$ (43). Therefore, our hypothesis that the RIR/ACV relationship would be exercise-specific was supported; however, our hypotheses of a stable RIR/ACV relationship from set-to-set and longitudinally were not supported according to the statistical significance threshold.

When comparing RIR/ACV slopes between sets, there were similar slopes established for sets 1 and 2, however, the slope in set 3 (0.024 ± 0.001 $m{\cdot}s^{-1}$) was statistically different compared to sets 1 (0.021 ± 0.001 $m{\cdot}s^{-1}$) and 2 (0.022 ± 0.001 $m{\cdot}s^{-1}$). Although the RIR × Set interaction was significant, the largest difference between sets was only 0.044 $m{\cdot}s^{-1}$ at a 0 RIR between set 1 (0.338 ± 0.012 $m{\cdot}s^{-1}$) and set 3 (0.294 ± 0.012 $m{\cdot}s^{-1}$), which is below the smallest ACV worthwhile change threshold of 0.06 $m{\cdot}s^{-1}$, established by Banyard et al. (13) (Table 6, Figure 2). Therefore, it does not seem that the same RIR was related to a meaningfully different ACV from set-to-set. Hickmott (13) also examined the RIR/ACV relationship from set-to-set and found that when all repetitions in a set to failure at 80% of 1RM were considered, the RIR × Set interaction was significant, but similar to the present study, the largest variation in the squat and bench press from set-to-set was only 0.05 $m \cdot s^{-1}$. Further, in a sub-analysis, Hickmott (13) only considered the last five repetitions in a set (0-4 RIR) and reported a stable RIR/ACV relationship from set-to-set. This difference in statistical significance can likely be explained by the RIR/ACV slope becoming steeper during the latter portion of a set (12, 14, 44, 45, 47), and with less repetitions considered, decreasing statistical power. In the present study, the slope was indeed steeper in the 1-3 RIR group (0.027 ± 0.001 $m \cdot s^{-1}$) when subjects were closer to failure versus the 4-6 RIR group (0.020 ± 0.001 $m \cdot s^{-1}$). Therefore, the current study is in agreement with previous data suggesting that the difference in the RIR/ACV relationship from set-to-set in the squat and bench press is not meaningful and this difference may dissipate as a set is performed closer to failure.

The utility in establishing a stable RIR/ACV relationship from set-to-set is to prescribe training in which an athlete can objectively terminate a set at a specific proximity to failure. For example, if an athlete wishes to train sets to a 2 RIR, then four sets could be prescribed with the stipulation to terminate each set at a velocity known to coincide with 2 RIR for that individual. Importantly, Moran-Navarro et al. (12) established that the RIR/ACV relationship at 2, 4, 6 and 8 RIR in the back squat and bench press was not different during one set to failure at 65, 75 and 85% of 1RM. Additionally, Sanchez-Moreno et al. reported similar ACV values during the last repetition of sets to failure on the Smith machine bench press at 50, 60, 70, 80, and 90% of 1RM (2). From set-to-set using the same load, Hickmott (13) found that the ACV at 1 RIR differed by only 0.002 $m \cdot s^{-1}$ from set 1 (0.307 ± 0.011 $m \cdot s^{-1}$) to set 4 (0.309 ± 0.012 $m \cdot s^{-1}$).

As noted earlier, when establishing an RIR/ACV relationship, it is likely essential to be close to or at muscular failure, which is evidenced by the significant RIR × Group interaction (Figure 3). Specifically, this interaction indicated that the RIR/ACV slope was significantly greater in the 4-6 RIR group (0.020 ± 0.001 $m \cdot s^{-1}$) than in the 1-3 RIR group (0.027 ± 0.001 $m \cdot s^{-1}$). This group difference indicates that toward the end of a set, the decline in ACV is more linear (i.e., a steeper slope is present), which has also been previously observed (12, 14, 44, 45, 47). Therefore, even if an athlete accurately gauges a 5 RIR, the slope established could not be used to accurately predict the ACV's associated with a 0-4 RIR. Therefore, an individual should perform a set close to failure (ideally to failure) when establishing the RIR/ACV relationship.

Controlling for proximity to failure during a set has been previously attempted with both RIR (6) and percentage velocity loss (7). However, Zourdos et al. (11) established that trained lifters significantly underestimate intraset RIR by 5.15 ± 2.92 repetitions when predicting 5 RIR during a set to failure at 70% of 1RM on the squat. Further, the percentage velocity loss method involves terminating a set at a pre-determined percentage of velocity decline (i.e., 10, 20, 30, or 40%) from the fastest (typically first) repetition in a set (7). For example, an athlete could be prescribed 70% of 1RM and a 40% velocity loss, then if the fastest repetition in a set was 0.70 $m \cdot s^{-1}$, the set would be terminated at an ACV of ≤0.42 $m \cdot s^{-1}$. However, as observed in the present study among others (2, 11, 44, 47), velocity loss is exercise-specific (Table 5). The present study and Hickmott (13) suggest that the change in the RIR/ACV relationship from set-to-set is not meaningful, if the first (or fastest) repetition ACV is different from set-to-set, then the same percentage velocity loss may correspond with a different RIR on each set. For example, the present study reports a 5.58% difference in velocity loss that corresponded with a 2 RIR on set 1 (62.09%) versus set 3 (56.51%). Therefore, establishing an RIR/ACV relationship and terminating a set at a specific ACV seems to rectify the subjective limitation of solely using RIR and the set-to-set variance of percentage velocity loss.

Although establishing an RIR/ACV relationship may allow an individual to effectively control for proximity to failure from set-to-set, the utility of this method is dependent upon its stability over time. While ACV at the same percentage of 1RM is reliable in sessions performed within 48 hours (48, 49), it is not known if this relationship is stable over time. The present study observed significant RIR × Time interactions in both the 4-6 ($p=0.040$) and 1-3 ($p=0.047$) RIR groups. Specifically, the RIR/ACV slope became steeper in both groups from week 1 to week 6 of training (Table 7, Figure 4). However, this significant interaction may be a product of the study design and not necessarily a true change in the RIR/ACV slope. Since subjects did not train to failure, the ACV could only be associated with a self-reported RIR. Although RIR ratings can be inaccurate, they are related to RIR experience and are more accurate in experienced versus non-experienced trainees (14, 38), and thus become nearly perfect with both experience and being gauged close (0-2 RIR) to failure (50). Therefore, it is possible that the slower ACV at the same RIR in week 6 versus week 1 was a product of improved RIR accuracy and not a true change in the RIR/ACV slope. Iglesias-Soler et al. (14) observed a significantly steeper slope in both the Smith machine squat and bench press ($p<0.001$) after 5 weeks of training; however, this finding was in untrained individuals (14). In cross-sectional studies, both Zourdos et al. (14) and

Ormsbee et al. (38) reported significantly slower ACV's at 100% of 1RM in trained versus untrained individuals, again indicating that velocity decreases at higher intensities with training experience. However, studies have failed to observe a change in ACV at 1RM over the course of 8 weeks (51); thus, it is possible that the significant interaction in the present study is due to improved RIR accuracy over time rather than a true change in the RIR/ACV relationship. However, more research is needed to elucidate if this relationship is stable over time in already trained individuals.

The present study is not without limitations. First, this study only utilized well-trained young men, and the free-weight back squat and bench press exercises. Thus, the RIR/ACV relationships presented should not be applied to other populations or exercises. Secondly, since the RIR/ACV slopes were estimated based upon submaximal loads, it is possible that the exact ACV values presented for repetitions close to failure are not exactly accurate. Lastly, since the ACV slope becomes steeper during the latter portion of a set, it is also possible that only analyzing the final repetitions in a set (i.e., last ~5 repetitions) would provide the most accurate RIR/ACV relationships for 0-5 RIR, the typical range in which sets are terminated during traditional strength and hypertrophy training. Therefore, future research should examine if the RIR/ACV relationship changes over time during a set to failure.

In summary, the present study is in concert with previous literature demonstrating that in the squat and bench press, the change in RIR is a significant predictor of ACV, the RIR/ACV relationship is practically stable from set-to-set, and that this relationship is exercise-specific. Further, the present results demonstrate that the RIR/ACV relationship varied over 6 weeks of training; however, it is possible this difference is due to improved

RIR accuracy rather than a true change in ACV slope. Practically, if a training session goal is to train to a 3 RIR on the squat in a specific session, then they could terminate each set at ≤0.40 $m \cdot s^{-1}$, which has utility over the subjective limitations of solely using RIR and the variability in velocity loss from set-to-set. Although group velocity profiles could be used, it is well-known that velocity profiles are individual (43) and we recommend against applying the mean values in the present study since the sets were not taken to failure. To create an RIR/ACV profile, one set to failure at a moderate intensity (i.e., 65-85% of 1RM) could be performed. If 10 repetitions were performed in this failure set, then the ACV on the 10^{th} repetition would be associated with a 0 RIR, the 9^{th} repetition ACV would be associated with a 1 RIR, the 8^{th} repetition ACV would be a 2 RIR, and so forth. Since ACV is reliable from session-to-session, practitioners can effectively use this strategy; however, future research is needed to truly determine if the RIR/ACV relationship changes over time.

APPENDICES

APPENDIX A: APPROVAL LETTER

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:	May 10, 2019
TO:	Michael Zourdos, Ph.D.
FROM:	Florida Atlantic University Health Sciences IRB
PROTOCOL TITLE:	Effect of Proximity to Failure During Resistance Training on Muscle Performance and Fatigue
IRBNET ID #:	1422879-2
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	May 10, 2019
NEXT REPORT DATE:	May 10, 2020
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. NO CONTINUE REVIEW IS REQUIRED FOR THIS PROTOCOL. Please submit VIA e-mail a brief progress report on or before the "Next Report Date".

- This study is approved for a maximum of **45** subjects.
- Please submit a progress report before the indicated date.
- It is important that you use the approved, stamped consent documents or procedures listed below:
  - Adult Consent Form - Proximity to Failure Consent Form Revisions (stamped)
  - Protocol - Proximity to Failure IRB Protocol Revision (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 or unanticipated problems must be reported to this office. Please use the appropriate serious adverse event (SAE)/ Unanticipated Problems (UP) report form 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.

- 1 -

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- Please note that all research records for federally funded or non-funded investigator initiated studies must be retained for a minimum of three years after completion of the research. For multisite, international studies conducted under ICH Guidelines, records must be retained until notification by the sponsor that all marketing applications have been completed. Research records involving protected health information (PHI) must be retained for a minimum of six years.
- Please submit an IRB final report when the study is completed or discontinued.

[If applicable] This approval is contingent on the successful execution of a [material or data] agreement.

If you have any questions or comments about this correspondence, please contact Donna Simonovitch at:

Institutional Review Board
Research Integrity/Division of Research
Florida Atlantic University
Boca Raton, FL 33431
Phone: 561-297-0777
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.

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APPENDIX B: INFORMED CONSENT

ADULT CONSENT FORM

Consent Form Version & Date: Version 1.0: March 22rd, 2019.

1) Title of Research Study: Effect of Proximity to Failure During Resistance Training on Muscle Performance and Fatigue

2) Investigator(s): Michael C. Zourdos, Ph.D., CSCS, Nicholas Sautter, B.S.

3) Purpose: The purpose of this research study is to assess how close performing resistance training sets to failure effects muscle hypertrophy, strength, and fatigue outcomes.

4) Procedures: If you choose to participate in this study you will be required to complete the following assessments among 25 laboratory visits over 57 days:

- 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 back squat and bench press
- Three resistance training sessions per week on the squat and bench press with moderate to heavy loads
- Ultrasound assessments of the quadriceps and chest to obtain muscle thickness
- Height and weight assessments
- Body composition by skinfold caliper (chest, abdomen, thigh)
- Provide ratings of readiness prior to each training session
- Provide a rating of fatigue following each training session
- Undergo a 10 ml (2 teaspoons) blood draw prior to each testing and training session from a prominent vein on the forearm
- Consume branched chain amino acids and whey protein immediately prior to each training session
- Delayed onset muscle soreness assessments through mild palpations of the quadriceps, hamstrings, and chest via an algometer prior to each training session
- 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, physical activity/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.

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, and all exercises (back squat and bench press) will be performed in accordance with the criteria of the United States of America Powerlifting (USAPL). After determining the 1RM in the squat, a five-minute rest period will precede a bench press-specific warmup (same protocol described for squat-specific warmup), followed by a 1RM test for the bench press. All 1RM attempts will be separated by 3- to 5-minute rest periods.

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.

During the bench press, you will lie supine on a weight bench with your head, butt, and shoulders in contact with the bench and, both feet in flat on the floor at all times. You will remove the bar from the rack and hold it in your hand with your arms extended in a stable position. You will then lower bar until it comes in contact with your chest where it will then be pressed upwards until the arms are once again fully extended.

At this time, you will be placed into your specific group for the study, and given your specific training protocol. After 48-72-hours of rest you will begin your introductory training. This training will include 3 alternating days of low volume resistance training (e.g. Monday, Wednesday, and Friday). This lower intensity training is specifically designed for each training group, and will prepare you for the upcoming 8-week long training protocol. Following the introductory training, you will perform the specific 8-week long training protocol you were assigned to, which will follow the same 3-day per week schedule as your introductory training. Lastly, you will begin taper training after completing your final week of your specific protocol. Similar to the introductory training, taper training will feature lower volume resistance training on two alternating days (i.e. Monday and Wednesday). After your second resistance training day you will rest for 48 hours and repeat the pre-study measures of:

- One repetition maximum (1RM) strength in the squat and bench press
- Blood collection
- Muscle thickness (MT) of the biceps, chest, and thigh muscles via ultrasound
- Body composition by ultrasound (chest, abdomen, thigh)
- Anthropometrics (height & weight)

Seventy-two hours following 1RM testing you will be asked to return to the laboratory for an introductory training week. During this introductory weeks and for the next seven consecutive weeks after that (i.e. 8 weeks in total) you will be asked to perform resistance training three times per week on non-consecutive days (i.e. Monday, Wednesday, Friday) as part of the study. The three groups in this study, of which you will be assigned to one of them, perform the same sets and repetitions of resistance training and only differ in terms of how close each set is taken to failure. To standardize when you should stop each set each group has a target rating of perceived exertion value, which will dictate how close to failure you each set will be. This rating of perceived exertion values/scale will be shown and explained to you. Furthermore, you will be asked to fill out the Daily Analysis of Life Demands, Perceived Recovery Status scale, and Motivation to Train scale before both testing and training days and average concentric velocity will be recording during all repetitions on both testing and training days using a linear position transducer. You will also be asked to complete a session rating of perceived exertion scale following each training session, which determines fatigue level. Additionally, prior to each training session and following each training session you will be asked to consumer branched chain amino acids and whey protein, respectively in a powder mixed with water. These will be provided to you by the investigators. The exact resistance training protocols that each group will perform can be seen below.

Table 1: 4-6 Rating of Perceived Exertion (RPE) Training Group

@ 4-6 RPE Group	*Day 1*	*Day 2*	*Day 3*
Week	*Protocol*	*Protocol*	*Protocol*
0	*N/A*	*N/A*	*1RM Test*
1 - Intro	*2 sets x 10 reps @ 3-5 RPE*	*2 sets x 8 reps @ 3-5 RPE*	*3 sets x 6 reps @ 3-5 RPE*
2	*3 sets x 10 reps @ 4-6 RPE*	*3 sets x 8 reps @ 4-6 RPE*	*4 sets x 6 reps @ 4-6 RPE*
3	*3 sets x 10 reps @ 4-6 RPE*	*3 sets x 8 reps @ 4-6 RPE*	*4 sets x 6 reps @ 4-6 RPE*
4	*3 sets x reps 9 @ 4-6 RPE*	*3 sets x 7 reps @ 4-6 RPE*	*4 sets x 5 reps @ 4-6 RPE*

5	*3 sets x 9 reps @ 4-6 RPE*	*3 sets x 7 reps @ 4-6 RPE*	*4 sets x 5 reps @ 4-6 RPE*
6	*3 sets x 8 reps @ 4-6 RPE*	*3 sets x 6 reps @ 4-6 RPE*	*4 sets x 4 reps @ 4-6 RPE*
7	*3 sets x 8 reps @ 4-6 RPE*	*3 sets x 6 reps @ 4-6 RPE*	*4 sets x 4 reps @ 4-6 RPE*
8 - Taper	*2 sets x 4 reps @ 3-5 RPE*	*2 sets x 3 reps @ 3-5 RPE*	*Post-Testing*

Table 2: 7-9 RPE Training Group

@ 7-9 RPE Group	*Day 1*	*Day 2*	*Day 3*
Week	*Protocol*	*Protocol*	*Protocol*
0	*N/A*	*N/A*	*1RM Test*
1 - Intro	*2 sets x 10 reps @ 3-5 RPE*	*2 sets x 8 reps @ 3-5 RPE*	*3 sets x 6 reps @ 3-5 RPE*
2	*3 sets x 10 reps @ 4-6 RPE*	*3 sets x 8 reps @ 4-6 RPE*	*4 sets x 6 reps @ 4-6 RPE*
3	*3 sets x 10 reps @ 4-6 RPE*	*3 sets x 8 reps @ 4-6 RPE*	*4 sets x 6 reps @ 4-6 RPE*
4	*3 sets x 9 reps @ 4-6 RPE*	*3 sets x 7 reps @ 4-6 RPE*	*4 sets x 5 reps @ 4-6 RPE*
5	*3 sets x 9 reps @ 4-6 RPE*	*3 sets x 7 reps @ 4-6 RPE*	*4 sets x 5 reps @ 4-6 RPE*
6	*3 sets x 8 reps @ 4-6 RPE*	*3 sets x 6 reps @ 4-6 RPE*	*4 sets x 4 reps @ 4-6 RPE*
7	*3 sets x 8 reps @ 4-6 RPE*	*3 sets x 6 reps @ 4-6 RPE*	*4 sets x 4 reps @ 4-6 RPE*
8 - Taper	*2 sets x 4 reps @ 3-5 RPE*	*2 sets x 3 reps @ 3-5 RPE*	*Post-Testing*

Table 3: Failure Training Group

@ 10 RPE Group	*Day 1*	*Day 2*	*Day 3*
Week	*Protocol*	*Protocol*	*Protocol*
0	*N/A*	*N/A*	*1RM Test*
1 - Intro	*2 sets x ~10 reps @ 8-10 RPE*	*2 sets x ~8 reps @ 8-10 RPE*	*3 sets x ~6 reps @ 8-10 RPE*
2	*3 sets x ~10 reps @ 10 RPE*	*3 sets x ~8 reps @ 10 RPE*	*4 sets x ~6 reps @ 10 RPE*
3	*3 sets x ~10 reps @ 10 RPE*	*3 sets x ~8 reps @ 10 RPE*	*4 sets x ~6 reps @ 10 RPE*
4	*3 sets x ~9 reps @ 10 RPE*	*3 sets x ~7 reps @ 10 RPE*	*4 sets x ~5 reps @ 10 RPE*
5	*3 sets x ~9 reps @ 10 RPE*	*3 sets x ~7 reps @ 10 RPE*	*4 sets x ~5 reps @ 10 RPE*
6	*3 sets x ~8 reps @ 10 RPE*	*3 sets x ~6 reps @ 10 RPE*	*4 sets x ~4 reps @ 10 RPE*
7	*3 sets x ~8 reps @ 10 RPE*	*3 sets x ~6 reps @ 10 RPE*	*4 sets x ~4 reps @ 10 RPE*
8 - Taper	*2 sets x ~4 reps @ 8-10 RPE*	*2 sets x ~3 reps @ 8-10 RPE*	*Post-Testing*

Lastly, prior to both testing and training days we will ask to draw a 10 milliliter (2 teaspoon) blood sample from you, which will be used to test for indirect markers of muscle damage and fatigue (i.e. creatine kinase and lactate dehydrogenase). 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.

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

5) Risks: 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 technician. 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 will be kept by the investigators with your name on a password-protected computer, and all data will be destroyed in seven years.

6) Benefits: The potential benefits to you are:

- Free measurements of body composition and one-repetition maximum testing
- Access to calibrated training equipment that is approved by and used within the International Powerlifting Federation (IPF) competitive events
- A greater understanding of how to design resistance training programs to improve muscle hypertrophy and strength

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.

7) Confidentiality/ 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 will be kept for seven years and then destroyed. 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.

8) 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.

- 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.

9) 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: ________________

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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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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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/week Average_______________ 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

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

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

_______________ % your maximum

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

Yes or No   If so, _______________ times/week

3. 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

4. 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?

REFERENCES

1. Cooke, Daniel M., et al. "Body mass and femur length are inversely related to repetitions performed in the back squat in well-trained lifters." *The Journal of Strength & Conditioning Research* 33.3 (2019): 890-895.
2. Sánchez-Moreno M, Rendeiro-Pinho G, Mil-Homens PV, Pareja-Blanco F. Monitoring Training Volume Through Maximal Number of Repetitions or Velocity-Based Approach. International Journal of Sports Physiology and Performance. 2021 Jan 5;1(aop):1-8.
3. Pareja-Blanco F, Rodríguez-Rosell D, Aagaard P, Sánchez-Medina L, Ribas-Serna J, Mora-Custodio R, Otero-Esquina C, Yáñez-García JM, González-Badillo JJ. Time course of recovery from resistance exercise with different set configurations. The Journal of Strength & Conditioning Research. 2020 Oct 1;34(10):2867-76.
4. Zourdos, Michael C., et al. "Novel resistance training–specific rating of perceived exertion scale measuring repetitions in reserve." *The Journal of Strength & Conditioning Research*30.1 (2016): 267-275.
5. González-Badillo J, Marques M, Sánchez-Medina L. The importance of movement velocity as a measure to control resistance training intensity. Journal of human kinetics. 2011 Sep 1;29(Special-Issue):15-9.
6. Helms, Eric R., et al. "RPE vs. Percentage 1RM loading in periodized programs matched for sets and repetitions." *Frontiers in physiology* 9 (2018): 247.

7. Pareja-Blanco, Fernando, et al. "Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations." *Scandinavian journal of medicine & science in sports* 27.7 (2017): 724-735.
8. Hackett, Daniel A., et al. "Accuracy in estimating repetitions to failure during resistance exercise." *The Journal of Strength & Conditioning Research* 31.8 (2017): 2162-2168.
9. Steele, James, et al. "Ability to predict repetitions to momentary failure is not perfectly accurate, though improves with resistance training experience." *PeerJ* 5 (2017): e4105.
10. Hackett, Daniel A., Stephen P. Cobley, and Mark Halaki. "Estimation of repetitions to failure for monitoring resistance exercise intensity: Building a case for application." *The Journal of Strength & Conditioning Research* 32.5 (2018): 1352-1359.
11. Zourdos MC, Goldsmith JA, Helms ER, Trepeck C, Halle JL, Mendez KM, Cooke DM, Haischer MH, Sousa CA, Klemp A, Byrnes RK. Proximity to failure and total repetitions performed in a set influences accuracy of intraset repetitions in reserve-based rating of perceived exertion. The Journal of Strength & Conditioning Research. 2021 Feb 1;35:S158-65.
12. Morán-Navarro, Ricardo, et al. "Movement velocity as a measure of level of effort during resistance exercise." *The Journal of Strength & Conditioning Research* 33.6 (2019): 1496-1504.
13. Hickmott, Landyn M. *Relationship Between Velocity and Repetitions in Reserve in the Back Squat, Bench Press, and Deadlift*. Diss. Florida Atlantic University, 2020.

14. Iglesias-Soler E, Rial-Vázquez J, Boullosa D, Mayo X, Fariñas J, Rúa-Alonso M, Santos L. Load-velocity Profiles Change after Training Programs with Different Set Configurations. International Journal of Sports Medicine. 2020 Dec 22.
15. Karsten, Bettina, et al. "Impact of two high-volume set configuration workouts on resistance training outcomes in recreationally trained men." *The Journal of Strength & Conditioning Research* 35 (2021): S136-S143.
16. Goto, K. A. Z. U. S. H. I. G. E., et al. "The impact of metabolic stress on hormonal responses and muscular adaptations." *Medicine and science in sports and exercise* 37.6 (2005): 955-963.
17. Moritani, Toshio, and Herbert A. Devries. "Potential for gross muscle hypertrophy in older men." *Journal of Gerontology*35.5 (1980): 672-682.
18. MacDougall, J. D., et al. "Biochemical adaptation of human skeletal muscle to heavy resistance training and immobilization." *Journal of Applied Physiology* 43.4 (1977): 700-703.
19. Drinkwater, Eric J., et al. "Training leading to repetition failure enhances bench press strength gains in elite junior athletes." *The Journal of Strength & Conditioning Research* 19.2 (2005): 382-388.
20. Izquierdo, Mikel, et al. "Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains." *Journal of applied physiology* (2006).
21. Willardson, Jeffrey M. "The application of training to failure in periodized multiple-set resistance exercise programs." *Journal of Strength and Conditioning Research* 21.2 (2007): 628.

22. Sampson, John Andrew, and Herbert Groeller. "Is repetition failure critical for the development of muscle hypertrophy and strength?." *Scandinavian journal of medicine & science in sports* 26.4 (2016): 375-383.

23. González-Badillo, Juan José, et al. "Short-term recovery following resistance exercise leading or not to failure." *International journal of sports medicine* 37.04 (2016): 295-304.

24. de Freitas, Marcelo Conrado, et al. "Role of metabolic stress for enhancing muscle adaptations: Practical applications." *World journal of methodology* 7.2 (2017): 46.

25. Belcher, Daniel J., et al. "Time course of recovery is similar for the back squat, bench press, and deadlift in well-trained males." *Applied Physiology, Nutrition, and Metabolism* 44.10 (2019): 1033-1042.

26. Mitchell, Cameron J., et al. "Resistance exercise load does not determine training-mediated hypertrophic gains in young men." *Journal of applied physiology* (2012).

27. Martorelli, Saulo, et al. "Strength training with repetitions to failure does not provide additional strength and muscle hypertrophy gains in young women." *European journal of translational myology* 27.2 (2017).

28. Nóbrega, Sanmy R., et al. "Effect of resistance training to muscle failure vs. volitional interruption at high-and low-intensities on muscle mass and strength." *The Journal of Strength & Conditioning Research* 32.1 (2018): 162-169.

29. Lasevicius, Thiago, et al. "Muscle Failure Promotes Greater Muscle Hypertrophy in Low-Load but Not in High-Load Resistance Training." *Journal of strength and conditioning research* (2019).

30. Carroll, Kevin M., et al. "Skeletal muscle fiber adaptations following resistance training using repetition maximums or relative intensity." *Sports* 7.7 (2019): 169.
31. Santanielo, Natalia, et al. "Effect of resistance training to muscle failure vs non-failure on strength, hypertrophy and muscle architecture in trained individuals." *Biology of Sport*37.4 (2020): 333.
32. Borg, Gunnar. "Perceived exertion as an indicator of somatic stress." *Scandinavian journal of rehabilitation medicine* (1970).
33. Hackett, Daniel A., et al. "A novel scale to assess resistance-exercise effort." *Journal of sports sciences* 30.13 (2012): 1405-1413.
34. Tuchscherer, M. "The Reactive Training Manual: Developing your own custom training program for powerlifting." *Reactive Training Systems* 15 (2008).
35. Helms, Eric R., et al. "Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training." *Strength and conditioning journal* 38.4 (2016): 42.
36. Sousa, Colby A. *Assessment of Accuracy of Intra-set Rating of Perceived Exertion in the Squat, Bench Press, and Deadlift*. Diss. Florida Atlantic University Boca Raton, FL, 2018.
37. Mansfield, Sean K., et al. "Estimating Repetitions in Reserve for Resistance Exercise: An Analysis of Factors Which Impact on Prediction Accuracy." *Journal of Strength and Conditioning Research* (2020).
38. Ormsbee, Michael J., et al. "Efficacy of the repetitions in reserve-based rating of perceived exertion for the bench press in experienced and novice benchers." *The Journal of Strength & Conditioning Research* 33.2 (2019): 337-345.

39. Helms, Eric R., et al. "RPE and velocity relationships for the back squat, bench press, and deadlift in powerlifters." *The Journal of Strength & Conditioning Research* 31.2 (2017): 292-297.

40. Klemp, Alex, et al. "Volume-equated high-and low-repetition daily undulating programming strategies produce similar hypertrophy and strength adaptations." *Applied Physiology, Nutrition, and Metabolism* 41.7 (2016): 699-705.

41. International Powerlifting Federation. International Powerlifting Federation Technical Rules 2019. Available from: http://www.powerlifting-ipf.com/rules/technical-rules.html.

42. Goldsmith, Jacob A., et al. "Validity of the open barbell and tendo weightlifting analyzer systems versus the optotrak certus 3D motion-capture system for barbell velocity." *International journal of sports physiology and performance*14.4 (2019): 540-543.

43. Banyard HG, Nosaka K, Vernon AD, and Haff GG. The reliability of individualized load–velocity profiles. *International Journal of Sports Physiology and Performance* 13: 763–769, 2018.

44. Rodriguez-Rossell, D, Yanez-Garcia, JM, Sanchez-Medina, L, Mora-Custodio, R, and
Gonzalez-Badillo, JJ. Relationship between velocity loss and repetitions in reserve in the bench press and back squat exercises. *The Journal of Strength and Conditioning Research* [Epub ahead of print], 2019.

45. Haischer, Michael H., et al. "Impact of Cognitive Measures and Sleep on Acute Squat Strength Performance and Perceptual Responses Among Well-Trained Men and Women." *The Journal of Strength & Conditioning Research* 35 (2021): S16-S22.

46. Morán-Navarro R, Pérez CE, Mora-Rodríguez R, de la Cruz-Sánchez E, González-Badillo JJ, Sanchez-Medina L, and Pallarés JG. Time course of recovery following resistance training leading or not to failure. *European Journal of Applied Physiology* 117: 2387–2399, 2017.

47. Fahs CA, Blumkaitis JC, and Rossow LM. Factors related to average concentric velocity of four barbell exercises at various loads. *The Journal of Strength & Conditioning Research* 33: 597–605, 2019.

48. Banyard HG, Nosaka K, Haff GG. Reliability and validity of the load–velocity relationship to predict the 1RM back squat. The Journal of Strength & Conditioning Research. 2017 Jul 1;31(7):1897-904.

49. Banyard HG, Tufano JJ, Weakley JJ, Wu S, Jukic I, Nosaka K. Superior Changes in Jump, Sprint, and Change-of-Direction Performance but Not Maximal Strength Following 6 Weeks of Velocity-Based Training Compared With 1-Repetition-Maximum Percentage-Based Training. International Journal of Sports Physiology and Performance. 2020 Sep 1;1(aop):1-1.

50. Odgers JB, Zourdos MC, Helms ER, Candow DG, Dahlstrom B, Bruno P, Sousa CA. Rating of Perceived Exertion and Velocity Relationships Among Trained Males and Females in the Front Squat and Hexagonal Bar Deadlift. The Journal of Strength & Conditioning Research. 2021 Feb 1;35:S23-30.

51. Ruf L, Chéry C, Taylor KL. Validity and reliability of the load-velocity relationship to predict the one-repetition maximum in deadlift. The Journal of Strength & Conditioning Research. 2018 Mar 1;32(3):681-9.